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The Wiley Handbook of Problem-Based Learning

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Contents

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Preface

Introduction

The first of its kind, the *Wiley Handbook of Problem-Based Learning* (PBL) provides a window through which leading scholars, researchers, practitioners and educational and training communities from 11 countries and 31 leading research institutions have joined to provide a comprehensive, definitive, and contemporary collection of scholarly papers that demonstrate the impact and scope of research-based practice in PBL. After many years of its successful implementation in medical education curricula, PBL is now being emphasized and practiced more widely in K–12, higher education, and other professional fields. Thus, never before has there been such a need for sound, but stimulating advice and reflection on the theory, research, and practice of PBL, and this handbook is a timely contribution to meeting that need.

The handbook has national and international appeal and relevance, as globally, PBL is being shaped by similar concerns and demands for learning that addresses twenty-first-century skills and responds to the needs for creating learning environments that are active, collaborative, experiential, motivating, and engaging. This is a volume to which young researchers and practitioners will turn to identify current research, practice, and emergent trends in PBL as well as identify gaps in the research and future directions for their own work, while experienced researchers and practitioners will find a rich collection of challenges to refresh their knowledge and rethink their assumptions. Perhaps the most important aspects of this handbook are its organization and inclusive approach that simultaneously addresses theory, design, and practice and offers insights for researchers, guidelines for instructional designers, and implementation and assessment strategies for practitioners. Additionally, as the researchers, designers, and practitioners examine the effects of PBL on student learning outcomes and performance from various perspectives and consider the process of PBL and how its principles and formats influence students' learning, the opportunities for collaboration and identifying research as an important factor in good practice, policy, and professional development will emerge.

Overview of Handbook Sections

The handbook contributes to the advancement of PBL through five sections and 29 chapters authored by 55 national and international experts and scholars who have explored PBL in various disciplines and contexts offering a contemporary view of the theoretical foundations, research, and practice of PBL. Each of the five sections features an editorial overview in which readers are introduced to the different topics covered in that section. The sequence and organization of the sections and chapters reflect the handbook's goal of providing a comprehensive and representative overview of the state of PBL as a practice field and field of practice through its historical origins, theoretical underpinnings, instructional and learning design principles, implementations in various contexts, and emerging trends and developments. While the chapter authors use the terms "problem-based learning" and "project-based learning" in their work, they have made distinctions in the meanings of the terms regarding the social and political contexts and history, as despite the common characteristics, these terms originated from different pedagogical–didactical and learning–theoretical assumptions.

Section I, an introductory section of the handbook consists of four chapters that describe the historical and theoretical foundations of PBL in various educational and training fields. The chapters define PBL pedagogical principles and epistemological underpinnings and discuss comparative pedagogical models of PBL to identify their differences, and demonstrate that despite such differences, the central or core features of PBL apply to these models.

Section II of the handbook consists of six chapters that focus on research in PBL. This section offers syntheses of empirical research on factors influencing learning in PBL such as the effects of PBL on student learning outcomes, critical thinking skills, problem solving, metacognitive skills, self-directed learning, motivation, and self-confidence, as well as research related to the role of the tutor in PBL, scaffolding in PBL, and the impact of PBL on group processes and dynamics.

Section III of the handbook bridges between research and practice to give an integrated and comprehensive view of the design and implementation of PBL. Specifically, Section III comprises eight chapters that focus on the cognitive and pedagogical processes, learning design principles, and assessment strategies required for the successful design and implementation of PBL.

Section IV of the handbook consists of six chapters that provide examples of real-world case studies that demonstrate successful design and implementation of PBL. Case studies from the fields of medical education, science education, technology education, business education, engineering education, and teacher education are provided.

Section V, the final section of the handbook, offers insights on new developments that will impact PBL practice, such as technology innovations and emerging learning theories and models. The section comprises five chapters that describe the abundant opportunities for conducting research and experimentation on designing PBL for digital spaces to better support the acquisition of twenty-first-century skills.

Use of the Handbook

This handbook is not intended to be read cover to cover as a novel. Rather, it provides multiple opportunities for use depending on the audience, topic of instruction, and field of practice context. For the novice researcher, Sections II and V of the handbook would be opportune in providing research direction, while for the practitioner and instructional designer, Sections II and IV would serve as a critical guide to the design and implementation of PBL. The handbook can also be used as a reference source in some courses and as a textbook in others. A selection of chapters can also be assigned to provide a curriculum that bridges theory and practice across disciplines. The usefulness of this resource is further enhanced by the addition of an author–subject index, and a selected bibliography.

Section I

Understanding PBL: Historical and Theoretical Foundations

Introduction

Problem-based learning (PBL), conceived and implemented more than five decades ago, has been deemed one of the most innovative pedagogies and continues to be adopted and spread throughout the world, enhancing students' competency and readiness for real-life challenges. Since its conception, PBL researchers have been diligently studying various aspects of PBL in terms of how to improve the pedagogy itself to better benefit student learning, and PBL educators have been implementing, practicing, and modifying the pedagogy in order to optimize student learning processes and experiences. To have a comprehensive understanding of this pedagogy, it is necessary for the handbook to provide a comprehensive discussion about where PBL has come from, how it has evolved throughout the decades, and the theories that bolster the pedagogy for supporting students' active learning and practical competence development.

This section consists of four chapters that provide an in-depth review of the fundamental groundwork of PBL. The section starts with Chapter 1 "A Short Intellectual History of Problem-Based Learning" authored by Servant, Norman, and Schmidt. The authors used rigorous historico-methodology, with their primary source including more than 50 interviews of witness accounts and historical documents in depicting this history. The chapter gives an interesting yet intellectual account of the development of PBL. With a few educational goals written on a piece of notepaper, the conception of PBL began with McMaster. Through integrating a number of instructional practices from other institutions to materialize the education goals over time, the basic format of PBL gradually formed. The pedagogy was then adopted by other institutions and migrated over the Atlantic Ocean, eventually spreading all over the world, and finally evolving into the various PBL models practiced today.

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In Chapter 2, "Cognitive Constructivist Foundations of Problem-Based Learning," Schmidt, Rotgans, and Yew provide a thorough discussion of how PBL supports student learning from a cognitive constructivist perspective. They first characterize PBL with three cognitive processes: inquiry, learning to learn, and mental model construction. Using these three perspectives, they discuss how the six main characteristics of PBL support these learning processes, and provide rich, solid empirical evidence from the PBL literature as well as their own studies. The chapter focuses on two hypotheses for explaining the driving force for learning in PBL: activation of prior knowledge and elaboration.

PBL is a pedagogy designed to support students' development in both cognitive and social competency. Thus, while Schmidt and colleagues' chapter dissects PBL from a cognitive perspective, Hung, Moallem, and Dabbagh examine PBL through the lens of sociocultural constructivism in Chapter 3 "Social Foundations of Problem-based Learning." This chapter addresses the socio-cultural aspects of learning in PBL by first discussing Vygotsky's sociocultural constructivism, activity theory, situated cognition, and community of practice. Then it continues to examine the relationships between the PBL instructional format and process and the learning outcomes related to social, professional knowledge, and skills, as well as the effects of PBL on social learning outcomes.

Lastly, since the term "PBL" is used to refer to various problem-oriented pedagogical models in the literature and practice, confusion and difficulty in precisely measuring the impacts of PBL have resulted in a call from the field to clarify and distinguish these models. In Chapter 4 "Comparative Pedagogical Models of Problem-Based Learning," Savery dives into various models of problem-driven instructional methods that are often all called PBL. He attempts to tease out the commonalities and differences among these models. The problem-oriented models examined in this chapter include PBL, case-based learning, project-based learning, inquiry-based learning, and Learning by Design. The chapter also discusses the context appropriateness for each model.

1

A Short Intellectual History of Problem-Based Learning

Virginie F. C. Servant-Miklos, Geoff R. Norman, and Henk G. Schmidt

Introduction

When the question of the origin of problem-based learning (PBL) arises in the literature, the consensus tends to be that the method was born at McMaster University in 1969, and that the ideas underpinning this program were in some way linked to the writings of the American philosopher John Dewey (Kolmos, Fink, & Krogh, 2004; Schmidt, 1993). From there, speculations abound as to the specifics of the history of PBL, with some asserting that the American neurologist Howard Barrows was its originator (Hillen, Scherpbier, & Wijnen, 2010), and others claiming a link to the Socratic Method described in Plato's *Meno* (Schmidt, 2012). In the contemporary turbulent context of higher education worldwide, some educators are prone to considering PBL as a panacea for all educational ills, while others vociferously resist its implementation. This sometimes leads to impassioned debates about the benefits or drawbacks of PBL at conferences, faculty boards, and in staff rooms that more resemble clashes of opposing political factions than reasoned educational arguments. To allow an informed debate about the ways in which PBL could serve education going forward, one must first understand where it came from; therefore, one must uncover its history.

In 2012, the authors undertook that task, using archival evidence collected from McMaster University, Maastricht University, and the two Danish Reformed Universities of Roskilde and Aalborg; oral history interviews from all four institutions and other institutions relevant to the early history of PBL; contemporary publications that indicate the development of thinking about PBL; and secondary sources reflecting on the history of PBL. These materials were processed using Whewell's inductive method of historical analysis (Whewell, 1858). This chapter summarizes the key findings of this 4-year research project to provide a broad overview of the history and development of PBL.

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For the purposes of this chapter, PBL can be defined as a pedagogical system used in tertiary education both undergraduate and graduate, particularly in medicine but also in fields as diverse as law, engineering, psychology, and liberal arts. The basic principles of this method are the use of realistic problems as the starting point of self-directed, small-group-based learning guided by a tutor who acts as a process guide rather than a point of knowledge transfer (Barrows & Tamblyn, 1980). In PBL, students are expected to spend the majority of their time studying on their own or with their classmates rather than under the instruction of a teacher, which means that the use of lectures must be limited and access to quality learning resources guaranteed.

The history of PBL will be described in three parts: first, we shall look at the historical development of the first two PBL programs at McMaster and Maastricht. Second, we shall investigate the influence of educationally pioneering programs from both sides of the Atlantic on the development of PBL at these schools. Then, we shall expound the philosophical, intellectual, and psychological antecedents of the PBL through the authors and thinkers who inspired the founders of the method at McMaster and Maastricht. Finally, we shall provide an overview of further developments in PBL, including the case of the Aalborg University and its later adoption of the PBL appellation.

The Early History of PBL: 1963–1980

The first institution to use PBL was McMaster University in Canada, whose medical program opened its doors in September 1969. It was followed in 1974 by Maastricht University in The Netherlands. Although the latter imported the idea from the former, the programs were sufficiently different to warrant treating them as two iterations of PBL.

McMaster's Pioneering Program in Medical Education

Plans to open a Medical School in Hamilton, Ontario, were etched as early as 1963 by the reformist President of McMaster University Harry Thode (Thode, 1963). Thode himself did not have a specific idea of what this school should look like, only that it should be different. To enact this change, he appointed the young Dr. John Evans from the University of Toronto as its founding Dean. In 1966, before any work had commenced on the project, Evans sketched out the principles of PBL in a one-page memorandum more likely intended for his own use than as a mission statement for the school (Evans, 1966; Table 1.1 and Table 1.2).

By 1967, Evans had formed an Education Committee comprising four trusted colleagues to draw up a plan for the forthcoming MD program: Bill Spaulding, Fraser Mustard, Jim Anderson, and Bill Walsh. Spaulding, the Chair of the Committee and Associate Dean to Evans, was largely responsible for drawing up the organizational principles of the first PBL program (Spaulding, 1968) and presided over the implementation of committee decisions (Kraemer, 1968a); Anderson can be seen as the man behind its pedagogical principles (Barrows, 1996);

Table 1.1 John Evans', 1966 General Objectives of the Faculty of Medicine

The Following is an outline of the objectives for the McMaster M.D. Program as expressed in terms of knowledge, abilities and attitudes that McMaster would like a graduate of the program to have acquired or developed:

1) The ability to identify and define health problems, and search for information to resolve or manage these problems.
2) Given a health problem, to examine the underlying physical or behavioral mechanisms.
3) The ability to recognize, maintain and develop personal characteristics and attitudes required for professional life […].
4) The clinical skills and methods required to define and manage health problems of patients, including their physical, emotional and social aspects.
5) The ability to become a self-directed learner, recognizing personal education needs, selecting appropriate learning resources and evaluating progress.
6) To assess professional activity, both personal and that of other health professionals
7) To function as a productive member of a small group, which is engaged in learning, research or healthcare.
8) To be aware of and able to work in a variety of healthcare settings

Table 1.2 McMaster Program Outline (Spaulding, 1968)

Summer course: for those who are lacking in basic scientific knowledge. Consists in behavioral science, biochemistry and cell biology.

Phase I: Normal structure and function—14 weeks: "The approach will be predominantly regional. For example, as the student learns about the structure and function of the eye, he will also learn how the doctor examines the eye to test the integrity of the organ and its associated controlling structures and mechanisms."

Phase II: Abnormal Biological Mechanisms—6 weeks

Phase III: Abnormal structure and Function—40 weeks. "This portion of the curriculum is organized by organ systems and includes relevant aspects of abnormal behavior, ethics, biomedical statistics and rehabilitation medicine." […] "Each system will be studied by an integration of relevant anatomy, biochemistry, physiology, microbiology, pathology, pharmacology and epidemiology." Organ systems: hematopoietic, cardiovascular, respiratory, gastrointestinal, urinary and electrolytes, nervous, loco-motor, endocrine/reproductive.

Horizontal program: 1 hr per day in Phase I–III

Electives: 2 × 6 week periods after phase III: "In addition, students will be encouraged to approach faculty members with projects which are not in the electives list" (p. 6)

Clinical skills: 1 week. Just before the clerkship.

Phase IV: Clerkship—40 weeks

Mustard and Walsh, thanks to their connections and prestige as eminent scientists, were instrumental in ensuring that the program was accepted within the school and the community of Hamilton (Spaulding, 1991).

The Education Committee drafted a plan for a new medical program that turned medical education on its head, did away with tedious lectures, years of basic science before there was a patient in sight, and the silos of disciplines. Bound together in a so-called "matrix management" format (Spaulding, 1991), the disciplines at McMaster combined into study units based around organ systems. Within these units, students were introduced to the material through biomedical and clinical problems. These problems were tackled in small groups of four to six students, under the guidance of a tutor whose role was not to provide content but to guide the discussion (Ad Hoc Committee on Undergraduate Education, 1969). It is worth noting that the McMaster curriculum did not wholly ban lectures: they were recommended for exceptional circumstances, alongside a host of other educational tools such as field trips, guided instruction, or recitations (Educational Programme Committee, 1968). Another noteworthy point of the program was its aversion to summative assessment: students were not to be tested during their entire 3-year stay at the Faculty of Medicine but would face their judgment day when the time came to take their medical license (LMCC), an official state exam. Summative assessment was deemed to go against the very idea of PBL, so tutors were asked to provide students with formative feedback—but the position of friend, guide, and evaluator proved to be very difficult for many tutors (Mueller, 2008) and the system eventually came to a grinding halt with high failure rates at the LMCC by the late 1980s, at which point summative examinations were introduced (Norman, Neville, Blake, & Mueller, 2010).

In the beginning, few guidelines were issued on how this educational method would play out, spreading much confusion among the newly hired staff at McMaster (Kraemer, 1968b). In practice, different unit coordinators imagined different ways of implementing Spaulding's recommendations: some preferred short, experiential biomedical problems, others paper cases, and the neurologist Howard Barrows, who joined McMaster on sabbatical in 1968 and on a long-term contract in 1970, even introduced the idea that simulated patients and decks of cards (known as "problem-boxes") could be used as problems. Barrows had very little to do with the running of the first McMaster curriculum from 1969 to 1972, and contrarily to what is sometimes cited, did not invent PBL. He did, however, provide two lasting contributions: a method of training actors to behave like patients (Barrows & Abrahamson, 1968), and a name for the founding fathers' brain child: problem-based learning, baptized in 1974 in an article published in the *Journal of Medical Education* (Barrows & Neufeld, 1974). Barrows is perhaps best known for his book, *Problem Based Learning, An Approach to Medical Education*, written with Tamblyn in 1980. The overwhelming historical evidence, both oral and archival, suggests that the methods described in this book were an interpretation of PBL based on Barrows' focus on clinical reasoning skills and his work with simulated patients and problem-boxes rather than a reflection of the actual McMaster curriculum (Servant, 2016).

In 1969, McMaster admitted its first class of 20 students for a 3-year medical program. The program was divided up into four phases, all incorporating elements from basic and clinical sciences:

In this setup, a Horizontal Program was introduced to cater to McMaster's ambitions to provide Ontario with socially conscious and community-oriented physicians (Horizontal Programme Planning Committee, 1968). The plan was to pair up students and family physicians from the community to give the former an idea of the challenges facing the latter, as an ongoing program to run in parallel to the regular medical studies. In practice this plan fell through, and the

Horizontal Program was rapidly discontinued. The rest of the setup remained roughly stable throughout the first curriculum of McMaster, which began in 1969 and was progressively dismantled after Evans' departure in 1972. As the old guard left and a new group of clinicians and managers such as Neufeld and Barrows came to the fore, their vision for PBL departed radically from the original views of the founding five, and must therefore be considered in its own capacity at the end of this chapter.

Maastricht University Reinterprets PBL

In 1970, an agreement was reached between the economically disadvantaged Dutch region of Limburg and the government, that a new medical school would be opened in the city of Maastricht on the condition that it provide something different to the existing seven medical schools in the country (Knegtmans, 1992). The desire to do something new was enshrined in the new faculty's Basic Philosophy (Basisfilosofie Achtste Medische Faculteit, 1972), but the exact shape of the curriculum to come remained to be seen. The newly appointed Dean Harmen Tiddens, a pediatric nephrologist, had befriended John Evans during a visit to the United States and organized for a Dutch governmental delegation to visit McMaster in May 1974 (Knegtmans, 1992). By the time the visitors returned, it was agreed that PBL would be the way forward for the new faculty. Tiddens had more of an external and political role as Dean and handed the development of the education program over to Wynand Wijnen, a psychologist.

The new medical school had to deal with students fresh out of high school rather than more mature students coming after a bachelor's degree; its program therefore had to be twice as long as McMaster's. Maastricht also did not have the LMCC to spur students to work and a reevaluation of the assessment policy was therefore necessary. To tackle these challenges, Maastricht endowed itself with a Department of Educational Research and Development from the start, headed by Wijnen and assisted by two young education researchers, Henk Schmidt and Peter Bouhuijs.

Thus, it became rapidly clear that Maastricht would offer a new interpretation of PBL. First, given the length of the program, the inexperience of the students, and the large number of students that was expected to go through Maastricht's door, the faculty had to structure the tutorial process in a more standardized manner than McMaster's ad hoc "leave-it-to-the-coordinator" policy. The first step was to institutionalize tutor and student training: after some trial and error, a training program was devised focusing on the simulation of likely situations in PBL classrooms rather than the popular "group dynamics" trainings that were all the rage in the 1970s (Schmidt, 1977a). Then, the tutorial itself had to be restructured to help students from high school cope with PBL. This challenge prompted Schmidt to devise in 1976 a systematic method for handling problems known as the *Zevensprong* (Seven Steps) (Schmidt, Majoor, & Wijnen, 1979; Table 1.3).

The interpretation of the tutorial function was narrowed to a more process-oriented role than it had been at McMaster, with a stricter enforcement of the "no-content expertise" rule. In practice, that did not mean that anybody could be

Table 1.3 The Seven Step Method as Described by Schmidt in 1976, 1979

Step 1	Clarify terms and concepts not readily comprehensible
Step 2	Define the problem
Step 3	Analyze the problem
Step 4	Make an inventory of the explanations inferred from step n°3, proceeding systematically
Step 5	Formulate learning objectives
Step 6	Collect additional information outside the group
Step 7	Synthesize and check the newly acquired information

a tutor, but all members of the scientific staff, regardless of their medical background, could tutor any block (Projektgroep tutorensysteem, 1979).

Two of Maastricht's additional innovations were the invention of the *Skillslab* and the progress test. The *Skillslab* was a systematized way of imparting basic clinical skills to students. At McMaster, it had been assumed that students would pick these up along the way, at Maastricht however, a separate skills training program was planned from the beginning (Knegtmans, 1992). From 1977, the *Skillslab* became a co-curricular activity running alongside the PBL tutorials, with its own dedicated rooms where students could go at any time to practice their clinical skills on a set of anatomical models and mannequins. However, the supervised skills training sessions were as closely aligned with the concurrent PBL block as possible.

The progress test was the brainchild of Wijnen, whose particular field of expertise was in assessment. Based on the observation that end-of-block summative assessment pushed students to exam-oriented study behavior, Wijnen realized that such exams were not compatible with PBL (Wijnen, 1976). To remedy this problem, he incepted an assessment format whereby students of all years would be confronted with the same test comprising 250 true/false questions, administered four times a year—first-year students would be able to answer very little whereas final-year students would be expected to obtain a score of at least 70%. This meant that students did not have to learn in any particular order, and that cramming information in before the test did not serve much purpose. This invention was so popular that, in the 2000s, it was extended to the majority of medical institutions in The Netherlands, and even eventually at McMaster.

Finally, Maastricht was the first institution to systematically investigate its own educational methods and, from 1977, produced a stream of publications under the authorship of Schmidt and Bouhuijs, sometimes seconded by Wijnen. These empirical studies, aimed at understanding the PBL process, were anchored in an ambitious research program proposed by the Department of Education Research and Development (Schmidt, 1977a). This yielded the book *Onderwijs in Taakgerichte Groepen* (Education in Task-Oriented Groups) (Schmidt & Bouhuijs, 1980) at the same time as Barrows published his book, and by 1980s had enabled Schmidt to uncover the basic principles of cognitive psychology that underpin PBL's success as an education method (Schmidt, 1982).

Historical Influences on the Development of PBL

The two PBL programs presented above did not develop in an educational vacuum: they were inspired by and drew from various educational institutions that proposed pioneering changes to pedagogy in the nineteenth and early twentieth century. These institutions included Harvard University, Western Reserve University (WRU) in the United States, and the so-called Oxbridge system in the United Kingdom. The way they practiced teaching and learning had a direct influence on the practice of PBL in its early years.

The Harvard University Case Method

It would be erroneous to speak of *the* Harvard Case Method as though it were singular and uniform. In fact, Kimball (1995) brought to light the existence of two Harvard Case Methods: the first, brainchild of Dean Christopher Columbus Langdell, was incepted in 1870 at the Law School (Garvin, 2003) and applied to the Medical School in 1900 (Cannon, 1900); the second, strongly inspired by the philosopher Dewey, was implemented at the Harvard Business School from the 1920s onwards (Fraser, 1931). The first method aimed to get students to reflect on cases by analogous reasoning, that is, by inducing general principles of law or medicine based on observations of a case as compared with another case. The second method was based on the use of real-life, open-ended business problems, the principles of which were harder to pinpoint and the solutions to which might be murkier than in the well-defined fields of law and medicine. While it was popular in legal education all over the United States, the use of the Case Method by analogy in medicine went by largely under the radar and by the 1920s had disappeared entirely. By contrast, the Case Method in business endured and became popular enough that, by the time McMaster was founded, it was a well-known educational innovation in North America (Kimball, 1995). The Case Method was introduced to McMaster through one of its founding fathers, Bill Spaulding, whose fraternity brother was a Harvard Business School alumnus (Spaulding, 1991): the practice of the Case Method at the Business School inspired Spaulding to devise a medical curriculum based on the use of problems.

There is however a notable difference between the case method as it was practiced at the Business School and PBL: whereas PBL students approached a new problem fresh and unprepared, with nothing but their prior knowledge to tackle what was at hand, Case Method students were required to prepare selected readings before attending a group discussion on the case (Fraser, 1931). Contrary to popular belief, the Case Method did not involve the mere application of information handed to students in lectures to practical cases for the sake of practice and elaboration. Students were expected to furnish the study effort on their own in both PBL and the Case Method—but the activation of prior knowledge through exploratory group discussion was absent from the Case Method, whereas it was a chief component of PBL.

The Western Reserve University School of Medicine Medical Education Experiment

While PBL is most well-known for its use of problems as the starting point of learning, it also featured the integration of various disciplines in thematic units rather than parallel courses competing for students' attention at both McMaster and Maastricht. This idea was brought over to PBL from a little-known institution from Ohio: Western Reserve University School of Medicine (WRU).

In 1952, WRU reformed its medical curriculum under the leadership of Joseph Wearn and Hale Ham, both of whom either had direct experience of or close contact with the Harvard Medical School's experimentation with the Case Method (Williams, 1980). Although they preceded McMaster by two decades, the objectives of the reformed WRU program were very similar in their humanist, interdisciplinary, and antitraditionalist stance. WRU successfully put together the first interdisciplinary curriculum in medical education, guided by "subject committees" rather than the traditional hierarchy of departments. Originally, 14 subject committees focusing on various components of the human body were drawn up to organize the students' learning. Eventually, these were concentrated into five thematic study units based around organ systems, such as "cell biology" or "endocrine and reproductive systems." However, despite the inclusion of research projects, the WRU program still maintained traditional teaching methods as the basis of the learning process, with almost half of students' time allocated to lectures (Williams, 1980).

Spaulding visited WRU in 1967 in preparation for McMaster's opening (Spaulding, 1967), and borrowed their idea of thematic units organized around organ systems wholesale (McAuley, 1978). The system of organ-based learning units was transferred to Maastricht where they became known as "blocks" and applied across all 6 years of the medical program (Knegtmans, 1992). In addition, the idea was broadened to include new themes such as life phases or complaints as the basis for the blocks. A similar idea was later adopted by the Maastricht Law School (Cohen & Crombag, 1978) and became a staple of PBL programs in multiple fields of study.

The Oxbridge Tutorial System

Oxbridge is a British contraction that refers to the two oldest universities in the country: Oxford and Cambridge. Over the many years of their existence, both institutions developed a mentorship role for teachers vis-à-vis their students known as a "tutor." During the nineteenth century, this role crystalized into a pedagogical function (Palfreyman, 2001). In addition to their lectures and private study, students were required to meet with their tutor once per week to present and discuss some of their written work (Moore, 1968). This tended to be a one-on-one or one-on-two relationship, reminiscent of the interaction of Socrates with his pupils. The specifics of the tutorial process were left up to the tutor, but in no case should the tutor be lecturing or providing new information to the student: it was the student's obligation to study, and the tutor's job to question and probe.

McMaster explicitly borrowed the term from Oxbridge (Mueller, 2008), as attested by the lengthy Education Committee debates on the subject (Kraemer, 1969a, 1969b). The inspiration was brought over the pond by British doctors hired to help start the McMaster program, and continued to hold sway over the description of the tutor role at McMaster, especially as more tutors came in who had themselves experienced the Oxbridge model (Dickinson, 1970). However, tutoring in PBL was done with small groups, rather than one-on-one; the mentorship aspect of the role was usually lacking, as tutors were instructed to serve as process guides on an equal footing with students rather than intellectual leaders of the group. Given this conception of the tutor, content expertise was deemed to interfere with the guidance role. This view of tutoring was advocated by PBL pioneer Jim Anderson, who argued that the Oxbridge model, taken wholesale, would be "too paternalistic for North American Universities in 1969" (Kraemer, 1969a, 1969b). Instead, he called for a system in which students should be exposed to as many teachers, disciplines, and professions as possible before choosing for themselves whether they wished to enter a mentoring role with one of them. The "tutor as a process guide" role was taken to its most advanced form at Maastricht University, where, in principle, any member of the faculty could tutor any problem, regardless of which disciplines the PBL block covered (Projektgroep tutorensysteem, 1979). This was later scaled back when evidence emerged that content expertise could be beneficial in tutoring (Schmidt, Arend, Moust, Kokx, & Boon, 1993).

Intellectual Influences Behind Central Concepts of PBL

Where does one begin looking for the theoretical foundations of PBL? There are so many thinkers and educators whose ideas could be construed as related to the principles of PBL. How to choose the most relevant ideas without veering into broad generalizations that have very little to do with PBL? Our method involved parsing through historical materials and oral history interviews and picking out sources of inspiration that were explicitly mentioned, or concepts that were so clearly tied to a particular theorist that the latter's influence became apparent. By starting at the source, with the thoughts and writings of those who actually founded PBL, we pieced together its intellectual history in a manner faithful to the original ideas behind the method. This led us to uncover many sources of inspiration for McMaster, Maastricht, and other prominent PBL programs around the world. However, in the interest of conciseness, we have selected the most interesting for the purposes of this chapter: the *Flexner Report* (1910), the humanist psychology of Carl Rogers, the pragmatist philosophy of John Dewey, Karl Popper's philosophy of science, and the 1960–1970s debates within cognitive psychology.

Abraham Flexner and Renewal in Medical Education

The *Flexner Report* was a comprehensive survey of the state of medical education in North America in 1910, conducted under the auspices of the Carnegie Foundation by Abraham Flexner. Perhaps because Flexner himself was primarily an educator rather than a doctor, the recommendations in his report carried strong pedagogical undertones, simmering just beneath the surface of his critique of the poor quality of medical education in the United States in the early twentieth century. Flexner was strongly influenced by the sorts of ideas on experiential learning and "learning by doing" that were floating around at that time, particularly in circles associated with John Dewey (Ludmerer, 2010). His chief bone of contention was the outdated lecture-based mode of learning, railing against "huge, badly lighted amphitheaters" (Flexner, 1910, p. 9) and their nefarious effect on instruction. As an admirer of the burgeoning Harvard case-method of legal education, he saw the potential of more active ways of learning for medical education. In addition, Flexner saw the medical world evolving toward a more preventive and socially aware mode of operation and called upon medical education to follow suit, developing in future doctors the knowledge, skills, and techniques they would need to face the future. Finally, Flexner argued that the common division between basic and clinical sciences in the medical curriculum was detrimental to doctors in training, who should instead consider the hospital as their training ground and laboratory.

These ideas found a strong echo within the team who founded the McMaster curriculum, and particularly with John Evans, who made the development of knowledge, attitudes, and skills the priority of McMaster's curriculum (Evans, 1966), citing Flexner as his main source of inspiration some years later in a retrospective interview (McAuley, 1979). Flexner's commitment to joining basic and clinical sciences was seconded by Fraser Mustard, who spurred the development of the integrated practice of both through PBL at McMaster (Mustard, 1968). Further references to Flexner began to appear in the meetings of the Education Committee in charge of setting up and running the first PBL program in 1969, with particular emphasis on the *Flexner Report*'s condemnation of teacher-driven instruction, and the distinction of research and teaching as two separate and often contradictory professions (Ad Hoc Committee on Undergraduate Education, 1969). Flexner's legacy on the McMaster program is poorly understood and very little mention is made of his report today, but it was to a significant extent his ideas on suppressing lecture-based education and learning basic sciences through clinical practice that gave rise to the use of clinical problems at McMaster.

John Dewey and Experiential Learning

When discussing the advent of the progressive education movement in the twentieth century, a reference to the American philosopher John Dewey is mandatory. Dewey was far more than an educationist: during his career, he penned 37 major works in education philosophy, psychology, and general philosophy (Apple & Teitelbaum, 2001) and he is also known as the father of pragmatist philosophy and a prominent scholar within the functionalist school of thought (Hergenhahn, 2001). Dewey's work on education was twofold: first, from a psychological perspective, he attempted to understand learning as an experiential process that should connect with the person's lived experience; this is what is often referred to as "learning by doing." Experiential learning, for Dewey, should be triggered by a "problem," understood as an unclear situation or phenomenon in need of an explanation (Dewey, 1933). Then, the learner should use what he already knew about the world from his everyday experience to seek out a solution. In many senses, Dewey's conclusions on education foreshadowed the cognitive revolution in psychology, with its emphasis on the activation of prior knowledge and contextualization. From a philosophical perspective, his work comprised a societal project in which persons bound to their own educational experience would become the grounded citizens required by a democratic society (Dewey, 1916/2011).

Although Dewey's ideas were not taken wholesale by the founders of PBL, and he was scarcely mentioned in any of the early PBL programs, his influence came through at McMaster in two ways. Indirectly, Deweyan ideas came to PBL via the influence of the Harvard Business School and its use of the Case Method inspired by Dewey's "problem-method"; namely the use of open problems as the starting point for learning problem solving and from specific problems inducing general principles (Kimball, 1995). Therefore, by adopting some of the ideas of the Case Method, McMaster indirectly bought into the Deweyan philosophy. More directly, Dewey was cited in support of the PBL philosophy in a report on the McMaster MD program from 1969 (Ad Hoc Committee on Undergraduate Education, 1969), and in one of the early publications describing McMaster's PBL program, written by one of its founding members Dr. John Hamilton (1976). Dewey also found favor with some of the theoretical architects of the Danish model of PBL, who cited him as a justification for their participant-directed, project-based approach to problem-orientation (Illeris, 1974).

Karl Popper and the Role of Problems in the Growth of Knowledge

Dewey was not the only philosopher to consider the role of problems in learning and inquiry. The Anglo-Austrian philosopher of science Karl Popper was also interested in problems, albeit from the perspective of scientific problem solving. Probably best known for his attempts to demarcate science for nonscience, Popper suggested that since nothing can ever be proven inductively, the best that science can do is to put forward hypotheses and theories and then attempt to falsify them (Popper, 1963). The best hypotheses are those that are the most resistant to falsification attempts—but they can never be held as eternal truths because the time may always come where their premises will be refuted through falsification. Therefore, anything that could not be subjected to a falsification test fell outside the remit of science. More importantly as concerns PBL, these scientific conjectures were content-bound: there was no stand-alone process of falsification without contextual and content-bound theories to support it. Indeed, problem solvers were engaged in a mental process, but these theories did not materialize from thin air: they were bound to a person's prior knowledge and understanding of the problem situation. Therefore, the role of problems was not to trigger some algorithmic process of problem solving but instead to prompt the formation of tentative theories explaining the underlying causes of the problem in the person's mind. These theories were then tested for errors and refined in confrontation with reality into better theories.

Popper's influence on PBL primarily came through the work of Henk Schmidt, particularly through the 1970s and 1980s. Schmidt saw in the Austrian philosopher's claims an explanation for the workings of PBL, particularly as regards the activation of prior knowledge (Schmidt, 1983). This particular understanding of problem solving discredited the idea that PBL should be about learning a set of "problem-solving skills" or about "learning to learn" and paved the way for a more content-bound version of PBL. Being thus delivered of the concept of the tutorial as a mere exercise in "playing doctors" or practicing "clinical reasoning," PBL became instead an education method capable of tackling any content from any field. From there, in the 1980s, it broke free from its medical sphere of practice and entered other fields such as law, economics, and psychology.

The Cognitive Revolution and Problem-Solving Skills

The debate surrounding the content versus process of learning in PBL took a new turn following the "cognitive revolution" in psychology—this movement, born in 1956, represented an attempted move away from the behaviorist paradigm that had dominated psychology since the 1930s (Miller, 2003). Cognitive psychology's principal contribution was the reinstatement of mental processes as the key to understanding human behavior and cognition, compounded with an attempt to understand the internal mechanisms through which the mind deals with information and knowledge (Bechtel, Abrahamsen, & Graham, 2001). This quest for understanding led cognitive psychology to split in two distinct camps: on the one hand, those that believed that reasoning and problem solving were content-independent algorithmic processes that could be trained, known as "information processing psychology"; and on the other hand, those who believed that knowledge was the foundation of all reasoning and problem solving and therefore to improve problem-solving capacity, the knowledge base needed to be expanded, known as "constructivist psychology." The former were championed by artificial intelligence specialists Newell and Simon (1972). The latter drew inspiration from the works of early twentieth-century psychologists Piaget and Vygotsky, whose ideas were synthesized and adapted by Jerome Bruner, one of the founders of the cognitive revolution. Information processing psychology proposed that learning could best be understood as the improvement of the heuristics of problem solving, whereas constructivist psychology posited that learning should be seen as the "accommodation" (or change) of mental "schemas" (or representations). From the end of the 1970s, information processing psychology was discredited as no evidence was found to support its propositions regarding problem solving, leaving constructivist psychology as the sole surviving paradigm (Anderson, 1977).

This debate took center stage in PBL in the 1970s, a time during which Howard Barrows and Henk Schmidt conflicted on their views of the purpose of PBL. Barrows supported the information processing view, as evidenced by his views on PBL laid out in his book *Problem-based learning: An Approach to Medical Education* (Barrows & Tamblyn, 1980), whereas Schmidt took the constructivist view (Schmidt, 1982). Although Schmidt, like Barrows, initially described PBL in terms of a hypothetico-deductive process (Schmidt, 1978), following the philosophy of science of Popper and the Gestalt psychologists, he later saw these hypotheses as content-laden theories by which students try to make sense of the problem and search for areas in which their prior knowledge falls short. The confrontation with emerging constructivist research (Anderson, 1977) led Schmidt to discard the problem-solving terminology altogether and adopt the view that PBL was about the construction of a knowledge base. The PBL problem served to activate prior knowledge, and the small-group discussion functioned as an opportunity to elaborate upon each other's knowledge (Schmidt, 1982).

The two views co-existed despite the lack of empirical support for information processing psychology, and spawned educational programs that, although both calling themselves "PBL," were built on fundamentally different learning principles (Schmidt, van de Molen, Te Winkel, & Wijnen, 2009).

Carl Rogers and Self-Directed Learning

Carl Rogers was an American psychotherapist and educationist who pioneered the humanist psychology movement with his colleague Abraham Maslow in the 1950s and 1960s. Humanist psychology assumed that people, left to their own devices, would naturally tend to become the best version of themselves, or "self-actualize" through what they called "self-directed learning." This theory, which Rogers originally developed in the 1940s and 1950s in works such as *Client-Centered Therapy* (1951), was most prominently expressed in his book *Freedom to Learn* (1969), a collection of essays on education based on his experience as a psychology lecturer and psychotherapist. Rogers' thinking was derived from the existentialist philosophy of Kierkegaard, which regarded learning as a deeply personal achievement, encased in the phenomenal bubble of experience. This meant that, according to Rogers, a person could not be taught but had to experience the learning process in a deeply and personally meaningful way. Thus, teachers could not impart knowledge, but could only guide the learning process of the students as they wrestled with their experience and feelings. By the same token, curricula should not attempt to impose fixed learning schedules, modes of instruction, and, least of all, mandatory formal examinations. Instead, students should be free to choose what they would learn and how they would learn it, including ignoring the advice of their teachers. This Rogerian idea sprung from his understanding of the self and knowledge, whereby in an ever-changing world where information is outdated almost in the moment it surfaces, only the person is capable of grasping what is truly worth learning to him or her. The belief that people, given freedom, would naturally use it for self-improvement regardless of culture, age, or socioeconomic background sprang from the fundamental humanist tenet that human nature is good.

Of all of Rogers' ideas, "self-direction" has most lastingly impacted PBL. It first surfaced at McMaster in Dean Evans' founding memorandum, which called for "a self-directed learner, recognizing personal education needs, selecting appropriate learning resources and evaluating progress" (1966). This concept was restated as "*zelfwerkzaamheid*" (the ability to work through one's own drive) at Maastricht University, the world's second PBL program, when they proclaimed their basic philosophy (Basisfilosofie Achtste Medische Faculteit, 1972). Self-directed learning has since been a core feature of all PBL programs; from this fundamental principle, nearly all other tenets of PBL could be derived from the guiding role of the tutor to the importance of self-study. However, some of the more extreme assumptions of Rogerian self-directed learning have been debunked as research has shown that the learning process is improved in PBL when the tutor has a content knowledge related role rather than a mere procedural role (Schmidt et al., 1993) and that examinations do improve the learning process in PBL (Norman et al., 2010).

Further Developments in PBL: 1975–1990

Over the years, PBL has spread to over 500 institutions (Moust, Bouhuijs, & Schmidt, 2007) all over the world, in a vast array of academic disciplines. It would be impossible to cite all the ways in which PBL has developed since McMaster and Maastricht, so we have selected two particular trends: the emergence of problem-solving curricula and community-oriented programs.

McMaster's Second Curriculum: Focus on Clinical Reasoning

By 1977, calls for change grew at McMaster as the Spaulding curriculum was perceived to stifle innovation in education. This feeling was particularly strong among a group of young researchers and clinicians led by Dr. Vic Neufeld who had, unlike the founding fathers of McMaster, studied a Master in medical education at Michigan State University. This was a time where hypothetico-deductive ideas of cognitive psychology were in their prime, and Neufeld, supported by Barrows, brought to the table the idea that the training of clinical reasoning skills could be the center piece of a reformed curriculum at McMaster. The new curriculum, rolled out between 1977 and 1984, did away with the biomedical nature of the first curriculum and instead focused on priority healthcare problems—that is, introducing students to the healthcare problems most commonly seen in the community (MacDonald et al., 1989). The emphasis was no longer on understanding a basic set of underlying mechanisms, but on solving the problems at hand, in whichever direction the students deemed most appropriate. The chief objective of the Faculty of Medicine was revised to read: "to identify and define health problems at both an individual and a community level and to search for information to resolve or manage these problems" (Educational Committee, 1978). This was also the first time that, under Barrows' direction, the training of clinical skills came to the fore at McMaster, particularly through the use of simulated patients (Sutton, 1977). The shift of focus from knowledge acquisition to a greater emphasis on professional practice and the training of reasoning skills sparked the division between what Schmidt and colleagues called “mental model construction” (or Type 1) PBL curricula of the type practiced at Maastricht or McMaster between 1969 and 1977, and “process of inquiry” (or Type 2) PBL curricula of the type exemplified by the second McMaster curriculum (Schmidt et al., 2009).

The second McMaster curriculum was discontinued when the failure rate at the LMCC became alarming, and in 1993 was replaced once again by a Type 1 curriculum (Norman et al., 2010). However, and despite the fact that information processing psychology and hypothetico-deduction have fallen out of favor for 40 years, many PBL programs continue to use a Type 2 curriculum. These curricula tend to promote “problem-solving skills,” “collaboration skills,” and “learning to learn” as the chief benefits of PBL, often preferring to leave the acquisition of content to more traditional means of knowledge transfer. This has spawned a generation of “hybrid” programs in which students’ time is divided between PBL and traditional lectures with anything ranging from less than 10% to more than 50% of their time allocated to PBL (Kwan & Tam, 2009)—PBL in this instance often being used as some form of case study, or skills training class rather than the basis for acquiring new knowledge.

Community-Orientation and the Network

Another major variation on the PBL theme is the emergence of medical programs whose primary purpose was the development of community-oriented primary care physicians. These programs saw PBL as an instrument to give the priority health problems of the population at large a central position in the curriculum. One of the first among these was a program that emerged in 1979 at University New Mexico (Kaufman, 1985). At the time, New Mexico was rife with medically underserved remote rural communities, but medical students preferred to orientate themselves toward tertiary, specialized care in major cities and large hospitals rather than choose a career in primary care in the countryside. To remedy this, the founders of the program Drs. Kaufman and Obenshain had the idea that students should be sent out to the community during their medical education, but could not make this fit within a traditional medical curriculum. By chance, they met Barrows in 1977 and he convinced them to use PBL to bring their idea to life. Since New Mexico already had a medical school, they opened a separate “primary care track” for PBL, with a restricted number of students. The particularity of this curriculum was that unlike the McMaster and Maastricht programs, students spent the last 6 months of their first year of medical school in underserved communities, working with family physicians; the rest of the program ran much like the McMaster model. Kaufman reported in his 1985 retrospective that a larger number of the “primary care” cohort chose to stay in primary care compared with the regular medical track. Whether this was because the program was effective or because those who chose the program were already more inclined toward primary care remains to be seen.

The idea that PBL could be used to foster community-orientation was a powerful one and took off quite dramatically in the 1970s and 1980s. From Malaysia

(Zabidi & Fuad, 2002) to Nigeria (Bollag, Schmidt, Fryers, & Lawani, 1982), on each continent of the world, community-oriented programmes emerged. The idea was so powerful that a "Network of Community-Oriented Educational Institutions for Health Sciences" was assembled under the auspices of the World Health Organization comprising almost 40 member schools, for which Maastricht long held the secretariat. The Network promoted conferences across the globe, the transfer of knowledge from institution to institution, and a number of publications evaluating the achievements of its members. These publications and conferences conflated PBL and community-orientation to a large extent, although community preceptorships are in no way necessarily bound together with PBL. Although the race to develop PBL curricula has slowed with many adopting hybrids instead, community-orientation remains popular in medical schools in developing countries.

Alternative Developments: The Danish Project Model

In the 1990s, a hitherto internationally unknown engineering program from Aalborg University in Denmark burst onto the PBL scene. Their commitment to PBL was such that in 2007 the United Nations Educational, Scientific and Cultural Organization (UNESCO) established a Chair for PBL in Engineering Education there (Kolmos, 2008), and in 2014, supervised the establishment of the Aalborg Centre for Problem Based Learning in Engineering Science and Sustainability under the auspices of UNESCO. Contrarily to all of the programs mentioned above, however, the emergence of the Aalborg phenomenon was not the result of the university's switch to a PBL curriculum of the McMaster or Maastricht type. On the contrary, the Aalborg educational model had been relatively stable since its establishment in 1974.

In the wake of the student revolt of 1968 in Copenhagen, the Danish parliament approved the establishment of two university centers whose pedagogy would be radically different to the traditional, professor-centered programs of the established Danish universities (Whitehead, 2007). The first was opened in Roskilde, 30 km outside Copenhagen, in 1972, and the second was Aalborg, 300 km away in the northern-most province of Denmark. Both institutions shared similar instructional principles: problem-orientation, participant direction, and interdisciplinarity bound together in *project work* (Berthelsen, Illeris, & Poulsen, 1977; Illeris, 1974). In its conception, this model was different from more application-oriented forms of project work common to many vocational studies such as architecture or agriculture in that the starting point of the learning should be a social problem from which theory and knowledge should be derived in a way relevant to practice (Roskilde Universitetcenter, 1972). The specific problem should also give access to the broader perspective on the subject, a principle borrowed from the German philosopher Oskar Negt and dubbed *exemplarity* (Negt, 1971). Key features of this model were that, first, responsibility for problem-formulation was a joint venture between students and teachers rather than teachers alone (Illeris, 1974); second, problems were not tackled in short week-long cycles like at Maastricht, but in semester-long projects usually done in groups of six to eight students (Aalborg Universitetscenter, 1976); third, although this was not the original intention, regular courses were an integral part of the model, the usual split being 50% project work and 50% coursework (Enemark & Kjaersdam, 1994).

Beyond these commonalities, the model developed in a somewhat fractious manner. First, there was a split between Roskilde and Aalborg: Roskilde University was founded as a dream project of the Danish Student Union, fed by radical teachers from Copenhagen and the neo-Marxist ideal of *fagkritik*, or the critical analysis of disciplines (Hansen, 1997). Aalborg University on the other hand was the product of years of lobbying from regional interest groups who longed to see a university in Northern Jutland, and although it also attracted a fair share of radical elements, this was not its defining characteristic (Clausen, 1984). Second, within Aalborg itself, there was a split of ambitions between the humanities and social sciences on the one hand, and the natural and technical sciences on the other: the former was to some extent concerned with social critique, while the latter was concerned with building the credibility of its model *vis à vis* other engineering institutions in Denmark, and thus, there was no coherent application of the educational model across the board (Kolmos et al., 2004; Whitehead, 2007).

Perhaps as a consequence of its desire for credibility on the international education scene, Aalborg's former Dean of Engineering Finn Kjaersdam moved to have the Aalborg model renamed to "problem-based learning" during his rectorship of the university in the 1990s. This move was accompanied by some soul-searching to determine whether project work could indeed be considered a part of the PBL family (Kolmos, 1996). By the 2000s, the adoption of the PBL terminology was complete and self-evident for Aalborg, which began releasing publications in which the distinction was either only briefly mentioned or no longer made (De Graaff & Kolmos, 2003). At the time of writing, researchers from the Aalborg model intermingle at conferences and in publications with those from the medical model and a whole host of hybrids, variations, and iterations of PBL across disciplines and types of education. It should be noted that Roskilde never partook in the PBL renaming, choosing instead to use the acronym PPL with emphasis on its critical heritage. Whether this serves to broaden the definition of PBL to a hold-all umbrella of progressive education methods or just creates a situation where different understandings of PBL co-exist confusingly remains to be seen.

Conclusion

The primary conclusion to draw from this brief intellectual history of PBL is that the advent and development of PBL has not been a smooth and straightforward process—it was a patchwork of borrowed innovations and diffuse understandings of various education philosophies set in a time where change and reform were in the air. For that reason, perhaps, it became a rather plastic terminology, able to envelope different interpretations of the model, as subtle as the changes made by Maastricht or far reaching as the adoption of the name "PBL" by Aalborg.

For that reason also, it has been the stage for numerous intellectual disputes over the purpose and principles that underlie it. If history is not able to hand us a definitive answer to the question: "what is PBL," then this question must be handled either bottom-up by psychology, to determine through experimentation and data, or top-down by philosophy to determine through definitive principles, though some might argue that the result in either case would amount to little more than a more consensual construction of the term. The question of whether a plastic catchall terminology is preferable to a strictly defined one is a whole other matter.

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2

Cognitive Constructivist Foundations of Problem-Based Learning

Henk G. Schmidt, Jerome I. Rotgans, and Elaine H. J. Yew

Introduction

In this chapter, we describe what is presently known about what works in problem-based learning (PBL) and why it works. We will not attempt here to review the entire literature on the topic; Thomson Reuters' database Web of Science alone presents more than 11,000 articles with "problem-based learning" in the title or abstract. Nor will we make another attempt to review outcomes of PBL schools in comparison to conventional curricula. Curriculum-comparison studies have been reviewed extensively over the past 30 years (Albanese & Mitchell, 1993; Colliver, 2000; Dochy, Segers, Van den Bossche, & Gijbels, 2003; Gijbels, Dochy, Van den Bossche, & Segers, 2005; Schmidt, Dauphinee, & Patel, 1987; Schmidt, Van der Molen, Te Winkel, & Wijnen, 2009; Vernon & Blake, 1993). Here we will focus on a review of studies into what happens to the learner in PBL: the process as it unfolds when students try to learn new things in this approach to education.

But Which Learning Process?

Since PBL is not a single educational treatment but a conglomerate of interventions, different authors have tended to define the purpose of PBL differently and stress different aspects of PBL as crucial. In earlier work, we have distinguished between at least three "types" of PBL: PBL as a process of inquiry, PBL as "learning to learn," and PBL as the construction of mental models of the world, the latter representing a "cognitive constructivist" approach to PBL (Schmidt, Van der Molen

The text of this chapter is based on an article published previously (Schmidt, Rotgans, & Yew, 2011) and extended with results from recent research.

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et al., 2009). However different, these three perspectives agree that PBL has six defining characteristics: (a) the use of problems as the starting point for learning, (b) students collaborating in small groups for part of the time, and (c) flexible guidance of a tutor. Since problems steer the learning in such curriculum, (d) numbers of lectures are limited. The latter agrees with the idea that (e) learning is to be student-initiated and that (f) ample time for self-study should be available (Evensen & Hmelo, 2000; Hmelo-Silver, 2004; Schmidt, 1983b, 1993). Since only the cognitive constructivist approach has led to a sizable volume of research, we will confine our review to this interpretation of what PBL is about.

This is our plan for this chapter. First, we will describe the process of PBL, emphasizing that it is a special way of acquiring *knowledge* of a domain. Second, we will interpret learning in this approach in terms of two hypotheses derived from cognitive psychology: the activation/elaboration hypothesis and the situational interest hypothesis, and review the evidence supporting these hypotheses. Third, we will take a look at the research into the educational aids supporting learning based on problems: the problems themselves, the tutorial group, the tutor, and the self-directed learning activities of the students. Finally, we will discuss several recently conducted studies, in which attempts were made to chart the learning process in PBL as a whole, using a *microanalytical methodology*.

The Process of PBL from a Cognitive Constructivist Point of View

In the following description of the process of PBL, we will rely on an earlier attempt to sketch its constituting elements in the light of the cognitive constructivist framework (Schmidt, Van der Molen et al., 2009).

In PBL, the problem comes first. A problem is usually a description of a set of phenomena or events observable in the real world that are in need of an explanation in terms of a *theory*; an underlying principle, process, or mechanism. The task of the students in PBL is to construct such a theory through small-group discussion and through self-directed learning (Schmidt, 1983b). The following example of a problem is taken from a first-year medical curriculum. The title is "Miraculous rescue":

> For more than 15 minutes an eight-year-old boy, Maurice, has been lifelessly floating around in water colder than 60 degrees F. Fortunately, a passer-by succeeds in bringing him out of the water. Mouth-to-mouth resuscitation is applied immediately. Everyone is astonished to notice that the boy is still alive. Presently, Maurice is on the intensive care ward of the local hospital and is out of danger. According to his doctor he is expected to recover completely. Explain why this is possible.

As can be deduced from this example, problems *actualize* important scientific ideas—here physiological survival mechanisms—that students must master as part of their education. In medical education, the phenomena to be explained often take the form of signs or symptoms of a sick person. In science education, natural phenomena observed in everyday life, such as a thunderstorm or the movement of a skier over a mountain slope, may be the starting point of learning. Important is that these problems are represented as *puzzles*; that is, that they describe phenomena that are not easily to relate, are counterintuitive, or otherwise have an element of surprise.

Students work on such problems in small tutorial groups of 6–10, discussing them initially based only on prior knowledge. The goal of such initial discussion is *to construct a tentative theory* explaining the phenomena or events described in the problem-at-hand in terms of its underlying principles or mechanisms. For instance, medical students discussing the fact that Maurice has survived in cold water for so long may come up with the idea that, in cold water, the oxygen needs of the body may be reduced because of changes in the body's metabolism. In addition, they may hypothesize that a child has a smaller body surface and may not decrease in temperature to the same extent as an adult, and so on.

Hypotheses proposed during this initial analysis of the problem are allowed to be inaccurate, superficial, or outright wrong, as long as they represent the conceptions students hold—or collaboratively construct—about the world. It is deemed important that students' misconceptions are expressed, because this has been demonstrated to facilitate remediation through the confrontation with new more accurate conceptions (Chinn & Brewer, 1993; Dole & Sinatra, 1998).

Based on this initial discussion, often lasting for more than an hour, learning issues (or called learning objectives) for individual study are formulated. These learning issues usually consist of questions arising from the discussion. For example, the medical students may have formulated issues for self-study such as: What is a mammalian diving reflex? Is the small size of the skin area of a child exposed to the cold a factor helping survival? Does the blood circulation to the skin and the extremities shut down? And if so: how? What happens to blood circulation to the vital organs?

Students will pursue these learning issues through individual, self-directed learning usually using a variety of resources: books, articles, movies, and internet sites. These resources may be teacher-suggested or student-selected, or a combination of both. In most PBL curricula, students are given some responsibility in choosing their own resources. It is suggested that making choices based on one's own judgment of the importance of a particular source of information supports the experience of being an autonomous learner, a condition conducive to the development of interest in the topic at hand. This in turn would foster autonomy (Ryan & Deci, 2000). In particular when students are in the early stages of a PBL-curriculum however, they tend to have difficulty overseeing their field of study and, therefore, tutor scaffolding takes place here more extensively than in later phases (Dolmans & Schmidt, 1994).

After this period of self-directed learning activity, usually lasting for 1 or 2 days, but in some curricula for up to a week, students return to their tutorial group, review and share what they have learned, and elaborate upon it. This second meeting is used to explore to what extent the students' understanding of the problem has developed and whether misconceptions remain that need to be addressed. A further role of continued discussion of the problem is that it enables students to *elaborate* on the knowledge acquired. It is assumed that elaboration helps students in the long-term retention of the subject matter studied (Pressley et al., 1992; Reder, 1980). Finally, continued discussion of the problem discourages "free riders." When students know that they are required to share what they have learned, their inclination to let others do the work diminishes. A tutor supervises all these activities. His or her role is not to teach, but to guide through conversation and cross-examination (Dolmans et al., 2002).

In summary, the initial analysis of a problem serves to activate prior knowledge, which is then used to collaboratively construct a tentative mental model of the situation described. This model is subsequently tested against the available literature and enriched and modified by it. Since the literature is studied with preconceptions activated in mind, discrepancies between faulty prior knowledge and new knowledge can be more easily resolved and better learning would ensue. In addition, prior knowledge, once activated, would provide better scaffolds for new information. Returning to the problem after individual study serves to further elaborate on what has been learned and to check whether a deeper understanding has evolved. This is, in a nutshell, how students learn in PBL. However, what drives this learning? We believe that it is the enigmatic nature of the problem with which they are confronted. The problem produces a state of *situational interest*; it temporarily arouses interest in the topic at hand, which acts as the motivational driving force to engage oneself at some length with the literature, to continue seeking relevant information until the thirst for new information about the problem is satisfied (Rotgans & Schmidt, 2014).

These two hypotheses about what happens to the mind of the learner in PBL, the activation/elaboration hypothesis and the situational interest hypothesis, have been tested in several studies. These studies will be reviewed in the next section.

Empirical Evidence Relevant to the Two Theoretical Claims

In this section, we will summarize the evidence relevant to the perspective of PBL outlined in the previous pages. First, we will present studies relevant to the activation/elaboration framework for PBL. Second, studies are reviewed with respect to the emergence of situational interest in problem-based classrooms.

The Activation/Elaboration Hypothesis

The literature on the constructive nature of learning and the role of elaboration through self-explanation (Chi, Siler, Jeong, Yamauchi, & Hausmann, 2001), discussion with peers (Webb, Troper, & Fall, 1995), practicing (Ericsson, 2004), or responding to questions (Pressley et al., 1992) is extensive. What needs to be demonstrated is that these processes are vital to the process of PBL. Below, several experimental studies will be reviewed, in which the following questions were asked and answered: (a) Does the initial discussion of a problem lead to the activation of previously acquired knowledge? (b) Is there evidence that having to explain the problem leads to elaboration? (c) Do these activities facilitate the comprehension and retention of relevant *new* information?

In a series of early studies aimed at elucidating the role of prior knowledge activation and elaboration in the initial discussion of a problem, Schmidt and colleagues (Moust, Schmidt, De Volder, Beliën, & De Grave, 1987; Schmidt, 1984; Schmidt, De Grave, De Volder, Moust, & Patel, 1989) presented students who had studied the biological process of osmosis while in high school either with the following problem:

> A red blood cell is put in pure water under a microscope. The cell swells and eventually bursts. Another blood cell is added to a solution of salt in water. It shrinks. Explain these phenomena,

or with an unrelated task. When subsequently asked to recall whatever they remembered about osmosis, the students who had discussed the blood cell problem produced almost twice as many osmosis-related ideas as the students involved in the unrelated task. According to the authors, this finding suggests that the initial discussion of a problem indeed has a considerable effect on activation of, and elaboration upon, previously learned knowledge. The authors were however not able to distinguish the influence of activation from the effect of elaboration (the students were prompted to explain), nor were they able to exclude the possibility that students simply learned from each other (the students explained things to each other) and therefore had more knowledge. To deal with this shortcoming, De Grave and colleagues compared effects of problem discussion in a small group with *individual* problem analysis and direct prompting for knowledge about osmosis (De Grave et al., 1985). They discovered that small-group discussion had a larger positive effect than individual problem analysis. Directly prompting for knowledge relatively had the smallest effect. The investigators concluded that the confrontation with a relevant problem with the assignment to explain, and small-group discussion of that problem each have additive facilitating effects relative to direct prompting for prior knowledge. The assignment to explain leads students to further elaborate on their prior knowledge even in the absence of other students. Group discussion had, in particular, a considerable effect, suggesting that elaboration on prior knowledge and learning from each other, even before new information is acquired, are potent means to facilitate understanding of problem-relevant information.

Schmidt et al. (1989) presented the blood cell problem to novices, 14-year-old high school students who had never heard of osmosis. In addition, they presented the problem to high school students who had studied the topic before. Control groups discussed an unrelated problem. Subsequently, all participants studied a six-page text about osmosis for a fixed amount of time. The group that had discussed the blood cell problem prior to reading the text remembered 26% more about the text than the group that had discussed an unrelated topic. The effect was strongest among the novice students (41%), suggesting that problem discussion is most helpful if students have only limited knowledge—or even only common sense knowledge—of the subject.

De Grave and colleagues (2001) replicated these findings in the domain of medicine. They presented first-year medical students with either a problem of a man fainting and presenting with a decreasing blood pressure after having been stung by a swarm of bees, or an unrelated problem. After discussion, all students studied, for a fixed amount of time, a text about factors affecting the circulatory system. The group that had discussed the man-stung-by-bees problem prior to reading the text remembered 24% more from the text than the group that had discussed the unrelated problem prior to studying exactly the same text.

The studies discussed so far had difficulty isolating effects on learning and retention of elaboration—that is, effects of students engaged in self-explanation—from other cognitive processes elicited by problem discussion, such as learning from each other. To deal with this problem, Van Blankenstein and colleagues (2011) introduced a new paradigm for studying effects of elaboration in small groups on the learning of individual students. They videotaped a group discussion about a problem and presented this video to individual students. These students either only watched the video and listened to the discussion, or were prompted to actively provide explanations themselves a number of times during the discussion. In this way, the investigators could keep the information provided by other students constant over the conditions of the experiment (all participants saw the same video). Subsequently, both groups studied the same problem-related text for the same amount of time and were tested for knowledge twice: immediately or after a month. The authors found that immediately after studying the text, the elaboration group had a 28% higher score. After a month this difference had increased to 30%. It seems that elaboration in a small group not only facilitates processing of a study text but also adds to its longer-term memorability. This view is reinforced by the fact that others also report long-term effects of PBL (Eisenstaedt, Barry, & Glanz, 1990; Mårtenson, Eriksson, & Ingelman-Sundberg, 1985; Tans, Schmidt, Schade-Hoogeveen, & Gijselaers, 1986).

Recently, Loyens and colleagues have compared effects of PBL with other instructional approaches (Loyens, Jones, Mikkers, & Van Gog, 2015). In their study, students in the problem-based condition had to discuss three Newtonian physics problems about the trajectory of objects falling. Subsequently, they studied a text about Newtonian mechanics. Their performance on an immediate and delayed posttest was compared with a group who received a lecture on the same topic for the same amount of time, and a group who only studied the text (the problems were part of the material but were not emphasized). The problem-based condition performed 26% better than the best on the two other conditions (the self-study condition), a difference that increased to 42% on the delayed test 1 week later.

The Situational Interest Hypothesis

The situational interest hypothesis underlying PBL states that problems or puzzles create a desire in students to find out more about a topic, leading to increased concentration, focused attention, and a willingness to learn (Hidi & Renninger, 2006). Situational interest, as the name implies, is not a stable or dispositional form of interest but is situationally aroused by an intriguing or captivating puzzle or problem. The underlying psychological processes explaining this *desire to learn* can best be explained in terms of a hypothesis proposed by epistemic curiosity researchers[1] (see Loewenstein, 1994 for a review). Humans seem to have a natural tendency to make sense out of the world and, when they encounter something they do not understand or something that violates their expectations, it leads to situational interest because this state of affairs makes them aware that *a knowledge gap* exists between what they know and what they want to know. This phenomenon has been referred to as a cognitively induced experience of (knowledge) deprivation (Berlyne, 1978; Litman, 2008). This experience of deprivation initiates information-seeking behavior to close the knowledge gap (Litman, 2005). As the knowledge gap closes, through assimilation of new information into existing knowledge structures, situational interest decreases until the knowledge equilibrium is reestablished (Rotgans & Schmidt, 2014).

In sum, the situational interest hypothesis proposes that the problem in PBL triggers students' situational interest by making them realize that they have a knowledge gap that needs to be closed. A good problem creates an adequate level of deprivation in students that provides sufficient "fuel" to carry them through independent self-directed learning.

Studies testing the situational interest hypothesis in the context of PBL are limited because situational interest has become the focus of attention recently (but see De Volder, Schmidt, Moust, & De Grave, 1986; Schmidt, 1983a). Rotgans and his associate have conducted several studies using a short rating scale to test this idea (Rotgans & Schmidt, 2011a, 2011b). This short rating scale would mention the topic to be studied and consists of items such as: "I want to know more about this topic" and "I think this topic is interesting." In these studies, they tested the level of situational interest of their students on several occasions: when arriving in the classroom, after presenting a relevant problem, and after the initial discussion about the problem. They demonstrated that the presentation of the problem significantly increased the level of situational interest in the students, an increase that was maintained during the small-group discussion and decreased after learning was terminated (Rotgans & Schmidt, 2014).

Research on PBL's Support Strategies

In this section, we will review research focusing on the means through which learning in PBL is fostered: problems, small-group collaboration, tutors, scaffolds, and self-directed learning.

Roles of Problems in PBL

Most of the research on problems in PBL revolves around the question of what makes a good problem in the views of the tutors and students. For instance, Des Marchais (1999) identified nine criteria that were rated by experts as most

1 Situational interest is considered here identical to epistemic curiosity, or curiosity for knowledge.

significant: (a) stimulating thinking, analysis, and reasoning; (b) assuring self-directed learning; (c) using previous basic knowledge; (d) proposing a realistic context; (e) leading to the discovery of learning objectives; (f) arousing curiosity; (g) choosing topics related to public health; (h) assuring contextual breadth; and (i) choosing an appropriate vocabulary. In a similar study, Sockalingam, Rotgans, and Schmidt (2010) found 11 problem characteristics that were identified by students and tutors as being most significant for PBL: an effective problem leads to appropriate learning goals; promotes self-directed learning; stimulates critical thinking; promotes teamwork; triggers interest; is of suitable format; is of suitable clarity; stimulates elaboration; enables application/is of relevance; relates to prior knowledge; and is of appropriate difficulty. In a further study—a review of 100 studies from various disciplines—Kim et al. (2006) identified five key problem (or "case") attributes: (a) relevance; (b) realism; (c) engaging; (d) challenging; and (e) instructional. The general message from these studies is that a problem should be authentic; it should lead to the identification of learning goals, stimulate self-directed learning, and should be interesting.

In addition to the above studies that helped identify key attributes of effective problems, studies were devoted to gaining insights into the ways these specific attributes influence student learning in PBL, such as how problems lead to the identification of learning goals. For instance, Dolmans, Gijselaers, Schmidt, and Vandermeer (1993) investigated the effectiveness of problems in a course by comparing whether the learning goals identified by students matched those intended by faculty. The reasoning behind this approach was that an effective problem should lead the students to the intended learning issues the problem designers had in mind when developing the problem. The results of the study revealed that, on average, 64% of the intended learning goals matched those of faculty. Mpofu, Das, Murdoch, and Lanphear (1997) replicated and extended the study to six problems in medical education. Their results were similar to the Dolmans et al. findings: the degree of agreement between the student-generated learning goals and intended learning objectives was relatively high (91%). The results of both studies highlight that effective problems lead students to the intended learning goals.

Jacobs, Dolmans, Wolfhagen, and Scherpbier (2003) applied a different approach, by developing a questionnaire to determine the "complexity and structuredness" of PBL problems. During the validation of their questionnaire they discovered that students had difficulty in dealing with complex and ill-structured problems (i.e., problems that have several solutions), because they did not fit in with the students' level of prior knowledge. As such, their study revealed that a problem should relate to students' prior knowledge.

In a study by Soppe, Schmidt, and Bruysten (2005) it was investigated whether the attribute *problem familiarity* had an influence on student learning. In an experimental setup, students worked with either a "familiar" or an "unfamiliar" version of the same problem. A measures of perceived problem quality was administered as well as outcome measures, such as the number of explanations for the problem put forward by the students, the quality of learning issues derived from the discussion, the amount of time spent on self-study, and the amount of knowledge gained as measured by a test. The results showed that participants in the "familiar problem" condition perceived the problem to be of higher quality than the participants in the "unfamiliar problem" condition. However, no significant differences in learning were found. The authors proposed that problems might be improved by making them more relevant to the everyday experience of students—an important consideration also stressed by Hung (2006).

In yet another study, Dolmans, Schmidt, and Gijselaers (1995) examined the relationship between student-generated learning goals and self-study. As in an earlier study, they found considerable overlap between the learning goals identified by students and the faculty-intended learning objectives, but this match did not result in more self-study time. They concluded that the learning goals produced during group discussion about the problem might not be the sole factor in what students decide to study during self-study. They propose that several other factors may also be involved, such as tutor guidance, contents already covered in other units, insights gained during self-study, and the nature of the learning resources available. The outcome of the study highlights a potential shortcoming of the aforementioned studies. If one is interested in the overall effects a problem has on other variables in PBL, one must conduct studies that incorporate all relevant variables and test all relevant relationships. For instance, does the problem or the tutor have a stronger influence on students' generation of learning goals; or what is the relationship between problems, how the groups function together, time spent on self-study, and academic achievement?

To address this shortcoming, Gijselaers and Schmidt (1990) developed and tested a causal model of PBL in which all key elements of PBL were included: (a) problem quality; (b) tutor performance; (c) prior knowledge; (d) group functioning; (e) time spent on self-study; and (f) interest in subject matter. Their study demonstrates that the quality of problems has a major influence on the functioning of the tutorial group and the time spent during self-study. Moreover, the quality of the problem had a significant effect on students' intrinsic interest in the subject matter. These findings were replicated in a study by Van Berkel and Schmidt (2000), who tested a causal model like that of Gijselaers and Schmidt. In both studies, the problem had a more significant effect on group functioning in PBL as compared to tutor performance, which signifies the important role problems play in PBL. Group functioning, in turn, was related to time spent on self-study, which predicted academic achievement.

Effects of Small-Group Collaboration

The cognitive benefits of small-group collaboration have been extensively documented in the literature (Slavin, 1990; Springer, Stanne, & Donovan, 1999; Webb et al., 1995) and need no further discussion here. Cognitive effects of small groups in PBL were discussed in the previous section. Here, we would like to draw attention to two other functions of small-group learning. First, the tutorial group is a source of friendships. In addition, the group enables students to develop more personal relationships with teachers than is possible in the larger classroom. Both factors are protective against dropping out of school (Severiens & Schmidt, 2009; Tinto, 1997). Second, regular small-group tutorials in problem-based schools provide peer pressure and natural deadlines for work to be completed and, therefore, encourage students not to postpone self-study. These two noncognitive "side effects" of small-group collaboration may be a reason why students from PBL curricula tend to graduate faster than students from conventional schools and drop out to a lesser extent (Burch, Sikakana, Seggie, & Schmidt, 2007; Howell, 2005; Iputo & Kwizera, 2005; Schmidt, Cohen-Schotanus, & Arends, 2009).

Role of the Tutor

The tutor's role in a PBL tutorial is different from that of the tutor in a conventional tutorial. In PBL, tutors are expected to facilitate or activate students' learning and to promote effective group functioning by encouraging active participation of all members, monitoring the quality of learning and intervening where necessary (Maudsley, 1999; Mayo, Donnelly, & Schwartz, 1995; Wetzel, 1996). Tutors are also to play active roles in the scaffolding of student learning by providing a framework that students can use to construct knowledge on their own (De Grave, Dolmans, & Van der Vleuten, 1999). By probing students to think more deeply and modeling for them the kinds of questions that they should be asking themselves during problem solving, the tutor–student relationship can be viewed as a type of cognitive apprenticeship (Collins, Brown, & Newman, 1989; Hmelo-Silver, 2004).

Effect of subject-matter expertise on students' achievement and learning process

With this shift of the tutor's role in the student-centered PBL process, there have been many studies seeking to better understand how tutors contribute to students' learning in PBL. One subject of considerable debate centered on the question of whether a tutor needs subject-matter knowledge to guide students or whether the possession of appropriate facilitation skills is sufficient. Several studies have demonstrated effects of tutor expertise on their students' achievement and effort. Davis, Nairn, Paine, Anderson, and Oh (1992), for instance, showed that student performance on a test measuring knowledge of influenza was enhanced when their tutors entertained an active research interest in that field. Schmidt, Vanderarend, Moust, Kokx, and Boon (1993) found similar effects of subject-matter expertise on achievement. Other studies, however, failed to demonstrate noticeable effects (Des Marchais & Black, 1991; Swanson, Stalenhoef-Halling, & Van der Vleuten, 1990). One hypothesis explaining the contradictory findings is that subject-matter expertise of the tutor seems to play a role predominantly when the scaffolds provided by the learning environment itself—the problems, the resources—do not contain sufficient cues as to what is important to study. Under such circumstances, students seem to rely on their tutor for guidance and might profit if their tutor happens to be someone knowledgeable regarding the subject under study (Schmidt, 1994).

Another group of studies investigated the influence of tutors' content expertise on the tutorial process. Silver and Wilkerson (1991) found that tutors with subject-matter expertise were more inclined to play a directive role in the tutoring process, speaking more often and for longer periods, supplying more direct answers to questions posed by students, and suggesting more points for discussion. They concluded that these tutor behaviors could have a negative impact on the development of students' skills in active, self-directed learning, and also collaborative learning. On the other hand, Eagle, Harasym, and Mandin (1992) demonstrated that students guided by content-expert tutors produced more than twice as many learning issues for self-directed learning, and these learning issues were almost three times more congruent with case objectives, as compared to students guided by nonexperts. The former also spent almost twice the amount of time on self-study. Similarly, Davis et al. (1992) found no significant differences between expert-led and nonexpert-led groups in the teacher-directed and student-initiated interactions, but instead demonstrated increased student achievement and satisfaction for groups led by experts. Both groups of authors suggest that the expert tutors, by virtue of their subject knowledge expertise, were better at posing questions at critical moments thus positively influencing students' learning. While content experts may be proficient in using their subject-matter expertise to direct students' discussion, knowing when and how to use their subject-matter expertise to facilitate students' learning is more beneficial to students' learning. Thus, ideally a tutor should be both an expert in the respective subject matter and an expert in facilitating students' learning process.

Effect of tutor behaviors on students' achievement and learning process

One theory of the effective tutor proposed by Moust merges these two qualities of an effective tutor (Moust, 1993). A key idea in this theory is the concept of "cognitive congruence," which is defined as a tutor's ability to express oneself in the language of the students, using the concepts they use, and explaining things in ways easily grasped by students (Schmidt & Moust, 1995). These authors suggested that both subject-matter expertise and "social congruence" were necessary conditions for cognitive congruence. Social congruence refers to interpersonal qualities such as the ability to communicate informally and empathically with students, and hence being able to create a learning environment that encourages open exchange of ideas. Thus, it was hypothesized that a tutor who is more socially congruent and better able in using subject-matter expertise, would be more cognitive congruent. Using structural equation modeling, Schmidt and Moust (1995) demonstrated that both social congruence and subject expertise influenced cognitive congruence, which in turn influenced tutorial group functioning and this indirectly affected the level of student achievement through an increase in time spent on self-study. Social congruence directly influenced group functioning during the problem-solving process while subject-matter expertise of tutors had a slightly direct positive impact on student achievement. Hence, this study showed that effective tutoring resulting in better student achievement requires both content knowledge of the tutor and an ability to interact with students on a personal level as well as to utilize language that is easily understood by students.

While the study described above shows the relationships between different tutor behaviors and student achievement, another study by Chng, Yew, and Schmidt (2011) looked further into how these behaviors influenced the learning *process* in PBL by studying 223 students and 7 tutors from the science faculty at a polytechnic in Singapore. Unlike the original study of Schmidt and Moust (1995), which made use of students' self-report data, this study examined the extent of students' learning at each PBL phase by using a "concept recall test." This test was designed to estimate the number of relevant concepts that students could recall at the end of each PBL phase: problem analysis, self-directed learning, and reporting (Yew, Chng & Schmidt, 2011). The underlying assumption of the concept recall test is that as students engage in problem analysis, self-directed learning, group discussions, and/or peer teaching, they are in fact building semantic networks of concepts related to the problem as well as constructing relations between their prior knowledge and new ideas (Glaser & Bassok, 1989). As learning progresses, students would master more specific terms to articulate the newly acquired knowledge. Hence, as these networks of knowledge in their minds broaden, reorganize, and become more tightly integrated, measuring the number of relevant concepts that can be recalled at any point in time can be considered an estimation of the quality and progress of students' learning.

Chng et al. (2011) hypothesized that tutors exhibiting more cognitive congruent behaviors would influence knowledge construction and acquisition at each learning phase of the PBL process, thus students under the tutelage of such tutors would be more extensively involved in the construction of knowledge (i.e., recall more relevant concepts at each PBL phase) and would ultimately achieve better results at the end of the learning process. Tutor behaviors were assessed by students and the tutors were then divided into three groups according to their level of subject-matter expertise, cognitive congruence, and social congruence. Students' achievement at the end of the PBL cycle was measured through an essay test. Using analysis of covariance (ANCOVA) with students' preexisting grade point average (GPA) score as the covariate, it was found, contrary to their original hypothesis, that only social congruence of tutors had a significant influence on students' learning process. This effect of social congruence was evident on the total number of concepts recalled at the end of all the PBL phases: problem analysis, self-directed learning, and reporting. No significant effects were found for subject expertise and cognitive congruence of the tutor on each of the learning phases in the PBL process. (However, in line with the Schmidt and Moust (1995) findings, all three tutor behaviors had significant effects on final student achievement.) The results indicate that the social congruence of the tutor influences the learning process in a more significant way as compared to cognitive congruence and subject-matter expertise, at least in this educational context. The willingness of a tutor to establish an informal relationship with the students and display an attitude of genuine interest therefore has a significant impact on the progress made by students during the PBL process. This is possibly due to socially congruent tutors being able to create a nonthreatening learning environment and developing strong tutor–student relationships that enhance an open exchange of ideas and questions and promote student engagement in the learning process.

The study by Chng et al. (2011) was carried out in a rather unique educational context where students complete the PBL process from initial problem discussion to reporting phase within a day and students have close contact with their tutors throughout the day (O'Grady, Yew, Goh, & Schmidt, 2012). As such, this may limit the generalizability of the findings to other educational contexts. More research on how tutor behaviors influence students' learning process in PBL still needs to be carried out. Recent studies on tutors are indeed moving away from investigating the role of tutors in influencing student achievement outcomes alone and instead focusing more on students' learning process, including how and when to intervene in the event of difficult incidents in tutorial groups (Gukas, Leinster, & Walker, 2010; Kindler, Grant, Kulla, Poole, & Godolphin, 2009). Studies such as those by Hmelo-Silver and Barrows (2006), which describe in detail how "collaborative knowledge building" is facilitated, provide deeper insight into the role of the PBL tutor. By analyzing the discourse that took place between five medical students and their facilitator as they worked on a problem over 5 hr in two sessions, they demonstrated how the facilitator supported knowledge building using open-ended questions that served as scaffolds for the students.

The Use of Scaffolds in PBL

From the descriptions above, it can be seen that the role of the tutor as a scaffold to facilitate meaningful learning is one that is generally agreed upon. Although Kirschner, Sweller, and Clark (2006) suggest that PBL is a minimally guided approach and is therefore less effective and efficient in helping students learn, others argue that PBL does provide guidance and scaffolding to help students learn (Belland, Glazewski, & Richardson, 2008; Schmidt, Loyens, Van Gog, & Paas, 2007).

The metaphor of scaffolding refers to the temporary support provided for learners to help them complete a task they would otherwise not be able to complete on their own (Wood, Bruner, & Ross, 1976). While scaffolds can occur in multiple forms, Saye and Brush (2002) suggest that most scaffolds can be classified as either soft or hard scaffolds. Soft scaffolds are dynamic and refer to tutor actions in support of specific learner needs, as described in the previous section on the role of the tutor in PBL (Berk & Winsler, 1995; Roehler & Cantlon, 1997; Saye & Brush, 2002). On the other hand, hard scaffolds are static supports that can be developed in advance based on typically expected learner difficulties associated with a task (Saye & Brush, 2002). Such scaffolds can be in the form of computer- or paper-based cognitive tools, for example, worksheets (Merriënboer, 1997). An example is the use of process worksheets as described by Schmidt et al. (2007), where hints or descriptions of the phases one should go through when solving a problem are provided. Students may consult the process worksheet while working on the tasks and may also use it to monitor their progress throughout the problem-solving process.

In line with the metaphor, scaffolds should gradually be withdrawn or faded, as the learner becomes increasingly responsible for their own learning (Van de Pol, Volman, & Beishuizen, 2010). For example, while novices in a PBL environment may be initially supported with some resources to scaffold their learning, with increasing expertise, fewer resources should be provided to the students. In this way, students develop as independent learners through a form of flexible scaffolding (Schmidt et al., 2007).

Studies investigating the use and impact of *hard* scaffolds in the PBL context are rather limited. A study by Simons and Klein (2007) examined the impact of hard scaffolds on the learning outcomes of middle school learners during the implementation of a problem-based learning unit. Student were subject to three experimental conditions—one where no scaffolding access was provided, one where an optional scaffolding was provided, and one where students were required to complete all scaffolds provided. Results showed that students in the optional and compulsory scaffolding conditions performed significantly better than students in the no scaffolding condition. Also, those in the scaffolding required condition produced more highly organized project notebooks containing a higher percentage of relevant entries. The PBL environment described in this study was one with very little consistent teacher support (soft scaffolding) and in a context of generally low-performing students. The conclusion therefore by Simons and Klein is that hard scaffolds seem to enhance student performance, especially under circumstances of limited teacher support.

Another study investigating the effect of worksheets as a scaffolding tool on students' achievement in a PBL environment was carried out by Choo, Rotgans, Yew, and Schmidt (2011). In this context, 17 PBL classes (241 students) were randomly assigned to two experimental groups—one with a worksheet provided and the other without. Using analyses of variance, they found that there was no statistically significant difference between the two groups in terms of their postlesson concept recall tests. Their findings therefore suggest that scaffolds such as worksheets may not play a significant role in enhancing students' learning within this PBL context. Furthermore, results from a survey administered indicated that the strongest factor perceived by students to impact their learning in a PBL context is the tutor, followed by team and class dynamics, while the influence of the worksheet was rated lowest. Two experiments provided hard scaffolds in the form of questions underneath the problem to be followed up during self-study. In one of these (Schmidt & Bouhuijs, 1977), the presence or absence of the scaffolds did not matter; in the other (Verkoeijen, Rikers, Winkel, & Van den Hurk, 2006), scaffolding was even detrimental to achievement.

In conclusion, the effects of scaffolding in PBL are rather inconclusive and more research is still needed in this area. When PBL was originally developed in medical schools for relatively mature and motivated learners, the use of hard scaffolds in PBL may not have been necessary. However, with increasing implementation of PBL by educators of different levels and disciplines (Gallagher, Stepien, & Rosenthal, 1992; Kolodner et al., 2003), research to shed further insight into the role of scaffolding to support student performance in PBL is necessary.

Effects of Self-Directed Learning

Self-directed learning is a core element of PBL and much emphasis is put on the developing ability of students to regulate their own learning. It should be noted here that the various instructional activities conducted both in the problem-based and in the conventional context are intended to support such self-study of students. However, emphasizing instructional scaffolding in the curriculum over direct instruction causes students to spend their time differently. Generally, students in the problem-based curricula spend less time in lectures and have more time for self-study. Because of the emphasis on self-directed learning PBL students were shown to borrow more books and seek more learning resources in the library than their counterparts in conventional schools (Blumberg & Michael, 1992; Marshall, Fitzgerald, Busby, & Heaton, 1993; Rankin, 1992), suggesting that these students are more self-reliant and feel more responsible for their own learning. A recent study involving graduation rate and study duration data from almost 14,000 graduates of the eight medical schools in The Netherlands found that time available for self-study in various PBL and non-PBL curricula was correlated .44 with graduation rate and −.48 with study duration; that is, the more time for self-study was available in these curricula, the more students graduated and the faster they could do this (Schmidt et al., 2010). These findings suggest that time available for self-study, as afforded in PBL, leads to better achievement of more students, hence to fewer delays and higher graduation rates. The study also demonstrated that the *more* lectures these students received, the *fewer* students graduated and the longer it took them to graduate. This finding is ironic in the light of the recent emphasis in the literature on the importance of direct instruction (Kirschner et al., 2006), because it demonstrates that this kind of support is not necessarily *good* for students. On the other hand, Wijnia and colleagues demonstrated that when students do not seek for information themselves based on the learning issues formulated in the tutorial group, but are presented with the teacher's interpretation of what needs to be studied, this increases performance on a posttest (Wijnia, Loyens, Van Gog, Derous, & Schmidt, 2014)

Charting PBL in the Classroom

A Microanalytical Approach to Studying Learning Processes in the PBL Classroom

If one wishes to study learning in PBL while it happens, if one is interested in surveying the underlying mechanisms of interest and learning during PBL, one should look for new approaches to measurement. In the subsequent sections, we present a series of studies on interest and learning, which we refer to as the microanalytical measurement approach (Rotgans & Schmidt, 2011a; Zimmerman, 2008). In this microanalytical measurement approach, a short questionnaire or a short knowledge test is readministered several times at critical moments during the course of a learning event. Administering a measure several times over a learning event may provide insights into what is actually happening during learning. From this, inferences can be made about the mechanisms underlying PBL. The following studies exemplify this.

Interest is Driving Force But is Consumed Over the Course of Learning

In a study by Rotgans and Schmidt (2011a) a microanalytical measurement approach was applied to investigate how students' situational interest develops during

PBL. To that end, five short measures of situational interest were administered over the course of a 1-day PBL session. The results of their study showed that once the problem was presented students' situational interest increased significantly. However, as the learning event progressed situational interest decreased—it seemed as if the initial increase of situational interest caused by the problem was slowly consumed over the learning event. The authors used the situational interest hypothesis to explain this phenomenon. The confrontation with a problem, containing unknowns that need to be known, triggers an experience of knowledge deprivation: a knowledge gap that needs to be bridged by finding information about the unknowns. Knowledge acquired during self-study closes this gap. Since situational interest is an indicator of the existence of such a gap, its decrease over time provides empirical support for their hypothesis. Their study also showed that situational interest predicted students' academic achievement with considerable accuracy, demonstrating that it drives learning.

Thus, applying a microanalytical approach to the study of student interest in PBL revealed the underlying situational interest processes, which would have been difficult to achieve with conventional survey measures or classroom observations. In the following study the microanalytical measurement approach was applied to measure how students' knowledge construction develops during the learning process.

Learning in PBL is Cumulative

The PBL process can be viewed as a sequential series of learning phases that emphasizes both collaborative and individual self-directed learning at different points in time (Hmelo-Silver, 2004; Schmidt, Van der Molen et al., 2009). The assumption underlying PBL is that learning in the PBL process is cumulative—learning in one phase is dependent on the previous, and that both co-construction with peers and individual construction of concepts during self-directed study contribute to student learning (Schmidt, 1983b). Although the idea that new learning is dependent on what has been learned previously is almost universally accepted, evidence of this has been largely confined to demonstrations in the psychological laboratory, particularly in the field of text comprehension. As argued by Yew, Chng, and Schmidt (2011), since social constructivism suggests that knowledge is mainly constructed by means of collaborative interactions (Cobb, 1994; Driver, Asoko, Leach, Mortimer, & Scott, 1994), it is possible that the effects of active learning on achievement are really only due to the group interactions and co-construction of knowledge. Alternatively, since research on self-regulated learning has shown that the use of self-regulated learning strategies strongly influences academic achievement (Zimmerman, 1990), it can be argued that it is the individual self-directed learning phase that is most important to students' learning.

A study by Yew, Chng, and Schmidt (2011) therefore sought to investigate the extent to which PBL is cumulative and whether it involves both collaborative and self-directed learning. They hypothesized that learning in PBL is a cumulative process where the learning in each new phase builds upon knowledge acquired in a previous phase. The process is initially driven by the prior knowledge that students bring with them to the classroom and the learning in each of the PBL phases influences student achievement. This hypothesis was tested against these alternative hypotheses: (a) learning in PBL is only influenced by phases involving collaborative learning and co-construction; (b) learning in PBL is only influenced by self-directed study; and (c) learning in PBL is influenced by both collaborative learning as well as self-directed study, but not in a sequential cumulative manner. The scientific concepts recalled by 218 students at the end of each PBL phase were used to estimate the extent of students' learning. These concepts, together with students' results in pre- and posttests were analyzed using structural equation modeling. Results demonstrated that compared with the alternative hypotheses, the hypothesized model best fit the data obtained. Learning in PBL is cumulative, with group discussions and self-study equally contributing to knowledge acquisition. The investigators found no support for the hypothesis that learning in PBL is best described in terms of collaborative learning and teamwork, nor for the hypothesis that only self-directed learning is important. This is important evidence showing that the three phases of PBL: problem analysis, self-directed learning, and the reporting phase, play specific roles in influencing students' achievement.

Discussion

In this chapter, we have sketched a picture of PBL emphasizing its cognitive constructive nature. We have reviewed empirical evidence supporting six propositions. The first is that the initial discussion of a problem in a small group of students leads to the activation of prior knowledge. This prior knowledge is elaborated upon to collaboratively construct a tentative theory explaining the phenomena described in the problem. The cognitive constructions that result from this exercise in the minds of these students subsequently facilitate the comprehension of new information and its long-term survival (De Grave et al., 2001). Second, problems drive learning through the generation of situational interest. We have demonstrated that the introduction of a problem in the learning situation leads to an increase in situational interest in the topic at hand, and that this situational interest is largely maintained over the course of learning (although it seems to be "satisfied" by the new knowledge acquired and diminishes over time). A higher level of situational interest, in turn, was related to higher levels of achievement (Rotgans & Schmidt, 2011a). Third, small-group tutorials do not only have cognitive benefits. They also contribute to students' feelings of being "at home" within their class socially and academically, which protects them against premature dropout (Tinto, 1997). In addition, since in these groups focus is on interaction aimed at explaining subject matter to one another, free riders are discouraged and students are encouraged to study regularly. This may be a reason why PBL curricula tend to have higher graduation rates (Schmidt et al., 2009).

Fourth, tutors' subject-matter knowledge, their ability to relate to students, and their ability to be cognitively congruent with them all contribute to learning in PBL. Findings in this area suggest that good tutors provide flexible scaffolding;

that is, support students' learning "just-in-time." Experiences with so-called "hard" scaffolds such as adding worksheets or questions to a problem were less unequivocal: the few studies conducted in this area suggest limited effects and in one case even showed hard scaffolds to be detrimental to learning.

Fifth, students in the PBL classroom were shown to be more ardent users of library resources than students in conventional programs, suggesting that these students are more self-directed in their learning. However, students need time to develop this propensity. One study showed that in the beginning students do not study much beyond the learning issues generated in the small group, while best performance on tests was related to the ability to study beyond the learning issues produced (Van den Hurk, Wolfhagen, Dolmans, & van der Vleuten, 1999). Real personal agency seems to need time to develop. But if it develops, it has surplus value over learning driven solely by external stimuli.

Sixth, the extent of learning in PBL is neither the result of group collaboration only (the social constructivist point of view), nor of individual knowledge acquisition. Both activities contribute equally to learning in PBL.

In summary, PBL seems to have fairly strong effects on learning and achievement compared to conditions where students do not work steered by problems. The studies reviewed generally showed learning gains among students that went beyond control conditions in which problems were not the focus of attention or in which students were not encouraged to elaborate on their prior knowledge. These findings seem to be at variance with findings of curriculum-comparison studies that do not generally report effects of PBL to be superior to forms of conventional training (Colliver, 2000; Kirschner et al., 2006). It seems that while finding effects at the micro level, these effects do not translate into visible effects at the curriculum level. The question, then, is why this is so: what would explain this apparent paradox?

We offer here two tentative hypotheses. The first is a "compensation" hypothesis. There is some evidence that students who study under less favorable circumstances tend to compensate by studying harder (Dubin & Taveggia, 1968; Johnson & Kieras, 1983). This would imply that although students profit more from PBL they compensate this additional support by working less hard. This is unlikely because we have shown that in fact students in a PBL curriculum spend more time on individual learning than those in more conventional environments.

A second hypothesis, more parsimonious with the micro-level findings reviewed in this chapter, has been forwarded recently. It assumes that differential dropout and study duration *mask* effects of PBL at the curriculum level. This hypothesis takes as its starting point the observation that PBL-curricula show less dropout and shorter study duration than conventional schools (Burch et al., 2007; Howell, 2005; Iputo & Kwizera, 2005; Schmidt et al., 2009). Comparisons between problem-based and conventional schools may therefore be biased against PBL; effects of PBL become masked by differential dropout and differential study duration. To test this hypothesis Schmidt, Muijtjens, Van der Vleuten, and Norman (2012) reanalyzed 134 curriculum comparisons among schools for which achievement, dropout, and study duration data were available. By correcting for differences between these schools on these variables, they could demonstrate robust effects of PBL both on knowledge attainment and on diagnostic performance. It seems that micro-level effects of PBL *do* replicate at the curriculum level.

In the Introduction, we have hinted at the fact that different authors tend to define the ultimate goals of PBL in a different way. This chapter took as its point of departure cognitive psychology and now well-known principles of constructivist learning with an emphasis on how people acquire knowledge. However, a point of view prevalent in some medical schools tends to define PBL as a *process of inquiry* (Barrows, 1990; Hmelo & Ferrari, 1997). According to this perspective, the ultimate goal of PBL is to help students learn the skill of diagnostic reasoning by mimicking the thinking processes of the expert. While working on a problem, the students engage in formulating diagnostic hypotheses and most of the tutorial time is spent weighing the evidence—signs, symptoms, laboratory data, or physical examination findings—in the light of these diagnostic hypotheses. The role of knowledge acquisition is somewhat blurred in this perspective. While it is acknowledged that knowledge acquisition has its role, proponents of this view sometimes seem to suggest that PBL particularly has a role to play in the fostering of "inquiry skills" or "problem-solving skills"—general cognitive skills that can be applied to gather, interpret, and integrate data from any (clinical) problem. This perspective has its attraction for educators, because professionals in the field seem to think that their expertise is indeed partly based on such elusive skills. What does the cognitive constructivist point of view have to offer in this respect? Thirty years of research in this domain have made clear that it is unlikely that general problem-solving skills can be learned through education, or even that there are such things as problem-solving skills independent of subject-matter knowledge (Norman, 2005). So, there is no shortcut to expertise, no domain-independent problem-solving skills whose acquisition could compensate to some extent for knowledge acquisition. The cognitive constructivist view of PBL incorporates this point of view that all reasoning is based on the cognitive structures acquired. If the task of education is to help students develop these cognitive structures, PBL may be a useful way to do so.

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3

Social Foundations of Problem-Based Learning

Woei Hung, Mahnaz Moallem, and Nada Dabbagh

Introduction

Toward the end of the last century, the rising awareness of the inadequacy of behaviorist and cognitivist theories in explaining human learning triggered a desire to seek different ways to better understand this important subject. During that time, constructivism gradually came to light. The then new philosophical paradigm brought about a whole new perspective from which researchers could appreciate human learning beyond basic knowledge acquisition, which is the focus of behaviorism and cognitivism. The significance of constructivism in education is that it explains learning as a process of construction rather than transmission of knowledge (Jonassen, 1991). Constructivism helps elucidate the complexity of human learning by considering the external influence of physical, social, and cultural environments and how they interact with and shape internal personal cognition and knowledge construction. In contrast to cognitive constructivists, who view knowledge construction as an individual activity, Vygotsky argued (1978) that human cognition development starts with interaction with others, which is social in nature, rather than within the individual. The importance of sociocultural context accounting for an individual's learning is widely accepted today by learning sciences researchers and educators (Spilg, Siebert, & Martin, 2012). Sociocultural constructivism is essential to the foundations of human learning theories.

From long before the time researchers and educators attended to the social components of learning, the idea of social learning not only informed the conception of problem-based learning (PBL) but also has been embedded in its instructional practice. The central idea of the eight objectives for PBL as a pedagogy drafted by John Evans in 1966 (Servant, Norman, & Schmidt, Chapter 1, this volume) revolves around cultivating medical students to be medical professionals who would be ready to solve problems and perform tasks in clinical settings. This idea may seem to largely address the students' cognitive development in medical

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domain knowledge application and problem-solving skills in tackling everyday tasks in medical professions. Yet, the learning goal of developing professional knowledge and skills was not narrowly defined in the curriculum. Rather, clinical skills, contextual, situational, and cultural knowledge of the profession, as well as the ability to work with others and engage in team-based decision making or problem solving (Hung, 2013) are also targeted learning goals. Social interaction and construction are the essence in the development and application of such knowledge and abilities. During the time of PBL's conception and formulation, behaviorism and cognitivism were the mainstream educational paradigms where personal behavior changes and cognitive structure modifications were the focus in the realm of learning, pedagogy, and instruction. The McMaster University faculty's pioneering vision was extraordinary in recognizing the critical role of social contexts and the reciprocal interaction between the social environment and the individual's cognition in shaping the wholeness of students' understanding and competence for their profession.

To realize these learning goals, PBL educators went through an evolution process of adopting instructional formats practiced from other institutes to afford these educational goals and the philosophy of sociocultural learning (Servant et al., Chapter 1, this volume) to gradually formulate the core features and process of PBL. Among which, utilizing authentic real-life clinical problems to structure and drive learning and students actively engaging in self-directed problem-solving and learning processes in small-group settings were three distinct features of PBL (Hung, Jonassen, & Liu, 2008) and later became the hallmarks of the pedagogy. Though the PBL pioneers did not formulate this instructional format and process with specific learning theories in mind, retrospectively, social constructivism and cognitive constructivism are clearly the bedrock that bolsters the theoretical foundation of PBL, in both cognitive and social aspects of student learning.

This chapter will examine the theories that provide foundations for PBL practices and their effects on the learning outcomes. It will first discuss a number of theories that address the social aspects of learning, and then it will examine the relationships between the PBL instructional format and process and the learning outcomes related to social, professional knowledge, and skills. Lastly, it will discuss the research findings from the literature on the effects of PBL on social learning outcomes.

Constructivism

According to Wilson (1997), constructivism is a philosophy that addresses the nature of reality, knowledge, human interaction, and science. Philosophically opposing behaviorism and cognitivism, constructivism views the world as multiple, changing realities where the knower cannot be separated from the known. No two persons share identical understandings and meanings for a given event, object, or perspective. The view of the world and reality is individual-specific, and there are multiple ways of structuring the world. Thus, Jonassen (1992) claimed that "there is no single reality or any objective entity," and "the meaning of the world is interpreted and constructed differently by each individual" (p. 29).

Cobb (1996) indicated that cognitive and sociocultural aspects of knowledge are the two major strands in constructivism's research and theory development. Cognitive constructivism is primarily based on Piaget's work and concerns an individual's cognitive state when he or she forms understandings about the world. Sociocultural constructivism is rooted in Vygotsky's work and mainly stresses the social and cultural influence on an individual's developments of knowledge construction. In the following section, these two strands of constructivism are discussed. However, the emphasis will be on sociocultural learning theories, which are the focus of this chapter.

Piaget's Cognitive Equilibrium Theory

von Glasersfeld (1996) suggested that cognitive constructivism was built on the concept of *cognitive equilibrium* proposed by Jean Piaget. von Glasersfeld (1998) elucidated that cognitive equilibrium is an adaptation process of maintaining an individual's cognitive structures coherent with the external world (or environment). Therefore, knowledge does not serve to produce representations of reality. Rather, knowledge results from a process of constructing one's perceptions and interpretations in order to adapt to the external environment. Piaget's (1977) cognitive adaptation process consists of three forms of equilibration. Fosnot (1996) described the first form as the assimilation of a series of related actions and the accommodation of these actions to objects or the environment; for example, coordinating the actions of moving 10 fingers and pressing different keys on a keyboard for typing. The second form is solving contradiction. When a contradiction occurs between the logical ideas received from the external world and the existing ones in an individual's own cognitive structure system, it causes *disequilibrium*. This contradiction will be solved through constructing plausible solutions for rationalizing the conflicts. The third form is a process of differentiating, integrating, and uniting different knowledge structures into a coherent whole cognitive system. Fosnot (1996) suggested that these equilibration processes are dynamic and nonsequential. A human's cognitive system is constantly adapting, growing, reorganizing, and changing, which keeps the cognitive system alive and always "under construction" (p. 18).

Although focusing his research primarily on individual's cognitive structuring, Piaget (1970) also acknowledged the social and cultural influence on knowledge construction. He contended that the collective knowledge within a particular social or cultural environment is a result of the social interaction (or in his words "social equilibrium") of all the individuals, which in turn, affects every individual's personal knowledge construction. Based on Piaget's works on cognitive equilibrium structuring, von Glasersfeld (1987, 1989) interpreted knowledge as a result of the adaptation process of an individual interacting with the environment in which he or she is. This adaptation process involves personal cognitive traits as well as social–cultural characteristics of the environment. Therefore, there is no identical interpretation of a given object, entity, or event shared among individuals. This uniqueness is largely attributed to the social–cultural influence on the individual's understanding of the world. When it comes to social and cultural aspects of human knowledge construction, Vygotsky is the most referred to theorist.

Vygotsky's Sociocultural Constructivism

Vygotsky agreed with Piaget's assertion that learning is a developmental process. However, he opposed the notion that the development of cognition starts within the individual. Rather, he argued that the developmental processes are predominantly led and influenced by social interaction (Vygotsky, 1978). The meanings of any signs and operations (language, gestures, symbols, etc.) are a result of an interactive process that an individual and others mutually experience, understand, agree upon, and eventually establish (for details, please refer to the "pointing" example in Vygotsky, 1978, p. 56). Consequently, the meaning of this "operation that initially represents an external activity is reconstructed and begins to occur internally" (p. 57). Thus, this interpersonal interaction is transformed into intrapersonal cognitive processing of the information and becomes part of the individual's knowledge base. A series of such interpersonal to intrapersonal transformations are manifested as cognitive developmental events of the individual. Accordingly, Vygotsky theorizes that "the true direction of the development of thinking is not from the individual to the socialized, but from the social to the individual" (Vygotsky, 1986, p. 36). Therefore, the social and dialectical process is not a supplemental but a fundamental mechanism of an individual's learning development (Cole & Scribner, 1978).

According to Fosnot (1996) and Wertsch (1985), Vygotsky viewed an individual's knowledge construction as consisting of two developmental strands: *spontaneous* (or pseudoconcept) and *scientific* concepts. The spontaneous concepts are the concepts instinctively constructed by an individual in a more elementary, primitive form in the developmental process of knowledge construction. The scientific concepts are the higher order, socially culturally formalized concepts. Vygotsky (1986) argued that there is a transition between the developments of these two forms of concepts. He termed this transition as the "*zo-ped*," (zone of proximal development or ZPD) to explain how the primitive, natural, spontaneous concepts converge with the socially, culturally agreed-upon or higher-order scientific concepts.

Vygotsky (1986) argued that spontaneous and scientific concepts develop in reverse directions. In the ZPD, scientific concepts develop downward through spontaneous concepts, while spontaneous concepts develop upward through scientific concepts, and they are closely connected. In the ZPD, scientific concepts work their way downward to create necessary structures and logic for the spontaneous concepts to build accordingly (Vygotsky, 1986). In contrast, everyday spontaneous concepts develop upward and embody and vitalize the structures supplied by scientific concepts. Vygotsky suggested that social and cultural influences are important factors in these bidirectional developmental processes of the scientific and the spontaneous concepts in the ZPD. This bidirectional development is shown in the processes that social and cultural beliefs (scientific concepts) impose the framework constructed downward to the individuals to follow and develop their spontaneous concepts accordingly. At the same time, these individuals' spontaneous concepts upwardly embody the socially or culturally collective concepts (scientific concepts).

Activity Theory

Originally developed around 1920, rooted in Lev Vygotsky, A. R. Luria, and A. N. Leont'ev's work in cultural–historical psychology or CHAT (Cultural-Historical Activity Theory), activity theory expands upon the individual development resulting from interpersonal and intrapersonal processes that extend to societal levels. Based on this view, every event an individual is engaged in is inseparable from a social–cultural activity system. A given activity system's behaviors and culture are determined by the interactions among its constituents. The original work of activity was further developed by Engeström (1987) as the second generation model of activity theory. The second-generation activity theory model consists of six main components (or actors). They include subject, objects, tools, rules, community, and division of labor. In this model, a subject refers to an individual or group of individuals (collective) who are the main actors engaging in the activity. Objects refer to the goal or motives the activity system is set to achieve. Jonassen and Rohrer-Murphy (1999) explained that object could be a physical or mental product upon which a subject acts in order to achieve a specific goal. The component of tools in this model is the tangible or intangible means used by the subject to act upon the object. Furthermore, the rules component refers to the constraints that regulate all the actions and operations within the system. These constraints could be hard rules, such as regulations or building code imposed by the authority or soft rules that regulate actors within the activity system, such as unwritten social or cultural customs that are not explicitly stated, but that dictate the actor behaviors. The component of community refers to the characteristics of the community where the activity occurs. It provides a broader environmental context for the analysis of this activity system. This component takes the supporting factors and resources into account in the analysis. Community also functions to distribute cognitive responsibility among the subjects and artifacts. Knowledge in an activity system is distributed among its members of the subject group and community. Within this community, the subject interacts with the tools, the supporting members of the community, as well as the products (object) they create. This distribution of cognitive and physical labor responsibilities is defined by the component of the division of labor. With this component, the members of the subject group not only need to know what their responsibility is but also what other members and supporting community members' cognitive and physical assets and responsibilities are. A clearly defined division of labor and the subject group members' possession of effective transactive memory (Wegner, 1987) (knowledge of their team members' knowledge, skills, ability, and responsibility) is critical to an effective activity system. In this model, tools are a mediating factor for the subject–object relationship, rules are the mediating factor for the subject–community relationship, and division of labor is the mediating factor for the community–object relationship (Kaptelinin, 2012).

The second-generation model of activity theory has been widely adopted to analyze the characteristics and behaviors of a system (e.g., an organization, a company, a school district, or a classroom). For example, Allen and his colleagues (Allen, Karanasios, & Slavova, 2011; Allen, Brown, Karanasios, & Norman, 2013) at Leeds University in the U.K. had used CHAT in analyzing how information-seeking behaviors were influenced and formed through interaction with context, technology, organizational adaptation, and change. Activity theory has also been used in analyzing a variety of social structures in medical care (e.g., paramedics' information behaviors, Allen et al., 2013; or healthcare problems, Greig, Entwistle, & Beech, 2012) and medical education (e.g., simulations in nurse training, Eppich & Cheng, 2015), bicultural pedagogies, policies and practices (Bourke & McGee, 2012), designing e-learning systems (Pena-Ayala, Sossa, & Mendez, 2014), analyzing learning in simulations (Battista, 2015) and serious games analysis and design (Carvalho et al., 2015), mobile learning (Liaw, Hatala, & Huang, 2010), or one-to-one technology initiatives (Holen, Hung, & Gourneau, 2017; Larkin, 2011).

Situated Learning

Brown, Collins, and Duguid (1989) argued that situations structure and define knowledge. The knowledge that is extracted from its physical, social, or cultural environment is artificial, unreal, and uncharacteristic of the actual phenomenon it represents (Norman, 1993). Therefore, the knowledge that can be used is context-dependent and the process to acquire it (i.e., learning) is a continuing enculturation process (Brown et al., 1989), rather than discrete instances of transmission of context-independent abstract knowledge. The enculturation process indexes the abstract knowledge with contextual or situational information for the knowledge to become meaningful and usable working schemata (Mandler, 1985). Discrete abstract knowledge is inert knowledge (Whitehead, 1929), while working schemata are what an individual refers to in order to function in everyday life. Therefore, learning should occur in the context where the knowledge is projected to be used.

Situated cognition and learning are not necessarily limited to concrete learning in localized situations (Wilson & Myers, 2000). Rather, knowledge and learning are inseparable from their social–cultural context because their "meaning and purpose are socially construed through negotiations among present and past members" (Brown et al., 1989, p. 34). This social practice is a primary phenomenon of humans and occurs at every level of an individual's life in which learning is part of the process (Lave & Wenger, 1991). The activities practiced by a particular group of people "are framed by its culture" (Brown et al., 1989). Therefore, learning is not only situated within the immediate environment surrounding the individual but within a much broader social–cultural environment.

Instructional Implications of Sociocultural Constructivism

From the philosophical view of sociocultural constructivist theories discussed above, four instructional implications are derived and will be elaborated as follows.

All Knowledge is Constructed

Learning is a social–internal reciprocal construction process, rather than a process of transferring or receiving of information from external sources. Knuth and Cunningham (1993) asserted that the formation of knowledge is through a process of construction in which the learner actively constructs his or her interpretations of events, entities, and perspectives through social interchanges and negotiation, as well as being guided by previous experiences. In light of this interpretation, Cunningham (1992) argued that the goal of instruction is to equip the learner with the capability to construct plausible interpretations, instead of ensuring that the learner is able to replicate what has been taught. In contrast to behaviorist and cognitivist views of instruction, constructivists see instruction as creating an environment in which the learner has opportunities to actively make interpretations of what they have explored or observed, and then construct them into a knowledge base.

Multiple Perspectives

Since there are many ways of structuring the world, the world can be and should be viewed through different perspectives in order to interpret events and entities comprehensively. Knowledge needs to be constructed from different perspectives so as to most closely represent the things being perceived. Given that assumption, Bednar, Cunningham, Duffy, and Perry (1995) asserted that instruction should provide learners with multiple viewpoints about an issue or the knowledge to be learned. A concept being applied in real-life situations may manifest itself in different ways due to the context or physical environment where it takes place, or the people and interest groups involved in the situation. Authoritative–transmitting type of instruction that conveys one view or one solution only may stifle students' chance or desire to explore and examine the topic under study from multiple possible ways. When learners are able to construct knowledge from different perspectives through social interactions and negotiation, the understandings are more holistic and thorough, and the knowledge is more complete.

Contextualization

Meaning is not absolute (Wittgentein, 1958). The meaning of a given concept or entity is context-dependent and determined by its use in that specific context. Thus, for knowledge to be meaningful, learning of that knowledge then must occur in the context in which the concepts or skills naturally exist and will be applied (Knuth & Cunningham, 1993). Moreover, the context in which learning will take place needs to be realistic, relevant in everyday life, and personally meaningful. Honebein (1996) argued that decontextualized learning oversimplifies concepts and extracts the complexity of meaning. As a result, learners may lose the ability to apply what is learned to the real-life situation due to their inability to tackle the nuances and irregularities commonly seen in real-life problems.

Social Negotiation

Cognitive constructivists assert that although each individual holds unique views and understandings about the world, commonly agreeable meanings do exist through social negotiation and are critical to knowledge construction. Without a socially collective agreement about the meaning of any given event or entity, there would be no meaningful interaction among humans. Social constructivists argue that learning is a meaning-making process, which occurs in social interactions (Vygotsky, 1978). Therefore, it cannot be separated from the social exchange process. As Vygotsky (1978) argued, this social negotiation process even starts at the early stages of human learning and is initiated externally (interpersonal process). Knowledge is constructed through a process of (a) mutual meaning-making; and (b) evaluating the viability of individual understandings against socially collective agreement through a means of social negotiation (Savery & Duffy, 1996). Thus, during instruction, it is important for students to have chances to collaboratively make sense of the topic where different interpretations and perspectives of the topic can be exchanged. In this social interaction process, learning and knowledge construction occur through negotiating meaning as well as observing others in this social group. The collective understanding about the topic would then be internalized into individuals' knowledge base.

ZPD and Community of Practice

In a social learning environment, old-timers or more competent individuals help newcomers or novices acquire and construct their knowledge, both explicit technical, and implicit social–cultural knowledge or skills, through the engagement of social practices and activities. In particular, the construction of implicit social–cultural knowledge and skills is not knowledge transmission, but an enculturation process. Students need to be given opportunities to engage in activities where they can observe how the knowledge or skills are used in certain situations by more experienced members and where they can actually practice what they have observed from the more competent members.

Community of practice is a concept stemmed from situated cognition, sociocultural constructivism, and ZPD. In practice, according to Wenger-Trayner and Wenger-Trayner (2015), "Communities of practice are groups of people who share a concern or a passion for something they do and learn how to do it better as they interact regularly" (p. 1). Knowledge of a particular community is collectively created, defined, and practiced by the members of the community through social exchange and negotiation. Through this continually social and evolving process, the community develops explicit and implicit collective knowledge as well as culture, which, however, is always under construction. This knowledge is not separable from its social and cultural domain and practice. There is no such thing where the knowledge can be extracted from the actual social–cultural practice and transmitted from one individual to another. Rather, an individual's learning and knowledge construction about the community is a cultivation process where members develop the knowledge through participating in the social practice with other members of the community (Wenger, 1999).

Accordingly, the concept of communities of practice has been used as a conceptual framework to provide a social–cultural perspective for understanding human learning and knowing (Wenger, 1999; Wenger-Trayner & Wenger-Trayner, 2015). After the initial work on a community of practice with Lave (Lave & Wenger, 1991), Wenger continued his work on the topic (see, for example, Wenger, 1999; Wenger-Trayner & Wenger-Trayner, 2015). Several components that comprise the social theory of learning, particularly pertaining to communities of practice, can be identified as follows:

- Meaning (learning as experience): through a social process, the members co-define and co-create knowledge of the community that is domain-specifically meaningful and connected with their experience. Learning is an experience-meaning construction process.
- Practice (learning as doing): through a shared practice, they create a repertoire of knowledge and tools, concrete or abstract, for daily operations or solving problems. For novices (learners), they learn about the community (profession) by participating in this shared practice through a gradually increasing level of involvement over time.
- Community (learning as belonging): through shared interests and relationships, a network and the mechanism for organizing shared practice are formed to provide the members with access to the repertoire of relevant information, knowledge, resources, and activities that are shared and participated in by the members.
- Identity (learning as becoming): opportunities and privileges to full access to the knowledge repertoire and participating in the practice are empowered by the membership (Lave & Wenger, 1991) and give the member a sense of belonging to the community as well as what it means to be a member of the community, and thus, an identity.

Lave and Wenger (1991, p. 93) argued that a "learning curriculum," is not a set of specific goals that the learner should achieve as it is in a "teaching curriculum." Rather, it is various opportunities unfolding at different times for engagement in practice, either technical or social, and the learning is embedded in these activities.

Sociocultural Constructivist Learning Components in PBL

The sociocultural constructivism is centered around the core concept of interactivity where individual, as well as collective knowledge, has been created. The construction of an individual's knowledge starts with the interactions with others and his or her surroundings. Individual knowledge cannot be formed within the individual's own personal cognition without the social interaction and mutual meaning-making process (Vygotsky, 1978). On the other hand, the socially negotiated and agreed-upon knowledge serves as a body of principle knowledge to make communication possible among the members within a community. Therefore, ensuring proper and sufficient interaction in the instruction is key for students to engage in and benefit from social learning.

We will discuss the features in PBL that afford this key principle and realize the social learning components discussed above.

Situated Learning with Authentic Problem Solving

To afford a learning environment for students to construct their knowledge through social, cultural, or environmental interaction, situating the learning in an appropriate social–cultural context is the first key instructional element to consider. The foremost distinct instructional feature of PBL, which is problem-driven/problem-solving instruction (Barrows & Tamblyn, 1980; Hung et al., 2008), provides a perfect platform to afford such a key social learning element. In PBL, learning is situated in the context of an authentic, real-life problem, rather than abstract content knowledge.

By solving authentic real-life problems, students are learning the content knowledge in meaningful and usable ways. Besides the cognitive advantages of learning by solving authentic real-life problems, the authenticity of the problems also introduces the students into the community of practice of their profession by providing the social–cultural as well as professional contexts for the students to construct and contextualize their knowledge. Each profession normally deals with specific types of problems, for example, diagnosis problems in healthcare fields or design problems in engineering. The professionals have a unique way of thinking, practicing, and culture that are a result of interactions between the nature and primary concerns of the profession as well as the members' social exchange. Through gradual participation in the social activities that are regularly practiced by the members of the community, newcomers (students) learn to become old-timers (experts) (Lave & Wenger, 1991; Wenger-Trayner & Wenger-Trayner, 2015). Solving authentic problems in an educational simulated environment is the first step and a safe way for the students to start their participation in the social activities of the professional community, thereby learning the professional and social practices as well as the culture. This enculturation process is achieved through not only solving authentic professional problems, but also with the facilitator's guidance and modeling questioning (i.e., profession-specific problem-solving/reasoning process) (Bridges, Chan, & Hmelo-Silver, 2016). Also, the involvement in the community of practice is critical for the students to develop their sense of belonging to the community, and thus, their identity within the profession (Wenger, 1999).

Ill-Structured Problems

Social–cultural constructivism takes a philosophical view that our world is not stable, unchanged, or a single reality. Rather, multiple realities exist, and the world is dynamic. Therefore, there are no absolutely facts or truths, but rather context-dependent descriptions of the event or phenomenon. This philosophical view in fact describes the real world we live in. Traditional instructional methods subscribe to the behaviorist and cognitivist views and treat knowledge as absolute and unchanging facts or truths, which not only does not reflect the real world, but also could possibly mislead the students.

The problems used in traditional instructional methods tend to be well-structured, which represent problems in a perfect world, rather than the real world where the students will need to apply their knowledge. Conversely, PBL uses ill-structured problems, which are problems of the real world. According to Jonassen (1997), ill-structured problems are defined as problems that are messy, possess multiple ways of interpreting the problem, and/or have multiple possible solutions. Real-life problems, especially problems that occur in professional contexts, are rarely simple and typically possess multiple plausible solutions. Authentic professional problems normally require the problem solver to take into account multiple possible hypotheses for the cause of the problem, multiple perspectives for the issues to be resolved (e.g., political problems), and multiple competing solutions. Thus, they are complex problems that cannot be properly resolved with a simplified, one-view-only, or compartmentalized understanding of the subject (Jonassen & Hung, 2008). In addition to helping students incorporate abstract content knowledge with concrete contextual and situational knowledge for future use, ill-structured authentic problems also require students to integrate knowledge from multiple disciplines and perspectives. It is highly unlikely for an authentic ill-structured problem to be confined solely to one discipline. Therefore, solving ill-structured problems requires students to take an interdisciplinary approach when interpreting the initial state of the problem, gathering relevant knowledge and information from other disciplines by working with others, inspecting and reconciling information from different disciplines, and so on. By working on ill-structured problems, students are enculturated with the multiple realities, perspectives, and philosophical views of the world, rather than a single answer, rigid world view. Moreover, acknowledging and considering multiple perspectives when solving problems is a critical step for students to develop their ability and disposition to engage in healthy social negotiation of meanings for issues being discussed. Only through positive social interactions and exchanges can students develop a complete and holistic understanding of the subject under study.

Small-Group Collaborative Learning

Small-group learning is another hallmark of PBL that affords the core concept of sociocultural constructivism, which is social interaction. In a small-group collaborative setting students collaboratively self-direct their own learning by interacting with peers and information as well as the facilitator to co-construct their knowledge of the subject. With small-group learning, PBL situates students in an environment where the students explore and interpret the topic to be studied based on their prior knowledge and experience. This social exchange and practice process by means of sharing, questioning, discussing, and debating on the issues helps students construct the meaning and understanding of the subject through the reciprocal social interactions. This social negotiation process injects multiple perspectives, social–intellectual exchanges, as well as professional practice into the students' learning process. Such socially tested or socially collaborated knowledge is likely to be more effective and useful than personally constructed untested conceptions since it not only reflects the learner's own understandings of the concepts being studied, but also the collective understandings and meaning of it (Jonassen, Myers, & McKillop, 1996).

Furthermore, besides the function of bringing in multiple perspectives from all members of the group on the problem to be solved, often students come to the group with different levels of knowledge and skills in various relevant areas. Therefore, small-group learning also serves a function of peer teaching for facilitating students' ZPD process. For example, in medical education, some students may have more clinical experience, while others may have a stronger basic science knowledge background. With individual students' strengths in different areas, peer teaching or sharing knowledge provides a foundation for effective ZPD process. Moreover, the facilitator also functions to enhance the ZPD process by modeling expert questioning and reasoning processes (Hmelo-Silver & Barrows, 2008).

Lastly, the small-group learning setting also serves as a prelude to the community of practice. Teamwork is an important learning objective in many disciplines as team-based problem solving is the norm, rather than an exception in most professions today (Curşeu, Schalk, & Schruijer, 2010; Pearsall, Ellis, & Bell, 2010; Savelsbergh, van der Heijden, & Poell, 2009). Though it may depend on how the small-group learning is structured in the curriculum, small-group learning creates an environment that simulates the working group environment, for example, how the professionals work together as a team; how they think and solve problems; how they use the lingo; how they support each other; and, more importantly, how they see themselves as a member in the community of the profession. Thus, small-group learning helps students build a sense of belonging and becoming a member of the professional community by doing what the professionals do (solving authentic problems) thereby accumulating their problem-solving experience and skills (Wenger, 1999).

Self-Directed Learning

Another distinct feature of PBL is self-directed learning (Barrows, 1996). The pedagogy of PBL incorporates the constructivist instructional philosophy that knowledge is constructed, instead of transmitted from the instructor to the students. With the facilitator's facilitation, PBL students take an active role in their own learning and knowledge co-construction process in a small-group collaborative learning setting. In PBL, through self-directed learning, the students in their own group collaboratively seek and co-construct content knowledge and skills into a working schema pertaining to the problem situation. This learning approach affords the students opportunities to explore many possible areas that may be relevant to the problem situation, rather than being limited to one known way of solving the problem taught by the instructor as with a traditional instructional method. Moreover, self-directed learning in PBL does not necessarily mean individual self-learning. Rather, the exploration process is social in nature. With small-group collaborative learning and a facilitator's guidance, the self-directed learning is a process of social interaction between the student and content, student and student, as well as student and facilitator (Anderson & Garrison, 1998). The learning environment in PBL is a community of practice where students are provided with ample opportunities to interact and exchange through the combination of group collaboration and self-exploration.

Effects of PBL on Social Learning Outcomes

As discussed earlier, the analysis of social constructivist foundations underlying principles of PBL suggests that PBL can have a major impact on enhancing the social outcomes of learning. The following section summarizes the results of the research on outcomes that are highlighted in the social view of knowing and explores how these outcomes are promoted by PBL.

Shared Outcomes or Artifacts and Communication and Relations With Others

As discussed earlier, in PBL, learning is a collective co-construction of knowledge process. This social view of knowing focuses on the notion that it is through the creation of *shared outcomes or artifacts* and *communication and relations* with others (or social discourse) that learners engage in developmental cycles that facilitate replacing an existing conception with a shared conception. *A shared artifact* refers to both shared products of knowledge building created collaboratively and the individual perspective on such meaning. A shared artifact, therefore, does not assume that individuals participating in social discourse have gained knowledge of the subject. Instead, *the act of creation of the shared knowledge space* confirms that the knowledge was successfully assimilated. Thus, there is a reciprocal relationship between shared meanings (taking place through collaborative interactions mediated by physical artifacts—knowledge creation) and individuals' interpretations of them (taking place from personal perspectives situated in an individual's current activities, goals, and backgrounds—knowledge construction/building). In other words, to engage in collaborative activities, individual members of a team must also come to recognize meanings and understand these meanings from their own perspectives. The creation of shared meaning is thus both an *interpersonal* (social and interactional—learning to think) and *intrapersonal* process (voice of mind or self-reflection).

Interpersonal skills

Interpersonal skills refer to the process of creating shared knowledge by which members of the collaborative team exchange information, emotions, feelings and meaning through both verbal (language) and nonverbal (tone of voice, facial expressions, gestures, and body language) communication. Two forms of communications often occur during implementation of PBL: dialogue and discussion. Dialogue is a process through which team members seek to understand one another's points of view. During the initial stage of problem solving, through dialogue team members engage in problem identification and analysis to form a common understanding of the problem and to generate goals for further exploration. Essential to dialogue is asking questions that clarify ideas, but without challenging or placing a value judgment on the ideas. During the dialogue, teams do not make decisions, but make meaning, generate an explanation, and build on one another's ideas to identify the focus for further investigation. Discussion, on the other hand, is used during the final stage of the problem-solving process. Discussion follows the dialogue on a shared understanding of the problem and shared ideas on what needs to be done. It allows the collaborative team members to make a decision and reach a conclusion on solving the problem. As a result of dialogue and discussion various interpersonal skills (e.g., listening; empathy and understanding of others; questioning skills; developing respect and responsiveness; managing relationships; managing disagreement; managing conflicts) are learned and improved. As one of the twenty-first-century competencies, interpersonal skills refer to communication, collaboration, conflict resolution, and leadership competencies (Pellegrino & Hilton, 2012).

Although the use of self-report data for assessment of interpersonal competencies is questioned by the National Research Council (NRC) (Pellegrino & Hilton, 2012) and other scholars, studies have primarily used the self-report to examine the effects of PBL on students' abilities to communicate effectively. These studies show a positive correlation between PBL and students' ability to effectively communicate, collaborate, show leadership, and solve problems. For example, van Dalen et al. (2002) conducted a longitudinal study in two Dutch Medical Schools (Maastricht and Leiden) to assess the effectiveness of different approaches to communication skills training. The Maastricht curriculum was based on the PBL model with emphasis on small-group collaboration sessions throughout the first 4 years, whereas Leiden Medical School was characterized by a more traditional, primarily lecture-based curriculum and offered communication skills training in courses in the preclinical phase. The results showed that Maastricht students obtained significantly higher checklist scores for their communication skills than their Leiden counterparts. Similarly, in a meta-analysis study, Schmidt, Van der Molen, Te Winkel, and Wijnen (2009) compared a number of PBL curricula and showed that students and graduates from particular PBL curricula perform much better in the area of interpersonal skills, and with regard to practical medical skills. Walters and Sirotiak (2011) used a controlled study to examine the effects of PBL on leadership and communication skills of construction managers. The results of their study also suggested that PBL positively influenced leadership and communication, and adaptability and management skills. In his review of research on project-based learning (PjBL) in K–12, Thomas (2000) concluded that there is evidence that PjBL improves interpersonal competencies (Cheng, Lam, & Chan, 2008; Hernández-Ramos & De La Paz, 2009; Kaldi, Filippatou, & Govaris, 2011; Mioduser & Betzer, 2007). PjBL has also been shown to benefit a variety of students in developing collaborative skills. For example, through PjBL, elementary students learned to understand multiple perspectives and conflict resolution skills (ChanLin, 2008), special education students developed social skills such as patience and empathy (Belland, Ertmer, & Simons, 2006), and low-ability students demonstrated initiative, management, teamwork, and conscientiousness as they worked in groups (Horan, Lavaroni, & Beldon, 1996).

Intrapersonal skills

Intrapersonal is communication within and to the self. Intrapersonal skills refer to the self-talk that according to Vocate (1994) can take two forms: "a) the silent, internal dialogic process of inner speech, and b) the audible, external dialogue addressed to self although others may hear it" (Vocate, 1994, p. 7). Theoretically, as discussed before, intrapersonal refers to what Vygotsky has called "the dynamic, dialogical nature of self in its social context" (Valsiner & Van der Veer, 1988, p. 133). Thus intrapersonal communication is the result of internalizing and transforming shared artifacts that arise in social interaction. It is communication that takes place within the individual when he or she is communicating with others. When working on collaborative activities, individual members of a team internalize the shared meaning by understanding it from their own perspectives. Internal talk, therefore, is an important component of what we call "thought" or "reflection." As a core element of thought, learning, and self-reflection, internal speech provides a sense of *self-consciousness or self-awareness*. Self-awareness results from internalizing the language of one's social community (Vocate, 1994). Internalization of the language or words used by the social group means internalization of meaning as they are understood by the individual. Thus, such meanings are dynamic and subject to frequent change. The inner speech is "the competence that makes possible all levels of performance although it occurs at the intrapersonal level" (Vocate, 1994, p. 4).

In PBL in addition to the multiple social interactions and collaborative opportunities for the members of the collaborative group to develop interpersonal communication and relations skills, students also develop their own intrapersonal intelligence by learning to communicate their ideas and express what they think. The process of self-talk or reflection brings about the level of self-awareness that is necessary for human interaction with others and with self. Thus, as a result of collaborative group work and due to the act of responding or providing feedback to oneself, the skills of reflective consciousness (metacognition), self-concept and self-awareness are built. In PBL, successful completion of a complex and multifaceted task is possible only through a cross-functional team in which the various members contribute their own knowledge.

Categorized as an affective domain by the NRC (Pellegrino & Hilton, 2012), intrapersonal competencies include outcomes such as *self-regulation, self-awareness or self-concept, reflection or metacognition, perseverance (motivation) and flexibility*.

Self-regulation and self-direction

As an outcome, self-regulation refers to the learner's ability to self-monitor or self-assess one's performance during task execution as well as monitoring the outcomes of performance (self-control). As a learning process, self-regulation is activating and sustaining one's own thoughts, behaviors, and emotions to reach set goals (Zimmerman, 2002). Thus, self-regulated learners set goals effectively, plan and use strategies to achieve their goals, manage resources, and monitor their progress (Zimmerman, 2002). Related to the outcome and process of self-regulation, is self-directed learning (SDL). Schmidt (2000) defines SDL as the learner's preparedness to engage in learning activities (Schmidt, 2000). In other words, the self-directed learner is ready to learn, set learning goals, engage in the learning process, and evaluate learning. Furthermore, to be prepared the learner should be able to assess learning needs, effective planning, and time management, a critical evaluation of the literature resources, as well as a critical evaluation of their own SDL skills (Blumberg, 2000; Candy, 1991). Although in some sources the two concepts of self-regulated and self-directed learners are presented as different concepts, they are very similar regarding the expected outcomes and process (Loynens, Magda, & Rikers, 2008).

Results of the various research that examined SRL and SDL in PBL show that PBL fosters SDL and SRL (e.g., Blumberg, 2000; Hmelo & Lin, 2000; Kivela & Kivela, 2005) and SRL (e.g., Sungur & Tekkay, 2006). Studies conducted in the context of medical schools suggested that PBL students make greater use of library resources than conventionally trained medical students and that PBL-trained physicians have more up-to-date knowledge in certain areas of medical practice due to their abilities to regulate their own learning (Woodward, 1997). Blumberg's (2000) review of relevant research also concluded that PBL students have more highly developed self-directed learning skills (e.g., use of library resources and online search tools) than students of traditional instruction. More specifically, a study reviewed by Blumberg (2000) concluded that PBL fosters the students' development of SDL. Stefanou, Stolk, Prince, Chen, and Lord (2013) studied student self-regulated learning strategies and their learning outcomes in PBL and project-based learning environments. Quantitative results showed that differences in cognition associated with self-regulated learning were observed in both settings. Additionally, students in the project-based courses reported higher perceived autonomy support or the degree to which they perceived their instructors provided them with supportive opportunities to act and think independently compared to students in the problem-based courses. Several other studies conducted in elementary and high school settings also revealed that PBL enhances the self-regulatory skills of students (e.g., Gallagher, Stepian, Sher, & Workman, 1995; Krynock & Robb, 1996; Sungur & Tekkay, 2006).

Self-awareness or self-concept and self-efficacy

Researchers contend that the initiation and continuing use of self-regulated and self-directed strategies (e.g., self-control, self-strategies, time management, so forth) depends on students' motivational feelings or beliefs about the effectiveness of one's goals, strategic planning, and perception of personal skills in implementing them. Thus, students' self-awareness or self-concept and self-efficacy beliefs play a major role in self-regulating and self-directing behaviors (Zimmerman & Schunk, 2011) during PBL. As an outcome, self-awareness (preexisting beliefs about one's own cognitive abilities) or self-concept refers to individuals' knowledge and perceptions about themselves in academic achievement situations (Wigfield & Karpathian, 1991), which emphasizes one's self-perceived ability given goals. Self-efficacy, as an outcome, primarily indicates students' self-perceived confidence to perform a particular task successfully. In other words, while self-concept refers to the perception of knowledge, self-efficacy refers to judgment about one's ability to organize and execute the courses of action necessary to attain a specific goal (Bandura, 1997; Pajares & Schunk, 2005; Zimmerman, 2000). Self-efficacy is goal-directed, and self-efficacy assessments focus on rating one's level of confidence for attaining a specific goal. Despite some psychological differences, both concepts demonstrate similar internal structures and essentially measure the same cognitive construct (e.g., self-perceived competence) (Pajares & Schunk, 2005).

Research shows that the PBL environment with the use of authentic problems of practice, collaboration, and reflection provides students with vicarious experiences and performance accomplishments, which in turn enhances self-concept and self-efficacy. For example, Dunlap (2005) examined how student self-efficacy, as it relates to being software development professionals, changed while involved in a PBL environment. Thirty-one undergraduate computer science students completed a 16-week capstone course in software engineering during their final semester before graduation. Using a self-efficacy scale as pre- and postmeasures, and guided journal entries as process data, students showed an increase in their levels of self-efficacy. Vazquez (2008) investigated the effects of PBL on nineth graders' self-efficacy, motivation, and knowledge as they relate to college preparation. The results showed that, generally, PBL did lead to increases in motivation and self-efficacy in college preparation as compared to outreach and college center services. Also, Papinczak, Young, Groves, and Haynes (2008) conducted a study in a first-year medical course to determine the influence of metacognitive activities within the PBL tutorial environment on the enhancement of individual learning self-efficacy. The results showed a statistically significant association between high self-efficacy and deep learning approach. Likewise, in the context of K–12 education, Liu, Hsieh, Cho, and Schallert (2006) examined the effect of a computer-enhanced PBL environment on middle school students' learning, self-efficacy, attitude toward science, and achievement. The findings indicated an increase in students' science achievement and self-efficacy for learning science. Baker and White (2003) also quantitatively measured the impact of two versions of a 9-day PBL unit for eighth-grade earth science students on students' attitude, self-efficacy, and achievement. The results showed that when students used collaborative GIS (geographic information system) to support their investigations, positive and significant improvements were noted in science self-efficacy and technology attitudes. Wijnia, Loyens, and Derous (2011) also investigated motivation in lecture-based (LB) and PBL. The results showed that PBL students had higher perceptions of competence compared to LB students.

Metacognition or reflection

Metacognition, a type of reflection, is a way of thinking about one's thinking in order to grow. Metacognition and reflection are terms often used interchangeably, but it is most helpful to distinguish metacognition as a particular form of reflection. As a process, metacognition involves knowing how to reflect and analyze thought, how to draw a conclusion from that analysis, and how to put what has been learned into practice (Kluwe, 1987). Thus, metacognition can be defined as possible strategies that can be utilized for the solution of different tasks (Flavell, 1999; Marchant, 2001).

Given the emphasis on the processes of learning in PBL approaches, rather than merely knowledge-based outcomes, it is not surprising that studies find more significant metacognitive development in students who engage in PBL when compared to those who learn through nonproblem-based approaches, which do not always require the same reflective performance. Downing, Ning, and Shin (2011) examined the effectiveness of PBL on student experience and metacognitive development in higher education based on a large sample of first-year undergraduates from two programs at a Hong Kong University. One program used an entirely problem-based approach to learning, while the other used traditional methods. To assess metacognition, they used the Learning and Study Strategies Inventory (LASSI, Weinstein, 1987). Despite the significantly weaker entry LASSI scores, the PBL group's final LASSI mean scores, taken 15 months after, demonstrated a dramatic improvement in metacognition. Additionally, expanding on their previous research, Wynn, Mosholder, and Larsen (2016) examined whether using PBL with explicit metacognitive reflection would promote the practice and acquisition of postformal cognitive skills (defined as thinking operations that involve recognizing various relevant variables and important contextual aspects of the problem or issue at hand) among first-year learning community students and nonlearning community students in a U.S. history survey course context. The findings suggested that PBL with metacognitive reflection had a significant relationship with the development of postformal thinking skills compared to a traditional method. Similarly, using a quasi-experimental, single-group, pretest–posttest design, Gholami et al. (2016) conducted a study to compare the effects of PBL and the traditional lecture method on critical thinking skills and metacognitive awareness in nursing students in a critical care nursing course. Results showed a significant increase in the overall critical thinking score and its subscales of evaluation and deduction and the overall metacognitive awareness score after performing the PBL method. Turan, Demirel, and Sayek (2009) also investigated the acquisition of metacognitive awareness and self-regulated learning skills in medical schools using PBL. The results suggested that PBL students demonstrated improved metacognitive awareness and self-regulated learning skills.

Motivation and perseverance

Another outcome that is also highlighted in the social view of knowing is *learner motivation*. The social construction of knowledge stresses that learning is an active rather than a passive process. Ultimately, each individual reconstructs his or her own understandings after engaging in co-construction with others. Thus, the learner has to actively access his or her pre-existing knowledge and beliefs, link them to what is currently being experienced, and modify them if necessary. If active learner effort is required for learning, then it follows that *motivation is also required*, because students will not make that effort unless they are motivated to do so. Specific features of PBL, such as working on meaningful, real-life problems independently in small teams under the minimal intervention of a facilitator, could promote student motivation and active learning (Schmidt et al., 2009).

As discussed earlier, the literature shows that student self-concept and self-efficacy (control beliefs), major components of learner motivation, improve because of engaging in problem solving (Wijnia, 2014; Wijnia et al., 2011). Students tend to immerse in tasks that seem worthwhile for them and promise them the possibility of success. Moreover, studies show that PBL enhances intrinsic student interest in the subject matter (Wijnia, 2014). Intrinsically motivated students are interested in the course content itself, persist in facing the difficulty, are willing to seek out new ideas, keep asking questions, and their learning progress is strongly affected by curiosity (Khairiyah, Harun, Jamaludin, & Syed Hassan, 2012). Jones, Epler, Mokri, Bryant, and Paretti (2013) examined how the instructional elements of PBL capstone engineering courses affected students' motivation to engage in the course. They employed a two-phase, sequential, explanatory, mixed-methods research design. For the qualitative phase, 47 undergraduate students completed a questionnaire that measured the following components of academic motivation: empowerment, usefulness, success, situational interest, individual interest, academic caring, and personal caring (MUSIC). The results indicated that most students were, on average, motivated during the courses and the elements of PBL-based courses appeared to be successful at motivating students in the courses. They also concluded that motivating opportunities occurred at various times in the courses and could have been related to several instructional elements of PBL. Drawing on survey responses from a sample of 3,852 high school students at inclusive science, technology, engineering and mathematics (STEM) schools across the U.S., LaForce, Noble, and Blackwell (2017) investigated how PjBLand PBL may work to expand the number of students interested in, qualified for, and actually pursuing careers in STEM. Multivariate regression results indicated that student ratings of PBL are associated with interest in pursuing a career in the STEM, as well as with intrinsic motivation for science and students' ability beliefs for both science and math. In his review of the literature on PjBL, Thomas (2000) pointed to several studies that showed PjBL's positive impact on student motivation and interest. For example, Bartscher, Gould, and Nutter (1995) examined the effects of PjBL on third-, fourth-, fifth-, and tenth-grade students identified as low in motivation. The results showed that taking part in project work motivated the students and increased their interest in the topics involved. Peck, Peck, Sentz, and Zasa (1998) asked students to reflect on their perceptions of learning in a traditional format and the project-based format. They observed that the high school students who participated in a project-based humanities course showed positive perception regarding using multiple texts, revisited texts, and evaluated information through their reading, writing, and researching for the projects.

Empathy and sympathy

Related to learner motivation and intrinsic interest are learner e*motions, feelings, and attitudes. Emotions, feelings, and attitudes* are integral parts of intellectual and social development. In a social learning environment, a *community of learners* must be created, and the community must collaborate productively to promote *group interaction* and to establish *the sociocultural context* in which meaning is formed. The ability to empathize and identify with others is essential to all human relationships and can be understood as a bond that makes social life possible (Eisenberg & Strayer, 1987; Hogan, 1969; Kohut, 1984).

Thus, a community of learners cannot function effectively if its members do not care for each other, maintain positive relationships with one another, and understand each other's feelings. Although very few studies directly investigated student empathy and sympathy in PBL, these learning outcomes that are underscored in social foundations of learning are attainable in PBL. Collaboration and peer and facilitator's feedback could encourage the development of empathy. Karaoglu, Pekcan, and Yilmaz (2013) studied the effect of PBL scenario on positive–negative affects and the empathic tendency of first-year medical students. The Positive and Negative Affect Schedule (PANAS), Empathic Tendency Scale (ETS) was applied before and after the PBL sessions. The results suggested that the PBL scenario significantly increased positive affect of medical students. There was also an increase in empathic tendency and a decrease in the negative affect of male participants. Rasoal and Ragnemalm (2011) studied the level of empathy among the students in a PBL engineering program at Linköping University. The results showed a significant increase in empathy between the first year and fifth semester. Seren and Ustun (2008) investigated conflict resolution skills of nursing students enrolled in a PBL curriculum and conventional curriculum. A questionnaire consisting of four sociodemographic questions and the 55-item Conflict Resolution Skills Scale (CRSS) was used to collect data. The conflict resolution skills scores and subscale (empathy, listening skills, requirement-based approach, social adaptation, and anger management) scores of PBL students were significantly higher than those in the conventional curriculum.

Attitude and perception

The joint construction of knowledge and understanding emphasizes the importance of *ideas, conceptions, and assumptions (intersubjective beliefs) that are widely shared among members of the group*. Ideas, conceptions, and assumptions are mental constructs held by individual members, sets of *distinctive beliefs, principles, and attitudes* that provide broad orientations for team members' behaviors. In PBL environments, ill-structured problems usually have divergent or alternative solutions; they require learners' justification or an argument for supporting the rationale of the selection of a particular solution (Voss & Post, 1988). Overall, PBL approaches have had positive effects on attitudes toward courses (e.g., Akınoğlu & Tandogan, 2007; Diggs, 1997; Ferreira & Trudel, 2012; Sahin, 2008).

For example, Ferreira and Trudel (2012) examined the impact of PBL on high school chemistry student attitudes toward science, problem-solving skills, and their perception of the learning environment. The results indicated that the implementation of PBL had a significant impact on student attitudes toward science and perceptions of their learning environment. Similarly, using a convergent mixed-methods research study, Mataka (2014) investigated whether or not students who participated in the PBL environment improved their self-efficacy beliefs (SEBs) in and attitudes toward chemistry. The results showed a positive relationship among attitudes, SEBs, and students' views of the PBL environment. Regression data further showed that scores on SEBs and attitudes contributed significantly to the explanation of each other. Chandrachood, Sivabalan, and Chandekar (2015) also conducted a descriptive study with cross-sectional survey approach to assess awareness, attitude, and perception on the PBL among the nurse educators. They collected data from 87 nurse educators employed in 11 nursing institutes at Ahmednagar district, Maharashtra. The findings revealed that the majority of nurse educators were well aware of PBL and its usefulness and had positive attitudes and perceptions toward the PBL method. In a recent study, Terashita, Tamura, Kisa, Kawabata, and Ogasawara (2016) offered practical training in plain radiography positioning techniques using the PBL approach to 38 third-year students. They used a survey of the changes in attitudes toward plain radiography held by students before and after practical training using the SeD (Semantic Differential) technique as a method to identify student's attitudes. They found that the attitudes of "reluctance," "confidence," and "exhaustion" existed before PBL practical training, while the attitudes of "expectation," "self-efficacy," and "realness" were present after training.

Conclusion

PBL is not just a pedagogy built upon cognitive theories to enhance students' abilities to apply knowledge to solve real-world, professional problems. More importantly, it is also a pedagogy that is heavily rooted in sociocultural constructivism and featured with specific instructional strategies to prepare students to be well-rounded problem solvers and professionals. The process of contextual, social, and cultural enculturation in PBL helps students develop the skill set and mindset of taking into account situational, environmental, social, or cultural considerations when dealing with the problems they encounter in their professional or personal lives. Educating students to be knowledgeable problem solvers does not satisfy all of the needs in a twenty-first-century society. Rather, cultivating students to be professionals who will take an interdisciplinary approach, consider individual unique constraints, and be effective team players is the goal of education today. The instructional features of PBL, such as small-group learning, ill-structured, interdisciplinary, and complex authentic problems, provide a learning environment where the social interactions that are vital to the students' co-construction of collective knowledge (shared artifacts) and their own knowledge construction occur. The dialogues, discussions, ideas and cultural exchanges, debates, and social negotiations that take place within these social interactions are critical to the students' hard and soft knowledge and skill building. Lastly, social learning is not just a fad that has gradually gained attention at the turn of the twenty-first century. It is a fundamental form of human learning that we have practiced since prehistorical times. We are just beginning to understand this complex and yet profound aspect of human learning. With a significant emphasis on social learning, PBL is a pioneering pedagogy in recognizing and incorporating social components in student learning processes. With the efforts from PBL researchers and educators, PBL will continue to evolve to fulfill the mission of educating well-rounded problem solvers for the good of society.

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4

Comparative Pedagogical Models of Problem-Based Learning

John R. Savery

Introduction

This chapter examines the key characteristics of the problem-based learning (PBL) pedagogical model and provides some critical distinctions between PBL and similar models such as case-based learning, project-based learning, inquiry-based learning, and Learning by Design. While these instructional strategies share a common epistemological foundation and similar learning goals, the implementation and pedagogical practices of the specific approaches help identify the key differences. The PBL model to be referenced in this chapter was developed at McMaster University in Canada in the early 1970s and was intended to address a concern with the effectiveness of medical education.

> Medical education, with its intensive pattern of basic science lectures followed by an equally exhaustive clinical teaching programme, was rapidly becoming an ineffective and inhumane way to prepare students, given the explosion in medical information and new technology and the rapidly changing demands of future practice. Medical faculty at McMaster University in Canada introduced the *tutorial process*, not only as a specific instructional method (Barrows & Tamblyn, 1980) but also as central to their philosophy for structuring an entire curriculum promoting student-centered, multidisciplinary education, and lifelong learning in professional practice. (Boud & Feletti, 1997, p. 2)

The conditions in the 1970s that prompted the development of the PBL instructional approach in medical education have expanded to multiple disciplines over the past (almost) half century. The success of the PBL model in medical education (Albanese & Mitchell, 1993; Strobel & van Barneveld, 2009) led to adoption by other medical schools and a further adoption by educators in other

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professional disciplines (Savery, 2006). As the PBL model (McMaster model) was adapted to different disciplines and learner populations several variations "named" PBL have developed as well as some variations in strategies for effective implementation of the model. This chapter will attempt to identify the critical distinctions between PBL and similar models.

Epistemological Foundation

Across disciplines (and within) there are varying views of what research is and how this relates to the kind of knowledge being developed. Paradigms guide how we make decisions and carry out research. Research in the field of teaching and learning employs different methodologies and different paradigms. There are different ways of viewing the world but for this chapter the focus will be on a constructivist epistemology and the instructional strategies and pedagogical practices that derive from that philosophical approach. For more depth, the references section has a separate listing for resources on constructivism. A few key elements however, to frame the discussion on instructional strategies are needed. Savery and Duffy (1996) listed three important characteristics of constructivism (p. 136):

Understanding is in our interactions with the environment

This is the core concept of constructivism. We cannot talk about what is learned separately from how it is learned, as if a variety of experiences all lead to the same understanding. Rather, what we understand is a function of the content, the context, the activity of the learner, and, perhaps most importantly, the goals of the learner. Since understanding is an individual construction, we cannot share understandings but rather we can test the degree to which our individual understandings are compatible. An implication of this proposition is that cognition is not just within the individual but rather it is a part of the entire context, that is, cognition is distributed.

Cognitive conflict or puzzlement is the stimulus for learning and determines the organization and nature of what is learned

When we are in a learning environment, there is some stimulus or goal for learning—the *learner* has a purpose for being there. That goal is not only the stimulus for learning, but it is a primary factor in determining what the learner attends to, what prior experience the learner brings to bear in constructing an understanding, and, basically, what understanding is eventually constructed. In Dewey's terms it is the "problematic" that leads to and is the organizer for learning (Dewey, 1938; Rochelle, 1992). For Piaget it is the need for accommodation when current experience cannot be assimilated in existing schema (Piaget, 1977; von Glaserfeld, 1989). We prefer to talk about the learner's "puzzlement" as being the stimulus and organizer for learning since this more readily suggests both intellectual and pragmatic goals for learning. The important point, however, is that it is the goal of the learner that is central in considering what is learned.

Knowledge evolves through social negotiation and through the evaluation of the viability of individual understandings

The social environment is critical to the development of our individual understanding as well as to the development of the body of propositions we call knowledge. At the individual level, other individuals are a primary mechanism for testing our understanding. Collaborative groups are important because we can test our own understanding and examine the understanding of others as a mechanism for enriching, interweaving, and expanding our understanding of particular issues or phenomena. As von Glaserfeld (1989) has noted, other people are the greatest source of alternative views to challenge our current views and hence to serve as the source of puzzlement that stimulates new learning. These three elements—learning within/through experience, cognitive puzzlement, and social negotiation of knowledge will appear prominently in the pedagogical models discussed in the next section.

Research on Teaching and Learning

Any discussion on how to teach (pedagogical models) should be grounded in research that explains how people learn. Bransford, Brown, and Cocking (2000) provide a synthesis of research on current understanding in the science of learning and identify areas where this understanding is well-developed including: "…(1) memory and the structure of knowledge; (2) problem-solving and reasoning; (3) the early foundations of learning; (4) regulatory processes that govern learning, including metacognition; and (5) how symbolic thinking emerges from the culture and community of the learner" (p. 14). Bransford et al. (2000) propose three key findings about learning and three implications for teaching as follows (Table 4.1):

Table 4.1 Key Findings About Learning

Key finding	Teaching implication
1: Students come to the classroom with preconceptions about how the world works. If their initial understanding is not engaged, they may fail to grasp the new concepts and information that are taught, or they may learn them for purposes of a test but revert to their preconceptions outside the classroom. (p. 14)	**1:** Teachers must draw out and work with the preexisting understandings that their students bring with them.
2: To develop competence in an area of inquiry, students must: (a) have a deep foundation of factual knowledge, (b) understand facts and ideas in the context of a conceptual framework, and (c) organize knowledge in ways that facilitate retrieval and application. (p. 16)	**2:** Teachers must teach some subject matter in depth, providing many examples in which the same concept is at work and providing a firm foundation of factual knowledge.
3: A "metacognitive" approach to instruction can help students learn to take control of their own learning by defining learning goals and monitoring their progress in achieving them. (p. 18)	**3:** The teaching of metacognitive skills should be integrated into the curriculum in a variety of subject areas.

Developing Expertise

In addition to these key findings from the science of learning and the implications for teaching, Bransford et al. (2000) argue that schooling prevents students from learning how experts perform their jobs. Apprentices learn while using the same tools and materials that experts use and while performing the same type of jobs that experts perform, which ensures a high rate of transfer of learning. Meanwhile, students in school are expected to imagine situations in which the skills they learn will be useful and to perform them without tools such as calculators, reference books, or the assistance of others, which would be available in the workplace. When the student is learning how to think and perform like a professional—doctor, engineer, architect, teacher, or researcher—the goal is to become an expert in the domain. Expertise is typically demonstrated by an ability to see patterns and meanings not apparent to novices, by a deep and well-structured knowledge in their field that is accessible, easy to retrieve, transferable to different situations, and with a capacity to learn new information. In the discussion of different pedagogical models the alignment between the learning principles listed above and the development of expertise will be examined more fully.

Research on Problem Solving

Jonassen has published extensively on problem solving (Jonassen, 1997, 2000, 2004, 2011) and states, "Learning to solve problems is the most important skill that students can learn in any setting. In professional contexts, people are paid to solve problems, not to complete exams. In everyday life, we constantly solve problems…. But as a field educators have largely ignored how to learn to solve problems" (Jonassen, 2004, p. xxi). Jonassen further argues that, "…problem solving is a special kind of learning outcome … [and] … there are many different kinds of problem solving and each require different forms of teaching and learning support" (p. xxii). While it appears self-evident that instruction aimed at learning to solve a math problem would be significantly different than instruction aimed at solving international political, economic, or military problems, it is often a hidden assumption that one size fits all when teaching problem solving. Concerning PBL, Jonassen (2004) describes the approach as, "…a pedagogical innovation … a systematic approach to preparing medical doctors to be problem solvers, because that is the nature of their job. PBL redefines curriculum and pedagogy in terms of problem-solving activities" (p. xxii). Jonassen also adds this caution, "[PBL] … is a pedagogical innovation that employs only one model for supporting problem-solving." As we examine different pedagogical models of PBL in this chapter, this caution will be included in the discussion. In the following, we will examine PBL first, followed by comparisons of PBL with other comparable pedagogical models that share similar characteristics.

The PBL Pedagogical Model

The instructional strategy developed by Barrows and colleagues at McMaster University—henceforth referred to as the McMaster Model—was designed to help students achieve these five goals: (a) construct an extensive and flexible knowledge base, (b) develop effective problem-solving skills, (c) develop self-directed, lifelong learning skills, (d) become effective collaborators, and (e) become intrinsically motivated to learn (Barrows & Kelson, 1995 as cited in Hmelo-Silver, 2004, p. 240).

The general pattern for instruction within PBL proceeds as follows: a small group of students is presented with a problem (in the content domain and aligned with the larger curricular goals); student learning is driven by this complex problem that does not have a single correct answer; students work in collaborative groups to identify what they need to learn in order to solve the problem; students engage in self-directed learning (SDL) activities to research answers to the learning issues; students report back to the group on their research and apply their new knowledge to the problem; the student team develops/presents their proposed solution to the problem, and concludes the activity by reflecting on what they learned and the effectiveness of the strategies employed. This cycle is repeated with new problems and support from the tutor to guide the development of metacognitive thinking skills so that the learners are becoming increasingly expert in the domain.

Distinguishing Characteristics of PBL

The characteristics of PBL were summarized by Savery (2006, 2015) and include the following:

PBL must be the pedagogical base in the curriculum and not part of a didactic curriculum

Planning, developing, and implementing a PBL pedagogical model is a significant undertaking that represents a major change to the status quo in many institutions. Both faculty and students may be comfortable with the familiar teacher-centered and lecture-based approach that they have experienced in previous educational settings. Switching to a PBL approach will require significant instructional scaffolding to support the development of problem-solving skills, self-directed learning skills, and teamwork/collaboration skills to a level of self-sufficiency where the scaffolds can be removed. Teaching institutions that have adopted a PBL approach to curriculum and instruction have developed extensive tutor training programs in recognition of the critical importance of this role in facilitating the PBL learning experience. An excellent resource is *The Tutorial Process* by Barrows (1988), which explains the importance of the tutor as the metacognitive coach for the learners.

The problem situations used in PBL must be ill-structured and allow for free inquiry

Problems in the real world are ill-structured (or they would not be problems). A critical skill developed through PBL is the ability to identify the problem and set parameters on the development of a solution. When a problem is well-structured learners are less motivated and less invested in the development of the solution.

Learning should be integrated from a wide range of disciplines or subjects

During self-directed learning, students should be able to access, study, and integrate information from all the disciplines that might be related to understanding and resolving a particular problem—just as people in the real world must recall and apply information integrated from diverse sources in their work. The rapid expansion of information has encouraged a cross-fertilization of ideas and led to the development of new disciplines. Multiple perspectives lead to a more thorough understanding of the issues and the development of a more robust solution.

The activities carried out in PBL must be those valued in the real world

A rationale for the selection of authentic problems in PBL and guidelines for developing problems is discussed extensively in Gijselaers (1996), Savery and Duffy (1996), Stinson and Milter (1996), Boud and Feletti (1997), and Macdonald (1997). The transfer of skills learned through PBL to a real-world context is also noted by Bransford, Brown, and Cocking (2000, p. 77).

Conditions That Facilitate PBL

Students must have the responsibility for their own learning

Learner motivation increases when responsibility for the solution to the problem and the process rests with the learner (Savery & Duffy, 1996). Inherent in the design of PBL is a public articulation by the learners of what they know and about what they need to learn more. Individuals accept responsibility for seeking relevant information and bringing that back to the group to help inform the development of a viable solution.

What students learn during their self-directed learning must be applied back to the problem with reanalysis and resolution

The point of self-directed research is for individuals to collect information that will inform the group's decision-making process in relation to the problem. It is essential that each individual share coherently what he or she has learned and how that information might impact on developing a solution to the problem.

A closing analysis of what has been learned from work with the problem and a discussion of what concepts and principles have been learned is essential

Learners are very attached to the immediate details of the problem and the proposed solution. The purpose of the debriefing process is to consolidate the learning and ensure reflection on all facets of the PBL process so students better understand what they know, what they learned, and how they performed.

Outcomes That Are Facilitated By PBL

Self- and peer assessment should be carried out at the completion of each problem and at the end of every curricular unit

These assessment activities related to the PBL process are closely related to the previous essential characteristic of reflection on knowledge gains. The significance of this activity is to reinforce the self-reflective nature of learning and sharpen a range of metacognitive processing skills.

Collaboration is essential

PBL provides a format for the development of essential collaboration and information-sharing skills. During a PBL session the tutor will ask questions of all members to ensure that information has been shared between members in relation to the group's problem.

Student examinations must measure student progress toward the goals of PBL

The goals of PBL are both knowledge-based and process-based. Students need to be assessed on both dimensions at regular intervals to ensure that they are benefiting as intended from the PBL approach. Students are responsible for the content in the curriculum that they have "covered" through engagement with problems. They need to be able to recognize and articulate what they know and what they have learned.

Role of the Tutor in PBL

The role of the tutor is to facilitate the learning process rather than to provide knowledge and to model expert thinking so students adopt these metacognitive processes. Barrows defines the role of the tutor and the critical importance of "metacognitive modeling" in shaping student thinking and problem solving:

> The oral statements and challenges he [the facilitator] makes should be those he would make to himself when deliberating over such a problem or situation as the one his students are working with. His questions will give them an awareness of what questions they should be asking themselves as they tackle the problem and an appreciation of what they will need to learn. In this way he does not give them information or indicate whether they are right or wrong in their thinking. (Barrows, 1988, pp. 4–5)

When PBL is used as the primary instructional strategy with adult learners who are refining their knowledge and skills in a chosen profession then this role for the tutor will produce the intended learning outcomes. This type of learner is not learning the basics but rather moving into becoming an expert. In general, an effective problem-based tutor should guide, probe, and support students' initiatives, not lecture, direct, or provide easy solutions. Barrows provides an example of tutor dialogue as follows:

> [The teacher] can ask, "Why?" "What do you mean?" "What is the evidence?" "Are there other explanations?" "Have you thought of everything that needs to be considered?" "What's the meaning of that?" to crank up tension and interest. To decrease the challenge, he can ask questions such as "Should we just tackle a piece of this problem (or task)?" "Let's revise our objectives and tackle those that are most important in this task."

Table 4.2 Summary of Characteristics of PBL

Parameters	PBL pedagogical model
1) Role of instructor	• Tutor presents and sets the problem situation • Tutor facilitates the problem-solving process • Tutor models and demands evidence of metacognitive thinking • Tutor does not provide information related to content/problem • Tutor facilitates a comprehensive assessment of learner content knowledge and the learning process
2) Role of the learner	• Small groups of learners • Self-directed learning is required • Teamwork and collaboration are required
3) Strategies for implementation	• Problems are disciplinary specific or interdisciplinary developed by expert faculty to address curricular goals • Problems are the driving force for learning and generate a need to know that motivates students to conduct research and gather relevant information related to the problem situation • Problems are ill-structured and authentic
4) Availability/access to resources	• Learners have access to all available data and information • Direct instruction on relevant information may be scheduled to coincide with learner needs within specific problems
5) Assessment of intended learning outcomes	• Both knowledge-based and process-based • Conducted after each problem exercise • Standardized tests specific to the profession determine learner and program success

> "Maybe we ought to stop here and read some resources or go talk to an expert?" "Would it be better to get the big picture now and fill in the details later?", etc. (Barrows, 1988, p. 11)

The degree to which a PBL course is teacher-directed is a decision that the individual faculty member must make based on the size of the class, the intellectual maturity level of the students, and the instructional goals of the course. Students do not become proficient learners after a single problem. It may take many problems but eventually the students take over the role of the tutor and demonstrate that they have developed the metacognitive skills necessary to function on their own.

Table 4.2 summarizes the critical characteristics of a PBL pedagogical model using these parameters:

1) Role of the instructor.
2) Role of the learner.
3) Strategies for implementation.
4) Availability/access to resources.
5) Assessment of intended learning outcomes.

First, how does the PBL pedagogical approach align with these parameters?

Case-Based Learning Compared With PBL

A case study is usually designed by an expert in the content domain with the intended purpose of telling a story that presents critical pieces of information needed to solve the case. Wasserman (1994) and Herreid (1997) proposed the following characteristics of an effective case.

1) Content is closely aligned with the overall instructional goals and objectives.
2) Clearly states and illuminates the dilemma without resolving it.
3) Well-written and its readability is appropriate for the age or level of the student.
4) Relevant to the reader.
5) Written in the present tense and deals with an authentic situation not more than 5 years old.
6) Provokes conflict and forces decision-making.
7) Includes direct quotes, using the characters' dialogue to tell the story.
8) General enough to be used in several applications.
9) Compelling and creates empathy with the main characters.
10) Is short.

With most case-based approaches the task for the learner is to analyze and evaluate the evidence provided in the case, determine the accuracy/completeness of the information provided, seek additional information to corroborate or refute or extend the information provided, and then write a response to the questions posed by the instructor that articulates clearly their thinking about the case. Case-based teaching has been used in law, medicine, and business (and others) to assess students' ability to synthesize, evaluate, and apply information and concepts learned in lectures and texts. Case studies can be used to organize and bring to life abstract and disparate concepts by forcing students to make difficult decisions about complex human dilemmas—such as ethics in the discipline or choosing between two difficult alternatives. Case-based learning is more teacher-centered than the other strategies being discussed. When learners work on a case, either alone or in groups, the task is to apply what was learned previously—through readings or lecture—to the specific circumstances as delimited by the information provided in the case. By narrowing the scope of the information provided and specifying the questions to be answered the designer of the case is intentionally leading the learners to arrive at a predetermined solution. The point of the case study is for students to learn the important lessons and critical concepts by thinking through the case as presented. Students will learn from the experience of others—those who prepared the case. Cases present complex well-structured problem situations—which contrasts with the ill-structured problems that drive the learning in problem-based approaches.

The Harvard University Law School and School of Business have increased the fidelity and complexity of the cases developed through the Case Development Initiative by using real-life examples from the business world to highlight and analyze business principles. The approach develops written and video summaries of strategic and organizational issues using interviews, data, and research. Learners must identify key challenges and develop appropriate strategies to resolve them. More importantly, learners must consider each situation from multiple perspectives and reconcile the interests of different groups or individuals; for example, the reader may need to analyze both the stakeholders' interests and motivations and the underlying incentives and mission of the institution before arriving at a solution to a strategic problem. In short, these enhanced case studies bring real-life situations to classroom settings, helping students prepare for their professional careers (Harvard Law School, n.d.). An extensive library of case studies organized by subject and implementation type (role play, workshop, or discussion) has been developed using this more authentic approach.

Williams (1992) notes that two principles of learning—cognitive apprenticeship and anchored instruction—are evident when using a case-based approach. Cognitive apprenticeship (Collins, Brown, & Newman, 1989) refers to the novice learning how to think like the expert. As the learner works through the case study and prepares their response and when debriefing on the case after it has been submitted, the learner will hear the voice of the expert and confirm or adjust their own thinking about the case. Similarly, with anchored instruction (Bransford, Sherwood, Hasselbring, Kinzer, & Williams, 1990) the case serves as an organizing structure for the key concepts that the learner is expected to master. When the learner encounters a situation with similar elements they will be able to retrieve the "case" they learned while in school. These two principles of learning are also evident in project-based and PBL as the students develop higher-order thinking skills and detailed experiences. While cases are engaging and challenging, there is a difference between a passive form of learning and an active form of learning.

How Does the Case-Based Approach Compare With the PBL Pedagogical Approach?

There is a significant difference between the two approaches. The two main differences reside in the degrees of self-directed learning and the structuredness of the problem used (how much information about the problem is given). With a case-based approach the learner is reading the narrative developed by the expert and the learning is largely directed by the instructor. With the problem-based approach the learners are writing their own narrative as they research and develop a viable solution to the problem situation prepared by the expert. Also, the learning with problem-based approach is mainly self-directed with an appropriate level of facilitation from the instructor. See Table 4.3 for a comparison of PBL and case-based learning.

Project-Based Learning Compared With PBL

Larmer, Mergendoller, and Boss (2015) trace the evolution of project-based learning from the development of schools in 1577 to prepare professional artisans using challenge projects, to the introduction by Kilpatrick of the Project Method (Kilpatrick, 1918), to the strong influence of John Dewey who called attention to the "…teacher as an indispensable mentor and senior partner in [project-based learning] design, planning, management, coaching, assessment, and reflection" (p. 28). They further describe the project-based learning pedagogical

Table 4.3 Comparison Between Characteristics of Problem-Based Learning and Case-Based Pedagogical Models

Parameters	**PBL pedagogical model**	**Case-based pedagogical model**
1) Role of instructor	• Tutor presents and sets the problem situation • Tutor facilitates the problem-solving process • Tutor models and demands evidence of metacognitive thinking • Tutor does not provide information related to content/problem • Tutor facilitates a comprehensive assessment of learner content knowledge and the learning process	• Instructor is the teacher for the class and usually a primary source of content information • Instructor presents the case to the learners and the questions to be answered by the learners • Instructor provides feedback and clarification on the learner response • Instructor evaluates learner response to the case
2) Role of the learner	• Small groups of learners • Self-directed learning is required • Teamwork and collaboration are required	• Primarily individual self-directed learning and application of prior learning • Usually competitive rather than collaborative
3) Strategies for implementation	• Problems are disciplinary specific or interdisciplinary developed by expert faculty to address curricular goals • Problems are the driving force for learning and generate a need to know that motivates students to conduct research and gather relevant information related to the problem situation. • Problems are ill-structured and authentic	• Cases developed/used by expert faculty to address specific learning and curricular goals • Cases are intended to develop problem-solving and higher order thinking skills • Small groups or teams may be allowed • Responses to case study assignments used for grading purposes
4) Availability/ access to resources	• Learners have access to all available data and information • Direct instruction on relevant information may be scheduled to coincide with learner needs within specific problems	• Learners have access to all available data and information
5) Assessment of intended learning outcomes	• Both knowledge-based and process-based • Conducted after each problem exercise • Standardized tests specific to the profession determine learner and program success	• Assessment is primarily knowledge-based—correct answer only • Standardized tests specific to the profession

PBL, problem-based learning.

model as an inquiry-based approach designed to enable students to develop the knowledge, understanding, and skills that prepare them for successful school and life experiences.

Characteristics of a Project-Based Learning Pedagogy

The starting point for a project-based approach is the question, problem, phenomena, or puzzlement that serves as an organizing structure for the learning process that follows. Projects are selected based on alignment with content standards and intended learning outcomes—particularly when implemented in K–12 education or vocational education programs. The project is the vehicle used to organize the learning experience and achieve the intended learning outcomes. It is through the experience of working on the project that the learner acquires new knowledge, confirms or adjusts prior learning, and builds their expertise in the content domain. Larmer et al. (2015) state that the design of a project begins with the intended learning outcomes (learner goals) in mind and during implementation addresses seven key design elements: (a) a challenging problem or question, (b) sustained inquiry, (c) authenticity, (d) student voice and choice, (e) reflection, (f) critique and revision, and (g) a public product. These design elements inform the sequence of activities used by students as they engage with "their" project—note that ownership of the project process and the development of a solution are supported by the teacher while facilitating the learning process.

Role of the Teacher

Larmer, Mergendoller, and Boss (2015, p. 33) characterize the role of the teacher using project-based learning as follows:

> The project based teachers we know spend considerable time creating or adapting the projects they do with their students. They still have to make sure that students learn the skills and concepts they will be tested upon each year, and they have to assess students and communicate to students and their parents about academic progress and problems. Although they may instruct their students in ways similar to that of a problem based tutor, they are responsible for so much more.

Instructors using a project-based approach employ multiple means of assistance (Gallimore & Tharp, 1990) also referred to as scaffolding to support the development of metacognitive thinking by learners as they become increasingly self-directed in their thinking and problem solving. A classroom teacher could assist a student working on their project by modeling problem solving using a think aloud protocol or providing a visual model or engaging in directive questioning to guide the student to the level of understanding needed to proceed with their project. The key for the teacher is to maintain a balance that allows the learner to achieve the intended learning outcomes while developing their skills as a self-directed learner. Given the significant developmental and maturation differences between students in K–12 education and adults in professional preparation/

graduate programs, it would be expected that the degree of expertise upon graduation would also be different. However, students graduating high school with highly developed skills that are fostered by participation in a project-based learning curriculum would be better prepared for careers in the twenty-first century than students who had not had a similar opportunity to learn these skills.

There are more similarities than differences between problem-based and project-based learning. For purposes of comparison we must assume that both are being implemented as a curricular approach and both are facilitated by instructors trained in their respective pedagogical models. We begin with examining how each aligns with the research on learning listed earlier and the key elements of a constructivist philosophical approach to instruction.

Commonalties Between PBL and Project-Based Learning

Both PBL and project-based learning use an authentic problem, question, or puzzlement as the *starting point* for learning. This provides the learner with a focus, motivation, and a contextual structure. The problem or project is relevant to the content domain(s). Also, both strategies are curriculum-based. PBL is most often associated with professional education. Teams of content experts design problems that lead the learners through the required knowledge base that students must master to pass the discipline required standardized exams. Well-designed curricula enable learners to apply knowledge developed in a previous problem to a new problem and this serves to reinforce learning. Project-based learning is most often associated with K–12 education as well as engineering education. In this context, project-based learning draws questions/projects from the state-mandated curriculum. Both approaches focus on the intended learning outcomes when designing the problem/project and this focus contributes to learner success.

Moreover, both approaches require social negotiation of knowledge while working collaboratively in a group to develop possible solutions to the problem or project and require contributions by all members of the team while working on the problem or the project. The problems or projects are large enough that no individual on the team would be able to do all the work while others on the team rested. There are clear expectations that each member will share their thoughts, suggestions, information, and research findings with the team—relative to the current problem situation—to advance the work of the group (Blumenfeld et al., 1991).

PBL and project-based learning support iteration as a process for developing a possible solution to the question/problem. Each strategy begins with a basic problem-solving strategy of determining what is currently known (facts) and what needs to be understood (learning issues) before proceeding. In project-based learning this is the critique and revision phase, where the team integrates results from research into the next phase of the development of the project. In PBL this integration and assessment and revision phase follows the sharing of individual research on learning issues that are brought back to the team for consideration.

Furthermore, these two approaches are intended to develop learners' metacognitive abilities—critical thinking, reflective thinking, self-directed learning, and

Table 4.4 Comparison Between Characteristics of Problem-Based Learning and Project-Based Learning Pedagogical Models

Parameters	PBL pedagogical model	Project-based pedagogical model
1) Role of instructor	• Tutor presents and sets the problem situation • Tutor facilitates the problem-solving process • Tutor models and demands evidence of metacognitive thinking • Tutor does not provide information related to content/problem • Tutor facilitates a comprehensive assessment of learner content knowledge and the learning process	• Instructor is critical to the successful implementation of this model • Instructor models/encourages higher-order thinking • Instructor scaffolds the learning in multiple ways and may provide information related to content/problem • Instructor assesses the learners, the learning experience, and the project artifacts
2) Role of the learner	• Small groups of learners • Self-directed learning is required • Teamwork and collaboration are required	• Students work in teams, often within the context of a larger class • Self-directed learning is an important element • Teamwork and collaboration are expected
3) Strategies for implementation	• Problems are disciplinary specific or interdisciplinary developed by expert faculty to address curricular goals • Problems are the driving force for learning and generate a need to know that motivates students to conduct research and gather relevant information related to the problem situation • Problems are ill-structured and authentic	• Projects are aligned with curriculum goals and content standards • Projects may be disciplinary specific or interdisciplinary • Projects and the required problem-solving process organize the learning and motivate students to conduct research and gather information related to the project • Projects are usually well-structured with varying degrees of authenticity
4) Availability/access to resources	• Learners have access to all available data and information • Direct instruction on relevant information may be scheduled to coincide with learner needs within specific problems	• Learners have access to relevant data and information • Teacher selected resources frequently provided as part of project design • Teacher may provide direct answers to questions or suggest appropriate resources
5) Assessment of intended learning outcomes	• Both knowledge-based and process-based • Conducted after each problem exercise • Standardized tests specific to the profession determine learner and program success	• Both knowledge-based and process-based • Conducted after project completion • Standardized tests specific to the grade level of the learners

PBL, problem-based learning.

lifelong learning skills. The "teacher" in a project-based approach has greater latitude to provide direct instruction and many other forms of support to the learner. The "tutor" in a problem-based approach is focused on the problem-solving process and the development/demonstration by the learner of metacognitive skills and content knowledge. The tutor does not provide content knowledge but will model metacognitive thinking processes.

Also, both approaches provide for a public presentation of their efforts as a team to develop a viable solution to the problem or provide a final product (report) for the project. The public presentation may include just the teacher and classmates or it may include members of school administration, members of the community, or recognized experts in the content domain. It is the public nature of the presentation that stimulates the learners to present their best thinking about the problem/project. Lastly, they both include a specific end-of- problem/project phase that ensures reflection on what was learned, the learning process itself, and the contributions/growth of the individual. See Table 4.4 for a comparison of PBL and project-based learning.

Inquiry-Based Learning Compared With PBL

Inquiry-based learning is used to describe an approach to instruction that can be applied to a broad range of disciplines and educational levels. In the domain of science education, Carin, Bass, and Contant (2005) describe the use of the scientific method as a driving force for student engagement

> inquiry-based teaching is a teaching method that combines the curiosity of students and the scientific method to enhance the development of critical thinking skills while learning science. As learners encounter problems they do not understand, they formulate questions, explore problems, observe, and apply new information in seeking a better understanding of the world. The natural process the learners follow when seeking answers and deeper understanding closely follows the generally accepted scientific method. (p. 21)

And regarding implementation of an inquiry-based approach the National Research Council (2000) states,

> Teaching science through inquiry requires a new way of engaging students in learning. It therefore requires that all educators take on the role of change agents. To foster the changes in teaching required by inquiry-based approaches, administrators and other leaders need to provide a wide array of support—from opportunities to learn, to materials and equipment, to moral support, encouragement, and "running interference." (p. 152)

Without such support, inquiry-based science programs are unlikely to succeed and even less likely to be sustained. With it, all students are much more likely to understand, appreciate, and actively participate in the scientific world.

Kirschner, Sweller, and Clark (2006) expressed concerns with instructional approaches they describe as providing minimal guidance to learners. The key argument made by Kirschner et al. (2006) is that learner-centered, minimally guided pedagogical approaches are inefficient. Students waste time attempting to discover scientific (and other disciplinary principles) and in the process develop cognitive structures that are not well-organized. They propose that a teacher-centered pedagogy that uses direct instruction, considerable teacher guidance, and many examples will result in more learning than discovery approaches. While these recommendations are based on research in cognition there is some value in considering exactly how teachers and students interact in an inquiry-based learning environment to ensure that intended student learning outcomes are realized. As noted the role of the tutor in a problem-based approach has clearly delimited responsibilities as does an instructor using a case-based approach. The teacher using a project-based approach or an inquiry-based approach has more latitude to assist students when difficulties are encountered. The role of the teacher is particularly critical with younger students engaged in inquiry-based learning to ensure that their discoveries are aligned with established theories and facts in the discipline. This is not to suggest that curiosity should be discouraged or that there are right answers that the students must discover, but rather to allow the students to integrate their discoveries within the larger and established body of knowledge in the discipline. See Table 4.5 for a comparison of PBL and inquiry-based learning.

Learning by Design Compared With PBL

Learning by Design is a more recent model that is a careful and deliberate amalgam of the critical characteristics of other models discussed in this chapter. This Learning by Design instructional approach is described by Kolodner et al. (2003) as:

> …a project-based inquiry approach to science learning with roots in case-based reasoning and problem-based learning, …[using] what we know about cognition to fashion a learning environment appropriate to deeply learning science concepts and skills and their applicability, in parallel with learning cognitive, social, learning, and communication skills…. LBD has students learn science in the context of achieving design-and-build challenges. (p. 495)

Learning by Design was introduced in 1996 as a combination of case-based learning, which provided a structure for the curriculum, and PBL, which provided the instructional strategy focused on integrating content and practice with problem solving and cognitive apprenticeship (Collins et al., 1989). Importantly, the model deliberately incorporates multiple recommendations/findings from the learning sciences to address three challenges: finding a way to engage nearly all learners, helping students learn important reasoning and social skills while learning content, and learning both content and skills well

Table 4.5 Comparison Between Characteristics of Problem-Based Learning and Inquiry-Based Learning Pedagogical Models

Parameters	PBL pedagogical model	Inquiry-based pedagogical model
1) Role of instructor	• Tutor presents and sets the problem situation • Tutor facilitates the problem-solving process • Tutor models and demands evidence of metacognitive thinking • Tutor does not provide information related to content/problem • Tutor facilitates a comprehensive assessment of learner content knowledge and the learning process	• Instructor is critical to the successful implementation of this model • Instructor models/encourages higher-order thinking • Instructor scaffolds the learning in multiple ways and may provide information related to content/problem • Instructor assesses the learners, the learning experience, and learner-generated artifacts
2) Role of the learner	• Small groups of learners • Self-directed learning is required • Teamwork and collaboration are required	• Students work individually or in teams, often within the context of a larger class • Self-directed learning is an important element • Teamwork and collaboration are encouraged
3) Strategies for implementation	• Problems are disciplinary specific or interdisciplinary developed by expert faculty to address curricular goals • Problems are the driving force for learning and generate a need to know that motivates students to conduct research and gather relevant information related to the problem situation • Problems are ill-structured and authentic	• Questions or challenges are aligned with curriculum goals and content standards • Questions or challenges may be disciplinary specific or interdisciplinary • Questions or challenges organize the learning and motivate students to conduct research (experiment) to gather information related to the question • Questions or challenges are usually well-structured (closed vs. open-ended) with varying degrees of authenticity
4) Availability/access to resources	• Learners have access to all available data and information • Direct instruction on relevant information may be scheduled to coincide with learner needs within specific problems	• Learners have access to relevant data and information • Teacher selected resources frequently provided as part of inquiry design • Teacher may provide direct answers to questions or suggest appropriate resources
5) Assessment of intended learning outcomes	• Both knowledge-based and process-based • Conducted after each problem exercise • Standardized tests specific to the profession determine learner and program success	• Both knowledge-based and process-based • Conducted after project completion • Standardized tests specific to the grade level of the learners

PBL, problem-based learning.

enough to be able to apply them in new situations (learning for transfer) (Kolodner et al., 2003, p. 498).

The target audience for this approach was eighth-grade students and the approved science curriculum. It was quickly determined that students at this age are not ready for PBL as described in the McMaster model. Middle schoolers do not understand how to organize themselves to solve a big problem or to make connections between what they know and the information they are encountering. Given the naïve level of knowledge and metacognitive skills, middle schoolers require additional scaffolding to support their learning. One of the strengths of the Learning by Design approach is the flexibility it affords the teacher to assume the necessary roles and responsibilities within the learning situation. This is also a significant challenge as teachers require additional training in both the discipline (science) and the pedagogical model to be effective in this environment.

Kolodner, Crismond, Gray, Holbrook, and Puntambekar (1998) describe a typical sequence of activities in a Learning by Design unit where students encounter a design challenge and attempt to develop a solution using only prior knowledge—individually and/or in small groups. Utilizing whole-class discussions, the teacher helps students compare and contrast their ideas, identify what they need to learn to move forward in addressing the design challenge, choose a learning issue to focus on, and design and/or run a laboratory activity to examine that issue. While this series of activities closely resembles a PBL approach, the role of the teacher is less that of tutor and much more that of facilitator of learning seeking to identify student misunderstandings and misconceptions and begin the process of scaffolding their learning. The teacher might also present demonstrations, assign readings, and/or present short lessons relevant to discovered knowledge gaps. Following this are cycles of exploratory and experimental work by the students, followed by reflection on what has been learned, application of what was learned to achieving the design challenge, evaluation of that application, and generation of additional learning issues. This process of iteration continues with potential solutions attempted and evaluated using different approaches. Students solicit feedback from peers and others through presentations during which they justify their design decisions and explain how their designs work (or would work) using science and engineering vocabulary. See Table 4.6 for a comparison of PBL and Learning by Design.

Summary

In the discipline of instructional design there is a clear relationship between the consequences of a failure to master the instruction and the rigor of the instruction needed to ensure mastery. For example, a pilot needs to demonstrate mastery of take-offs and landings at a level of 100% proficiency. The consequences of failure are too great for anything less. Therefore, the instruction needs to be effective at the same 100% level of mastery. By comparison, the consequences for a student making a transposition error in a mathematical calculation are much

Table 4.6 Comparison Between Characteristics of Problem-Based Learning and Learning by Design Pedagogical Models

Parameters	PBL pedagogical model	Learning by design pedagogical model
1) Role of instructor	• Tutor presents and sets the problem situation • Tutor facilitates the problem-solving process • Tutor models and demands evidence of metacognitive thinking • Tutor does not provide information related to content/problem • Tutor facilitates a comprehensive assessment of learner content knowledge and the learning process	• Instructor is critical to the successful implementation of this model • Instructor models/encourages higher-order thinking • Instructor scaffolds the learning in multiple ways and may provide information related to content/problem • Instructor assesses the learners, the learning experience, and learner-generated artifacts
2) Role of the learner	• Small groups of learners • Self-directed learning is required • Teamwork and collaboration are required	• Students work individually or in teams, often within the context of a larger class • Self-directed learning is an important element • Teamwork and collaboration are encouraged
3) Strategies for implementation	• Problems are disciplinary specific or interdisciplinary developed by expert faculty to address curricular goals • Problems are the driving force for learning and generate a need to know that motivates students to conduct research and gather relevant information related to the problem situation • Problems are ill-structured and authentic	• Questions or challenges are aligned with curriculum goals and content standards • Questions or challenges may be disciplinary specific or interdisciplinary • Questions or challenges organize the learning and motivate students to conduct research (experiment) to gather information related to the question • Questions or challenges are usually well-structured (closed vs. open-ended) with varying degrees of authenticity
4) Availability/access to resources	• Learners have access to all available data and information • Direct instruction on relevant information may be scheduled to coincide with learner needs within specific problems	• Learners have access to relevant data and information • Teacher selected resources frequently provided as part of inquiry design • Teacher may provide direct answers to questions or suggest appropriate resources
5) Assessment of intended learning outcomes	• Both knowledge-based and process-based • Conducted after each problem exercise • Standardized tests specific to the profession determine learner and program success	• Both knowledge-based and process-based • Conducted after project completion • Standardized tests specific to the grade level of the learners

PBL, problem-based learning.

Table 4.7 Summary of Characteristics of Pedagogical Models

	PBL	CBL	PjBL	IBL	LBD
Teacher	Tutor process manager, metacognitive coach	Content expert Provides direct instruction, models metacognitive skills	Content expert Provides direct instruction, models metacognitive skills	Content expert Provides direct instruction, models metacognitive skills	Content expert Provides direct instruction, models metacognitive skills
Learner	Primarily adult, postsecondary	K–12 through postsecondary	Primarily K–12 with postsecondary	Primarily K–12	Primarily K–12
Implementation	Problems developed by expert faculty to address curricular goals Problems generate a need to know that motivates students to conduct research and gather relevant information related to the problem situation Problems are ill-structured and authentic	Cases developed by expert faculty to address curricular goals Cases are intended to develop problem-solving skills Cases are well-structured and provide information needed to develop a solution	Projects aligned with curriculum goals and content standards Projects organize the learning and motivate students to conduct research to gather information related to the project Projects are usually well-structured (closed vs. open-ended) with varying degrees of authenticity	Questions aligned with curriculum goals and content standards Questions organize the learning and motivate students to conduct research (experiment) to gather information related to the question Questions are usually well-structured (closed vs. open-ended) with varying degrees of authenticity	Questions aligned with curriculum goals and content standards Questions organize the learning and motivate students to conduct research (experiment) to gather information related to the question Questions are usually well-structured (closed vs. open-ended) with varying degrees of authenticity
Resources	No restrictions	No restrictions Aligned with content domain	No restrictions—often "teacher-directed/ selected" Aligned with grade level curriculum	No restrictions—often "teacher-directed/selected" Aligned with grade level curriculum	No restrictions—often "teacher-directed/selected" Aligned with grade level curriculum
Assessment	Standardized tests, professional board certification	Standardized tests aligned to grade level	Standardized tests aligned to grade level	Standardized tests aligned to grade level	Standardized tests aligned to grade level

PBL, problem-based learning; CBL, case-based learning; PjBL, project-based learning; IBL, inquiry-based learning; LBD, Learning by Design.

less serious and the mastery level can be significantly less than 100%. The pedagogical models examined in this chapter can also be viewed using this relationship between degree of mastery and consequences of nonmastery. Each of the pedagogical models discussed in the chapter has a similar epistemological foundation. The most significant differences can be found in the degree of mastery that is expected of students.

PBL is best used in the preparation of professionals. This pedagogical model stresses the integration of theory and practice by presenting learners with ill-structured problems within the content domain. Content knowledge, problem-solving processes, and the development of mature metacognitive skills are critical learning outcomes. These are the characteristics that professionals (experts) are expected to demonstrate and the knowledge and skills that are assessed through rigorous standardized examinations.

Case-based learning provides learners with a story that serves as a container for key concepts within the discipline. A story is a very effective way to organize information and retrieve it for future use. However, the cases are generally well-structured and the learning goal is to find the correct answer using the information provided. With ill-structured problems in PBL, the scope is greater and the potential for multiple viable responses is also greater.

Project-based learning is best used in preparing students to apply their knowledge and skills while acquiring additional knowledge and skills in the process. When effectively supported by teachers this pedagogical approach fosters student ownership for learning, the development of lifelong learning habits and the development of higher-order thinking skills.

Inquiry-based approaches provide learners with an opportunity to explore and discover and ultimately make sense of their world. Teachers assist learners in this process and model strategies that enable learners to organize information gained through experience. There is less rigor involved with this approach as the goal is the development of general knowledge rather than deep disciplinary content.

Learning by Design attempts to combine key elements from problem-based, case-based, project-based, and inquiry-based models and seamlessly integrate instructional strategies demonstrated by research from the learning sciences to help students to learn content, reasoning skills, and social skills that enable them to transfer classroom learning to real-world situations. Critical to the success of this approach are well-designed challenges for the students and teachers who are knowledgeable in both the discipline and the application of the pedagogical model. See Table 4.7 for a summary of all the models described herein.

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Section II

Research in PBL

Introduction

Problem-based learning (PBL) is one of the most researched pedagogies in the history of education. With its epistemological philosophy and innovative instructional approach, PBL has drawn a great deal of enthusiasm from the field of education. However, its unconventional philosophy and instructional practices also evoke skepticism, questioning the effects and value of PBL on student learning. Over five decades, a significant body of research has been conducted to attempt to settle this debate. Unfortunately, the research results have not cleared all of the dust from the air, even today. Nevertheless, the effort from PBL researchers and educators has not gone to waste. These studies give us small pieces of information each time but every bit helps piece together the big puzzle that we are trying to solve.

In this section, six chapters have been collected together to give a general yet focused picture of the research findings on the effects of PBL on students' learning, as well as the research interests and development of research directions in the PBL field. In Chapter 5 "Effects of PBL on Learning Outcomes, Knowledge Acquisition, and Higher-Order Thinking Skills," Moallem gives a comprehensive review of what the PBL research found with regard to student learning outcomes, specifically knowledge acquisition and higher-order thinking skills. This chapter first considers the factors that might affect student learning outcomes and compares how the unique features in different PBL models might affect these factors in manifesting themselves in the learning process. A thorough review of the students' learning outcomes follows to answer the question of the effects of PBL on student learning.

Dabbagh takes a slightly different approach in Chapter 6 "Effects of PBL on Critical Thinking Skills." Using critical thinking as an overarching concept, Dabbagh defines this higher-order thinking skill as problem solving, decision

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making, causal reasoning, meta-cognitive/reflective thinking, communicative, and collaborative skills. In this chapter, she reviews the literature on the effects of PBL on students' development of these skills. This chapter also contains a discussion on the implementation principles of how to effectively design PBL to better facilitate students' development of these two thinking skills based on the research findings from the field.

Motivation has long been a research interest of PBL researchers. In Chapter 7 "Effects of Problem-Based Learning on Motivation, Interest, and Learning," Rotgans and Schmidt discuss the major motivation factors in PBL for student learning, which include tutorial groups as well as problem design. In this chapter, besides the general literature review on motivation in PBL, they also provide research evidence from a series of empirical studies to support their argument for using micro-analytical measurements to study motivation during the PBL process, as well as situational interest as a potential indicator for measuring students' motivation.

Self-directed learning is one of the hallmarks of PBL. A great deal of the debate about the effects of PBL on student learning may be seen stemming from this instructional practice because of the concern about the amount of directive guidance given by the instructor. Chapter 8 "Self-Directed Learning in Problem-Based Learning: A Literature Review," authored by Leary, Walker, Lefler, and Kuo, focuses on surveying the research findings on self-directed learning in PBL. The authors discuss the research findings from the perspectives of cognitive, affective, and conative learning objectives, and goals of PBL.

Group work and group dynamics are some of the most complex implementation issues in PBL, and therefore some of the most researched topics in PBL literature. The importance of group dynamics in PBL is not just theoretically understandable, but empirically confirmed. Fonteijn and Dolmans take the readers through Chapter 9, "Group Work and Group Dynamics in PBL," examining the factors that influence group processing in relation to different learning tasks, processes, and context. The chapter also touches on the research findings suggesting potential structural and personal losses when negative group dynamics occur, as well as their remedies.

Lastly, empirical research in K–12 settings has traditionally been relatively less present than in professional studies and higher education. With a relatively smaller research body to work with, Grant and Tamim have made the Chapter 10 "PBL in K–12 Education" a valuable read. This chapter discusses similar research in PBL to the other chapters in this section, but from a K–12 perspective. This different perspective questions many of the assumptions made in PBL implementation in higher education, and therefore, gives an important reminder of the importance of learner characteristics, cognitive maturity, and emotional readiness when implementing PBL.

5

Effects of PBL on Learning Outcomes, Knowledge Acquisition, and Higher-Order Thinking Skills

Mahnaz Moallem

Introduction

Enthusiasm for problem-based learning (PBL) has increased since PBL was first introduced in medical education more than 50 years ago (Barrows & Tamblyn, 1980). PBL is now used in a variety of different disciplines, and its appeal has spread beyond the traditional boundaries of formal education. In general terms, PBL is defined as a teaching and learning method in which students engage in solving a real-world problem without preparatory study and with prior knowledge sufficient to solve the problem, requiring that they extend existing knowledge and understanding while working in groups, facilitated by a tutor or a teacher, and apply their enhanced understanding to generate a solution to the problem. An essential element in PBL is that problems posed are ill-structured and do not have a single, clear-cut formulaic solution, thus motivating students to ask questions and to seek additional information.

A review of many programs using PBL shows that contemporary analogous approaches of project-based learning (PjBL), Learning by Design (LBD), inquiry-based learning (IBL), and design thinking (DT) are often used to refer to PBL. Yet, despite common goals and implementation features (Barron & Darling-Hammond, 2008; Savery, 2006), PBL, PjBL, LBD, IBL, and DT are distinct theory-based approaches, and some are used more widely in particular fields or disciplines. Whether using PBL, PjBL, LBD, IBL, or DT, the question that continues to influence adoption and implementation of PBL since its inception is "what exactly do students learn in PBL?" or more specifically "what effects does PBL have on student learning outcomes (e.g., knowledge acquisition, and higher-order thinking skills)?" In other words, to what extent does PBL produce the types of changes in learners that it was designed to produce? The answers to these questions are still lacking. The purpose of this chapter is to respond to these questions. It first analyzes and synthesizes the literature regarding the factors that influence the effectiveness of PBL to identify questions that designers and researchers should ask

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about results of learning. It will then explore important characteristics and features of PBL compared with its analogous approaches of PjBL, LBD, IBL, and DT to understand how features of each approach influence the effectiveness of learning outcomes. Further, the chapter examines how PBL and its analogous approaches define learning outcomes and how various learning outcomes are measured. Finally, the chapter uses the results of the current research on the effectiveness of PBL to offer recommendations for the future researchers and designers.

Factors Affecting Outcomes of Learning in Problem-Based Learning

PBL promises that it will improve students' learning and enhance their higher-order thinking and problem-solving skills. Researchers and proponents of PBL argue that PBL approaches allow learners to achieve the desired knowledge sets, skills, and outcomes recommended for the twenty-first-century workforce and prepare them for lifelong learning through development of self-regulation, inquiry, and metacognition (Ertmer & Simons, 2006; Hmelo-Silver & DeSimone, 2013; Schmidt, Loyens, Van Gog, & Paas, 2007). In other words, rather than emphasizing the acquisition of knowledge and skills, PBL offers opportunities for students to apply knowledge and skills in the real world or an authentic context. Nevertheless, the studies examining the effects of PBL on student academic achievement in secondary and higher education continue to compare student acquisition of knowledge in PBL with lectures-based instruction. Thus, while the results of the meta-analysis studies examining the effects of PBL on student academic achievement are conclusive regarding the problem-solving ability of students, they are still inconclusive regarding the effects on the acquisition of knowledge (e.g., Albanese & Mitchell, 1993; Dochy, Segers, Van den Bossche, & Gijbels, 2003; Vernon & Blake, 1993; Walker & Leary, 2009). In other words, the results of these meta-analysis studies indicate that even though PBL students perform similarly or better compared with students in lectures-based traditional instruction on the application of skills measures, there is still considerable variance among the studies on achievement related to the acquisition of knowledge (declarative knowledge). Moreover, even though the results of the studies that examined the effects of project-based or PBL in secondary education show positive effects of PBL on overall student academic achievement (often measured by standardized tests) compared with postsecondary education (e.g., Condliffe, Visher, Bangser, Drohojowska, & Saco, 2015; Jensen, 2015; Thomas, 2000; Wijnia, Loyens, Noordzij, Arends, & Rikers, 2017), there is still variability among these studies that concerns advocates of PBL. Thus, both the proponents and opponents of PBL continue to question its advantages over the traditional didactic lecture-based curriculum.

Researchers offer several possible explanations for these inconclusive outcome results. Some of the reasons identified include:

1) *Differences in practices or approaches that are called PBL and the way they are used in various disciplines (e.g., medicine, engineering, business, education, etc.), for different age groups (adults, young adults) and content domains* (e.g.,

Maudsley, 1999; Norman & Schmidt, 2001; Wijnia et al., 2017). Thus, lack of consistent reporting of the key features of the PBL approach in different settings, for different disciplines and age levels, makes it difficult to isolate the processes involved in PBL for comparison purposes. The majority of current research on the impact of PBL on students' learning outcomes has been in the medical field, and there is still a lack of research on the effectiveness of PBL on student learning outcomes in other areas (Gijbels, Dochy, Van den Bossche, & Segers, 2005; Hmelo-Silver, 2004; Walker & Leary, 2009). Furthermore, De Koning, Loyens, Smeets, Rikers, and Van der Molen (2012) and Jensen (2015) investigated the association of several student characteristics with achievement in a PBL bachelor's program (De Koning et al., 2012) and grades 6–12 (Jensen, 2015). The results of De Koning and his colleagues' study (2012) demonstrated that tutor or facilitator ratings of students' observed learning activities/engagement, prior educational achievements, conscientiousness, and verbal ability were consistent predictors of academic achievement in PBL. The results of Jensen's (2015) meta-analysis study also showed a larger PBL effect on achievement for middle schools and mathematics and sciences courses. Thus, the execution of the process of learning (particularly scaffolding and guiding) in PBL is influenced by the discipline, content domain, student age, prior knowledge of the topic, and ability to self-direct one's learning process.

2) *Ambiguity in the conceptualization of learning, and how learning outcomes are defined and measured and in many cases, lack of theoretical frameworks for the variables and constructs being assessed given various practices of PBL* (e.g., Belland, French, & Ertmer, 2009; Strobel & van Barneveld, 2009; Wijnia et al., 2017). Meta-analysis reports suggest that researchers often do not define the constructs under examination in their studies. In a meta-analysis conducted by Belland et al. (2009) focusing on how the target outcomes of deep content learning, problem-solving ability, and self-directed learning were measured, very few studies provided a theoretical framework for defining the targeted desired outcomes of PBL (e.g., increased self-directed learning, deep content learning, and increased problem-solving ability). They concluded that, without a clear explanation of the theoretical frameworks that authors use to explain and predict the target outcomes, it is hard to evaluate the validity of test scores to support evidence of PBL effectiveness on learning outcomes. Furthermore, depending on how learning outcomes are defined in each study, a variety of assessment measures have been used, which makes it difficult to synthesize the research results. Inconsistent results may also arise because some measures used are either not reported properly, or are not valid or reliable for assessing problem-solving skills (Belland et al., 2009; Strobel & van Barneveld, 2009). For instance, when factual knowledge or short-term learning have been assessed using standardized tests, PBL was not as effective as when other kinds of long-term and application-based outcomes have been assessed. Also, meta-analysis studies show that, while measures of learning related to factual and application of knowledge are critical to determining outcomes related to content learning, they do not measure the increases in students' problem-solving abilities directly, especially if the goal

of PBL is to improve students' problem-solving skills. As Belland et al. (2009) observed, finding or creating high-quality assessments that are aligned and valid for the specific content, context, and learning objectives of PBL studies is needed to show the effectiveness of PBL.

3) *Variability in the implementation process across various PBL practices.* PBL suggests a very different learning experience than that of a traditional classroom. For example, in PBL, students work in small collaborative groups to learn what they need to know to solve a problem. The teacher acts as a facilitator to guide student learning through the problem-solving process (e.g., identifying or analyzing the problem, identifying relevant facts, generating hypotheses, engaging in self-directed learning to acquire new knowledge, applying knowledge, exploring the solution, and looking back to evaluate the solution) (Hmelo-Silver, 2004). Hence, the differences in how teachers across classrooms implement these and other PBL activities may be another factor that contributes to the varied results in student outcomes documented in the literature (e.g., Ertmer, 2005; Kolodner, Hmelo, & Narayanan, 2003b; Savery, 2006).
4) *Variability in the types of problems used to engage students in the problem-solving process (Walker & Leary, 2009) and the quality of problems* (e.g., Sockalingam, Rotgans, & Schmidt, 2011). According to Jonassen (2000), problems are varied regarding their structure, open-endedness, and abstractness. In other words, at one extreme a problem might be ill-structured where context is crucial, solutions may not even exist, and evaluation is more about the evidence and chain of reasoning employed than the solution itself. At the other extreme, a problem might be highly structured with a focus on accurate and efficient paths to an optimal solution where context is a secondary concern (Walker & Leary, 2009). On the basis of their meta-analysis study, Walker and Leary (2009) conclude that it is very likely that there is a relationship between PBL outcomes and problem type, but we simply do not have enough data to show this relationship. Furthermore, some researchers argue that problem quality also impacts student understanding of a topic. Sockalingam and her colleagues (2011) investigated two characteristics of a quality problem: "problem clarity" (defined as whether the problem statement is clear to the learners) and "problem familiarity" (defined as whether the learner can relate to the problem) in the process of learning: group discussion, identification of goals, and self-study (p. 123). They concluded that a clearly formulated problem is the most significant aspect of high-quality problems in PBL and could result in deeper understanding of the topic.

Thus, a careful analysis of the key characteristics and variables that may contribute to a lack of consensus on the effectiveness of PBL can shed some light. Furthermore, an exploration of the characteristics of the context, learners, design specifications, implementation process, and assessment or measurement strategies, instruments, and procedures associated with differences in effectiveness of PBL (U.S. Department of Education, Office of Planning, Evaluation, and Policy Development, 2010) could guide researchers in the design of their studies and provide guidelines for evaluation of the effectiveness of PBL and other similar approaches on learning outcomes.

Contemporary PBL Practices and Approaches: An Overview

The term *problem-based learning* (PBL) refers to what Barrows (1996) defined as an instructional method in which problems are the core instructional materials and serve to initiate the learning process. Problems typically are descriptions of the real-life situation that students are required to solve (Barrows & Tamblyn, 1980). To solve the problems, students work in their groups to: (a) discuss and analyze the problem, (b) generate learning goals that require further exploration, (c) use the learning goals to guide them in their self-directed learning activities and gathering more information about the problem, and (d) return to their groups to share and compile information gathered and find the best possible solution. Critical to the success of the PBL approach is the selection of ill-structured problems (often interdisciplinary) and a tutor or facilitator who guides the learning process and conducts a thorough debriefing at the conclusion of the learning experience (Savery, 2006).

Project-Based Learning (PjBL)

PBL represents an important development in higher education practice, particularly, medical and health education and continues to have a major impact across subjects and disciplines (e.g., business, social sciences, computing, mathematics, economics, arts, dentistry, law, and architecture) in higher education. However, *project-based learning* (PjBL) has evolved in K–12 and engineering education (see Condliffe et al., 2015; Harmer & Stokes, 2014) as a method of instruction that addresses core content through rigorous, relevant, hands-on learning in which the *product* is a *project* or a real-world task rather than a problem solution (Bell, 2010; Kolmos & de Graaff, 2007; Hanney & Savin-Baden, 2013; Thomas, 2000). Whereas some conceptualize PjBL as a broader concept composed of several problems that students will need to solve (Barron et al., 1998; Blumenfeld et al., 1991; Hanney & Savin-Baden, 2013), others argue that "the project is carried out in response to and centered on a real-world problem" (Lehmann, Christensen, Du, & Thrane, 2008, p. 284). Hanney and Savin-Baden (2013) contend that placing the problem at the center of the project emphasizes the open-ended and creative nature of inquiry and eliminates the rigid project management protocols focused on achieving an end product. Whether the problem or the project is at the center of the PjBL activities, like PBL, PjBL provides challenging and motivating contextualized, authentic experiences necessary for students to scaffold learning and build meaningfully powerful concepts (often within the fields of science, technology, engineering, and mathematics—STEM) (Capraro, Capraro, & Morgan, 2013). Although problems and projects do not require convergent solutions, students are required to explain their solutions and to be able to justify the suitability of a proposed solution to the specifications of the problem.

Learning by Design (LBD)

First coined by Kolodner and her colleagues (2003a), *Learning by Design* (LBD) has been used to promote science learning primarily in K–12 education. It is defined as "a project-based inquiry approach to science learning with its roots in *case-based reasoning* (CBR) and problem-based learning" (Kolodner et al., 2003a, p. 495). It is argued that to promote science learning students should engage in the kinds of reasoning that is suggested by CBR. However, although CBR offers the kinds of experiences and reasoning students should do to learn deeply, PBL is also needed to promote learning of content and practices at the same time (Kolodner, 1993; Schank, 1982, 1999). Thus, LBD proposes a merger of CBR and PBL in its approach.

The term CBR has been referred to as "reasoning based on previous experience" (Kolodner et al., 2003a, p. 501). In CBR, students use the lessons that they have learned or solutions they have used in previous situations (cases or problems) to understand the new situation or to solve the new problem in light of similar situations (Kolodner, 1993). The basic premise of CBR is to help students reason using specific and the most cohesive applicable knowledge available. It uses cognitive processes of learning and the role that memory plays when solving problems as its foundations. Proponents of CBR argue that the ways previous experiences are stored and indexed in memory impact how they are recalled, analyzed, and used for the new experiences. Thus, in CBR indexing new knowledge and experiences with old experiences is important and makes the knowledge more accessible and generalizable (Eshach & Bitterman, 2003). When applying CBR, students are provided with a situation or a case that records knowledge at an operational level and represents specific knowledge tied to a context from which the previous cases can be retrieved. Cases may cover large or small time slices, associating solutions with problems, outcomes with situations, or both (Kolodner, 1993). The students will then use their current goals to interpret the new situation and identify at least some of the lessons learned from previous cases that might be used most productively in the new situations. When recalling the past experiences, students use the current understanding of the new situation to look for cases that are similar to the new one to create an equivalent solution to a new problem (Kolodner et al., 2003a). Thus, students' willingness and ability to interpret the new situation determines the quality of recall and retrieval. CBR gives failure a central role in promoting learning. During reasoning and when students' expectations fail, it informs the learner that his/her knowledge or reasoning is inadequate and thus there is a need to learn. Feedback then becomes a critical factor in the process of learning from the failure.

While LBD suggests a particular process for implementation, Kolodner and her colleagues (2003a) incorporate PBL and its principles in LBD. For example, using PBL, they ask students to solve problems and then reflect on what they have learned. LBD also makes suggestions about the problem-solving process and recommends that learning from experience requires assessing what lessons an experience teaches and predicting and identifying the conditions under which those lessons might be applied. In addition, LBD emphasizes the importance of feedback on decisions made in order to identify the gaps in one's knowledge.

Inquiry-Based Learning (IBL)

As a method that was largely used in science teaching, *inquiry-based learning* (IBL) refers to acquiring knowledge from direct observations by using deductive questions. Therefore, IBL learning activities start with questions based on real-world observations (the art of questioning or the art of raising questions by the facilitator/teacher is the key element). The open-endedness of the questions engages learners in the discussions and explanations based on evidence, which further allows students to generate new open-ended questions (Blumenfeld et al., 1991; Linn, Songer, & Eylon, 1996). For IBL, students use very basic prior knowledge and skills as the knowledge is constructed by students while carrying out observations and experiments. Thus, the IBL process starts with questions based on real-world observations. The characteristics of the questions allow for and conclude with discussion(s) and explanation(s) based on evidence (Cuevas, Lee, Hart, & Deaktor, 2005). The questions used in IBL have single-step answers based on observation(s) and allow for generating new open-ended questions, as the process is driven by questions generated by learners (Blumenfeld et al., 1991; Linn et al., 1996). However, most of the driving questions are often created by the teacher to guide and direct inquiry. The teacher-generated questioning process and proper use of students' prior knowledge and skills suggest specific and different roles for teachers and students (Oğuz-ünver & Arabacioğlu, 2011). The teachers' roles change from the leader (to stimulate motivation and engagement, establish inquiry and experimentation) to facilitator (to guide the inquiry, ask good questions and assist in constructing new knowledge) or coach (to scaffold students' action and exploration). Students' roles will be predicting, explaining, hypothesizing, designing, and directing their own tasks (Oğuz-ünver & Arabacioğlu, 2011). Students also are guided to ask and refine questions, plan, design, and conduct experiments, answer their questions/ideas, share ideas, and make sense of data. Hence, the outcomes of learning in IBL are the acquisition of scientific literacy, vocabulary knowledge, conceptual understanding, attitudes toward science (Anderson, 2002; Minner, Levy, & Century, 2010), critical thinking (Anderson, 2002; Panasan & Nuangchalerm, 2010), science process skills, cognitive achievement (Anderson, 2002; Lawson, 2010; Panasan & Nuangchalerm, 2010), content learning (Minner et al., 2010), as well as discipline-specific reasoning skills and practices (Hmelo-Silver, Duncan, & Chinn, 2007). Although IBL is appropriate for many fields, it is primarily used for teaching sciences at the elementary level.

Design Thinking (DT)

The emergence of the concept of *design* as a recognizable field of inquiry or research (Buchanan, 1992; McKim, 1973; Rittel & Webber, 1973; Simon, 1969) has led to the evolution of *design thinking* (DT) (Brown, 2009; Kimbell, 2011; Martin, 2009). Since its inception, DT has developed its reach and relevance from product innovation into a range of nondesign disciplinary spaces to develop and promote creativity and innovation in problem solving through the use of the iterative, exploratory, and sometimes chaotic process. Thus, DT has been used in conjunction with or as a parallel approach with PBL and is taught and promoted as part of science, business, and engineering education in higher education (Mills & Treagust, 2003). More specifically, DT is defined as a process for problem solving in which designers perform in a systems context, making decisions as they proceed, often working collaboratively with teams in a social process and communicating in several languages of design (Dym, Agogino, Eris, Frey, & Leifer, 2005). Within the process used for DT, problems can be identified and framed, the right questions can be asked, more creative ideas can be built, and the best answers can be chosen. Furthermore, the DT process is similar to PjBL and IBL in which the designer begins with the identification of an ill-defined problem or situation (problem-finding phase) followed by stating or asking questions and forming a hypothesis and then, via a feedback mechanism, continues iteratively to form a model or theory. The difference between PBL and DT is perhaps in the problem identification phase. While PBL or PjBL begins with an identified ill-structured problem or project, in DT significant time and energy are dedicated to the problem-finding phase (Beckman & Barry, 2007). A primary difference between IBL and DT is that the feedback in the scientific inquiry is mostly observational evidence on observable/measurable facts, whereas in DT feedback often is provided by the consumer needs of a product to be formed. As observed by Dym et al. (2005), design problems reflect the fact that the designer has a client (or customer) who, in turn, has in mind a set of users (or consumers) for whose benefit the designed artifact is developed. In sum, the generative and iterative process of DT for nondesign disciplines could complement existing PBL approaches or be used as a standalone approach and provide inspiration for change and innovation, which is the strength of DT. DT could also be thought of a potential form of teacher scaffolding for encouraging students to engage in PBL, PjBL, LBD, and IBL approaches.

Contemporary PBL Approaches and Their Impacts on Learning Outcomes

Tables 5.1–5.4 provide a review of the characteristics of PBL and similar contemporary approaches of PjBL, LBD, IBL, and DT, followed by a discussion of their respective impacts on the achievement of learning outcomes.

The Impact of Different Settings, Disciplines and Age Levels

Table 5.1 shows that PBL and similar approaches are used with multiple age groups. However, PBL and DT are widely implemented in higher education, whereas PjBL, LBD, and IBL are typically applied in K–12 settings. Furthermore, in terms of discipline, currently, PBL is practiced in various discipline areas including medical fields, while PjBL and DT are primarily practiced in engineering, business, and architecture programs. In K–12 settings, PBL, PjBL, LBD, and IBL are mostly associated with teaching STEM subject areas, particularly sciences.

Table 5.1 The Comparison Between PBL and Its Analogous Approaches Regarding the Settings, Discipline Areas, and Age Groups

	PBL	PjBL	LBD	IBL	DT
Context	• Higher education • K–12 mathematics & sciences	• K–12 education • Higher education	• K–12 education • Higher education	• K–12 education	• Higher education
Discipline areas	• Medical and health education • Business • Social sciences, Computing, Mathematics, Economics, Arts, Dentistry, Law, and Architecture	• K–12: primarily science, technology, engineering, & mathematics (STEM) • Higher education: primarily engineering	• K–12: primarily science, technology, engineering, and mathematics (STEM) • Business and economics • Teacher education	• K–12: primarily sciences	• Higher education: engineering & architecture education
Age Group	All age groups (children, young adults, and adults)	All age groups (children, young adults, and adults)	All age groups (children, young adults, and adults)	Elementary grade age group	Adults

PBL, problem-based learning; PjBL, project-based learning; LBD, Learning by Design; initiative-based learning, IBL; DT, design thinking.

As noted earlier, the question to consider is how and in what ways does the practice of PBL approaches in different settings, disciplines, and with various age groups affect achievement of learning outcomes? PBL scholars and meta-analysis studies remind us that, due to practical issues, the ways PBL, PjBL, LBD, or IBL are implemented in the K–12 settings are different from those applied in higher education or professional schools (e.g., Condliffe et al., 2015; Jensen, 2015; Kolodner, 1993; Kolodner et al., 2003a). Contextual factors such as limited time and skills for planning and broader curriculum focus (often mandated), lack of human resources (in K–12 often one teacher works with a group of 20–35 students), lack of teachers' skills in facilitating inquiry or problem solving, as well as in developing a collaborative culture in their classrooms and providing an iterative process, have an impact on the achievement of learning outcomes. Often these contextual factors in K–12 settings result in using externally developed PBL curricula with a more prescribed implementation process, which, in turn, influence addressing student needs, group dynamics, and teacher scaffolding or guidance, and consequently, student acquisition of knowledge and skills. Furthermore, in higher education, PBL and similar approaches are often used for professional education (e.g., medical, engineering, or business schools) where students are mature and solving problems could be the entire curriculum. However, this is not the case in elementary, middle, and secondary education settings, where students are less mature, and a broad range of goals and curricular materials must be covered (Mirabile, 2013). Moreover, PBL and similar approaches are characterized by ill-structured tasks or problems and self-directed learning process. The success of the problem-solving process, however, depends on the complexity of the ill-structured problem and whether there is a balance between problem difficulty and students' abilities. Hence, to create a balance, it is critical that when students encounter a challenging problem, the teacher or facilitator supports students in the form of scaffolding and guidance to enhance understanding of the concepts and to maintain student autonomy, interest, and self-determination in solving the problem. Designing scaffolds (teacher, peers, and technology) that are flexible and adjusted to students' different levels of background knowledge, learning skills, and motivation, therefore, is necessary to achieve and promote learning outcomes. Researchers note that in contrast to students in professional education when encountering ill-structured problems, K–12 students do not have the prerequisite knowledge, and they lack the motivation and self-directed skills to face the challenges presented by the problem. Thus, the characteristics of the age group require changes in the research questions, the design of the PBL process, data collection and analysis plans, which, in turn, influence learning outcomes. In sum, in higher education, despite widespread application of PBL and similar approaches in diverse settings, disciplines, and age groups, still more research studies are conducted in medical fields. In K–12 education, on the other hand, the studies are mainly implemented in science courses. Consequently, there is a lack of evidence on how these factors influence the effectiveness of PBL approaches in various settings, disciplines, and age groups. Therefore, researchers conducting PBL approaches must take into account these contextual factors and their impacts on the targeted learning outcomes.

The Impact of Core Principles and Features, and Role of Teacher and Students

Table 5.2 compares the basic principles and features, as well as the roles of the teacher and students, across PBL and related approaches. As Table 5.2 shows, PBL, PjBL, LBD, IBL, and DT share some core principles and features and assume similar roles for the teacher or facilitator and students. The following shared principles and features of the PBL approaches have also been noted widely in the literature (e.g., Dochy et al., 2003; Wijnia et al., 2017).

- The authentic, real-world, ill-structured problem or task is central to the practice of PBL, and other similar approaches across the disciplines, settings, and age groups.
- The students' active role in identifying their learning needs and directing their own learning process is essential in all PBL approaches.
- The teacher acts as a facilitator, guide, or tutor in the learning process in all PBL approaches.
- Students work together in collaborative groups, sharing their expertise, experience, ideas, and time in all PBL approaches.

Despite the above-listed commonalities across various forms of PBL approaches, some notable differences could impact learning outcomes and the measures of their achievement.

Forms and presentation of the problem

PBL emphasizes formulating an ill-structured *problem* in which students will have to analyze to identify their knowledge gaps. In other words, when faced with a problem, PBL students are not expected to have prior knowledge of the content, but they are expected to identify and acquire the missing knowledge (Barrows, 2002; Hmelo-Silver & Barrows, 2006). PjBL, in its more comparable form with PBL, as well as DT, on the other hand, are organized around a real-world, complex *task* or *product*, which often takes a longer time to complete, requires solving multiple ill-structured problems that are merged in a task, and demands an iterative process for the development of the project or product. Furthermore, in PjBL and DT students should have some choice of the topic as well as the nature and extent of the content to apply to the project (Kolmos, 1996). In LBD, conversely, the focus is more on formulating a real-world case or scenario that archives knowledge at an operational level, representing specific knowledge tied to a context or situation (Kolodner, 1993). The case should require students to reason from old situations that are relevant to a new one in order to interpret a new situation or to create an equivalent solution to a new problem. Therefore, in LBD the assumption is that the new case or problem has a resemblance to a case or problem that students have encountered previously, making it possible to recall prior experiences and "adapt old solutions to meet new demands, using old cases to explain new situations, and using old cases to critique new solutions" (Eshach & Bitterman, 2003, p. 493). Finally, in IBL, although students are expected to engage in an investigation in response to a direct observation of a problem (a driving question), the focus is directed toward

Table 5.2 The Core Features of PBL and Its Analogous Approaches of PjBL, *LBD*, *IBL*, and *DT That Are Impacting Learning Outcomes*

	PBL	**PjBL**	**LBD**	**IBL**	**DT**
Core features	• Focuses on authentic, challenging, and real-world problems • The problem is ill-structured and has multiple solutions (often interdisciplinary) • Students work in their groups to solve the problems • A tutor or facilitator guides student groups Barrows (2002)	• The *product* is a *project* or a real-world task within their natural settings • The project/product is carried out in response to and centered on a real-world problem • Projects are student driven to some significant degree • The project/product provides challenging and motivating contextualized, authentic experiences Thomas (2000)	• Focuses on cases or problems to solve considering similar previous situations • Emphasizes reasoning using specific and most cohesive applicable knowledge available based on previous experience • Defines lack of knowledge during failure to reason • Gives iterative refinement a central role • Stresses the importance of feedback Kolodner et al. (2003a)	• The key principle is acquiring knowledge from direct observations by using deductive questions • The art of questioning by the facilitator is the key element • Questions generate discussions and explanations and further questions by learners • Most of the driving questions are created by the teacher to organize and direct inquiry Minner et al. (2010).	• Is a process for problem solving in which designers perform in a systems context, making decisions as they proceed • The design ideas are generated, and hypotheses are formed as a result of asking questions • Through continuous feedback (from the consumer) and an iterative process forms a model or theory to anticipate the unintended consequences Brown, 2009; Kimbell, 2011; Martin, 2009

Role of the teacher	The teacher acts as a facilitator and tutor, asking students the kinds of metacognitive questions he or she wants students to ask themselves	The teacher facilitates and scaffolds the learning process by increasing students' scientific conception, guiding and controlling student collaboration throughout the process of developing products by using forms and rubrics	The teacher is the modeler, coach, and articulator of the process, gradually having students take over these roles. Coaches are trained to help students manage the complexity of problems. The teacher provides design prompts while students are working in small groups. The teacher balances time between investigation and iterative design	The teacher starts the inquiry process and guides the discussion. The right use of students' prior knowledge and skills burden teachers' different roles (leader, coach, and facilitator) Most of the questions (driving questions) created by the teacher to organize and direct the inquiry	The teacher starts by asking questions and guiding students to define the problem and a series of objectives for a designed artifact. Throughout the process, the teacher acts as a facilitator and guide
Role of the student	Students are responsible for determining whether a problem exists, creating an exact statement of the problem and a working plan, identifying information, data, and learning goals, and finally producing a tangible solution Students work in collaborative teams	Students could have the opportunity to design their own products in the classroom Students work collectively, and they never let group mates stay passive	Students work together in collaborative groups, pooling their expertise, experience, ideas, and time Students build on each other's strengths. Working in groups also promotes learning how to articulate andjustify	Students' roles are predicting, explaining, hypothesizing, designing, and directing their tasks. They are also encouraged to ask and refine questions, plan, and design how to answer their ideas, share ideas, make sense of data, and design and conduct experimental work	Students are required to expand the boundaries of the design to include such factors as environmental and social impacts in their designed systems Since the design is a social process in which teams define and negotiate decisions students work in teams

PBL, problem-based learning; PjBL, project-based learning; LBD, Learning by Design; initiative-based learning, IBL; DT, design thinking.

students' abilities to use a deductive questioning approach to conducting an inquiry. As mentioned earlier, contrary to LBD, an open-ended driving question in IBL requires very basic prior knowledge and skills as the knowledge is constructed by students while carrying out observations and experiments. Hence, depending on the PBL approach, the problem forms and presentations, along with the students' recall of prior knowledge will differ and thereby affect the implementation of the process and identification of the targeted learning outcomes and their achievement.

The degree of student autonomy and the level and quality of scaffolding

All PBL approaches assume an active role for the students and a facilitator role for the teacher. However, there exist some differences in the degree of autonomy, choice, and authority for students and the amount and quality of scaffolding required of the facilitator to tailor his or her guidance to the students' current level of understanding (not too much assistance and not too little). As indicated earlier, the contextual factors (e.g., setting, content, age group, time) effect changes in the design of the PBL process and the degree of the facilitator's support during various phases of PBL. For example, while in PBL students design their own driving questions during their small-group discussion and later direct their own self-study, in PjBL, particularly in K–12 settings, teachers and curriculum developers design the driving question and engage students often in a large-group discussion. Furthermore, when PBL is implemented in professional schools, a trained tutor is assigned to a small group of five or six students to provide support during problem-analysis and problem-solution phases. However, when PjBL or IBL or LBD is implemented in K–12 settings, because of a lack of human resource (trained tutors), one teacher often supports both large and small groups of students during the guided inquiry and product creation process, which results in depending more on providing hard scaffolds (static supports through technology and other resources) instead of offering soft scaffolds (dynamic, learner, and situation-specific guidance) (Brush & Saye, 2002) that are adjusted to students' prior knowledge, skills, interest, and self-determination. Thus, whereas the core principles of the learner-directed and teacher-facilitated learning process are shared among all PBL pedagogies, the variation in student choice and autonomy and differences in forms and quality of scaffolding directly impact achievement of learning outcomes.

The Impact of Implementation Process

Table 5.3 summarizes the implementation process across different PBL approaches. The following implementation phases are shared between PBL and related approaches.

- Phase I: Problem presentation and exploration.
- Phase II: Problem analysis and identification of the learning issues (knowledge gaps).
- Phase III: Information gathering or conducting an inquiry.
- Phase IV: Group discussion of applying acquired knowledge in solving the problem.
- Phase V: Reflection on the process and the solution using feedback and identification of revisions.

Table 5.3 The Differences and Similarities in the Implementation Process of PBL and Its Analogous Approaches That Are Impacting Learning Outcomes

	PBL	PjBL	LBD	IBL	DT
Process	• Students work in their groups to discuss and analyze the problem • Groups generate learning goals that require further exploration • Individual students use the learning goals to conduct a self-study and gather more information about the problem • Individual students return to their groups to share and compile information gathered and find the best possible solution	• Starts with high-quality driving questions (feasible, worthwhile, contextualized, meaningful, and ethical) • The project targets significant learning goals (important content standards, concepts, and in-depth understanding that are fundamental to school subject areas) • Positions the project within the broader curriculum • Occurs over an extended period of time	• Students work in large group (whole class) to discuss learning issues related to design challenges • Students work in small groups to work on the problem (e.g., investigation) • Student groups stay on task and not fall behind as the teacher brings the class together as a group each time they need to prepare for a new activity and after investigations • During whole-class time, students present to each other, the teacher help student see similarities across what the different groups were doing • The teacher provides presentation and reflection time	• Lesson starts with orienting and asking questions based on real observations • The characteristics of the questions allow concluding with the discussions and evidence-based explanations • The questions have single-step answers on observations and allow generating new open-ended questions, and the process is driven by questions and ideas generated by the learners • The process of forming ideas is followed by planning, investigation, interpretation, conclusions, and evaluation	• Asking questions and understanding the problem emerges as a beginning step • The client or the teacher defines a series of objectives for a designed artifact • They brainstorm with first thinking about systems dynamics to anticipate the unintended consequences • A prototype (a model with incomplete information and ambiguous objectives is designed • Influential variables are defined before experiments/tests are conducted • Feedback from consumers and the test are received to update understanding and revise the prototype • The project is presented

PBL, problem-based learning; PjBL, project-based learning; LBD, Learning by Design; initiative-based learning, IBL; DT, design thinking.

However, despite the above core implementation features, as shown in Table 5.3, PBL approaches exhibit differences regarding the following areas that could impact learning outcomes:

1) As indicated earlier, how is the problem identified or presented, is students' recall of prior knowledge needed, and how does such recall of prior knowledge influence the process of problem analysis?
2) Who sets the goals or content learning outcomes and develops driving questions?
3) When are the collaborative groups formed and how do students interact in their groups during the problem analysis and reporting phases of the PBL process?
4) What happens during the processes of problem analysis and self-directed study, and how much time is spent on individual study?
5) Who guides students' inquiry or investigation (the teacher or a trained tutor or computer software), and how does the expert facilitator use open-ended metacognitive questions to facilitate students' discussion?
6) Who monitors students' progress and provides feedback (the teacher or the trained tutor or the user), or how is students' progress monitored and when and how is feedback communicated with students?
7) How often do reflection and adjustments occur throughout the process?

Responses to these questions are often varied depending on the type of PBL approaches and how they are implemented. Therefore, it is important that the researchers define the type of PBL approach and provide documentation of the implementation processes before reporting the outcomes.

How Learning Outcomes Are Defined Across Various PBL Approaches

Table 5.4 summarizes the learning outcomes across different PBL approaches, given their essential features and processes. As Table 5.4 shows, despite slight variation in learning outcomes across PBL approaches, the following types of content knowledge, cognitive, metacognitive, and affective learning outcomes can be identified.

1) Acquisition of content or domain-specific knowledge (facts, concepts, and principles) that can be recalled or retrieved and is structured in interrelated networks of concepts. This outcome is referred to as factual and conceptual knowledge (domain of declarative and conceptual knowledge).
2) Application of content- or domain-specific knowledge or ability to link concepts and principles to conditions and procedures to facilitate their use in unfamiliar situations (also referred to as clinical skills).
3) Acquisition of problem-solving skills or ability to set goals, select strategies, evaluate, or reflect on goals and problem-solving strategies. Listed as twenty-first-century skills, these cognitive skills are also defined as self-regulation or self-learning skills (may also be called intrapersonal skills; National Research Council, 2012) or one's ability to willingly (desire to engage in self-regulation) acquire new knowledge and skills needed to attain the set goals and monitor feedback concerning achievement of the goals. Self-regulation, therefore, demands self-motivation (control of one's attention and emotion) and self-monitoring (cognitive control or metacognition—knowing about knowing).

Table 5.4 The Differences and Similarities in *Targeted Goals or Learning Outcomes* of PBL and Its Analogous Approaches

	PBL	PjBL	LBD	IBL	DT
Outcomes	• Factual knowledge • Application knowledge (understanding the concepts, the principles that link with concepts and link between concepts and principles) • Problem-solving and metacognitive skills (self-learning skills) • Motivation • Critical thinking and communication skills • Collaborative skills	• Knowledge (defined as learning and remembering) • Applying knowledge to new circumstances • Skills of asking questions, formulating problems, developing solutions, assessing self and peers, collecting data according to assessment results, analyzing them, and reaching results • Increasing desire to learn or attitude toward learning	• Learning content knowledge • Reasoning and social skills while learning content • Apply both content and skills in new situations • Inquiry skills in the context of solving real-world problems or addressing big questions that experts might focus on • Skills of asking important questions, carrying out investigations, interpreting data, and applying what learned	• Knowledge of scientific literacy, vocabulary knowledge, conceptual understanding • knowledge and understanding of scientific ideas as well as how scientists study the natural world • Attitudes toward science • Critical thinking and discipline-specific reasoning skills and practices	• Knowledge that can be used in professional settings • Application of design thinking skills • Ability to reason about knowledge • Ability to make decisions throughout the design process • Applying the design thinking methods and the process to become critically aware of what it is doing, how well it is doing it, and how to evaluate what is doing

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These skills are considered as both cognitive and metacognitive skills (domain-specific and domain-general knowledge).

4) Improvement of motivation and desire for learning, classified as an attitude or affective domain.
5) Enhancement of social and communication skills, categorized as interpersonal skills. As opposed to intrapersonal skills (self-talk to regulate thinking), interpersonal skills underline learners' ability to communicate ideas, thoughts, and feelings when interacting with others.
6) Development of critical thinking and discipline-specific reasoning skills and practices. Often listed as a distinct domain-specific thinking skills outcome of PBL approaches, critical thinking is defined as the evaluative process that assists learners in selecting the best solution for the real-world problem. It is described as an awareness of one's own thinking (self-reflection) and the ability (skills) and willingness (disposition) to clarify and improve understanding (self-monitoring) of the problem. The awareness, ability, and willingness aid the learner in drawing appropriate conclusions and making the best decisions possible within a context (knowledge base) (Weissinger, 2003).

The above domains and types of learning outcomes, therefore, define the effectiveness of PBL approaches. In other words, as conceptualized by Sugrue (1995), successful problem solving results from the interaction of the domains of knowledge structure, cognitive and metacognitive functions, and motivation, each with specific variables. Figure 5.1 uses the above list of learning outcomes, the

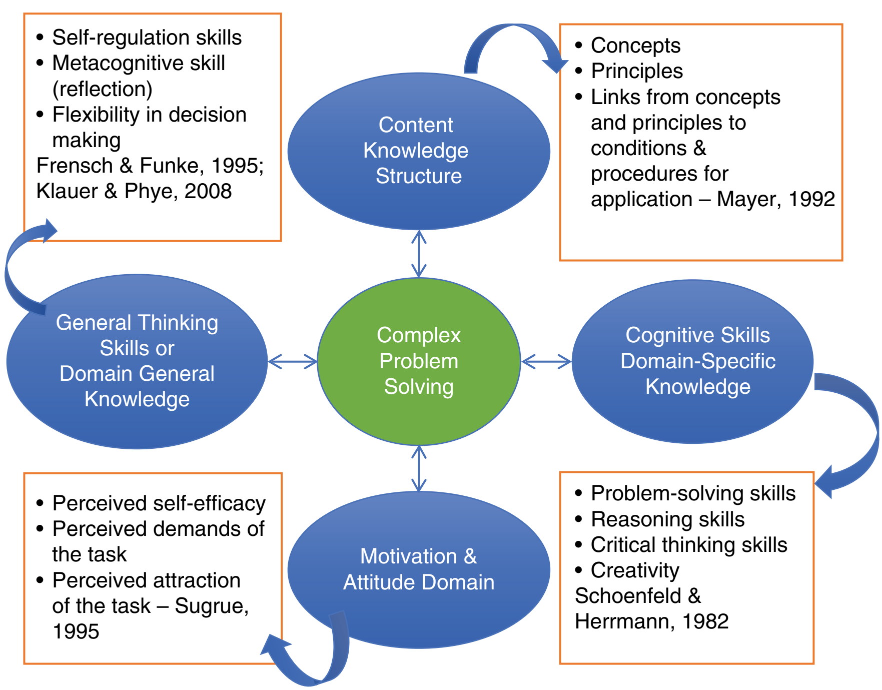

Figure 5.1 Components of PBL Learning Outcomes.

literature on complex problem solving (e.g., Mayer, 1992; Sternberg, 1994), and Sugrue's (1995) conceptualization of PBL domains to provide a framework for domains of outcomes and specific variables within each domain. The figure emphasizes that complex (ill-structured) problem solving requires skills closely related to domain-specific knowledge (knowledge structure) and problem-solving strategies (embedded in the content) (Mayer, 1992) as well as general thinking skills (domain-general knowledge) applicable in a variety of contexts (Sternberg, 1994) and motivation to learn.

Outcomes Versus Process of Learning

It should be noted that although each category or domain of learning and its specific variable shown in Figure 5.1 is measured as a learning outcome and often by an instrument (e.g., a test, self-report questionnaire or survey), the PBL processes should also be monitored and tracked throughout the implementation. In other words, to assess the effectiveness of PBL, it is not enough to measure just the outcomes. The input variables or the processes and mechanism(s) where PBL achieves its effectiveness are also important to predict students' learning outcomes. The input factors that directly impact learning outcomes include:

- PBL implementation process (e.g., how PBL phases are implemented; how much group discussion occurs during initial problem analysis; what students do during self-study).
- The problem analysis and related learning activities (e.g., how prior knowledge is activated during problem analysis; how engaged students are during problem analysis, self-study, and group report; how verbalizations occur throughout the PBL process).
- The role of the tutor or teacher (e.g., how teacher beliefs and perception of students and themselves impact the PBL learning process; how prepared the teacher/tutor is to facilitate student inquiry/investigation; how capable the teacher is of creating a coherent curriculum [particularly in K–12 settings]).
- Problem representation or the nature of the question (e.g., what is the nature and type of the problem—well versus ill-structured problems; routine versus nonroutine problems; well versus ill-defined problems).

How Learning Outcomes Are Measured Across Various PBL Approaches

As discussed earlier, to assess the effectiveness of PBL approaches in comparison with traditional, lecture-based methods, a broad range of learning outcomes must be targeted and measured in conjunction with monitoring and tracking learning processes. However, according to the results of the meta-analysis studies (e.g., Albanese & Mitchell, 1993; Berkson, 1993; Colliver, 2000; Condliffe et al., 2015; Gijbels et al., 2005; Jensen, 2015; Smits, Verbeek, & De Buisonje, 2002; Thomas, 2000; Vernon & Blake, 1993), not all of these outcomes are targeted and measured in studies comparing effectiveness of PBL approaches with traditional, lecture-based instructional methods. Furthermore, except for some naturalistic descriptive studies on the process of PBL (e.g., Dolmans, Schmidt, & Gijselaers, 1995; Hmelo-Silver & Barrows, 2008; Visschers-Pleijers, Dolmans, DeLong,

Table 5.5 Summary of the Learning Outcomes and Instruments Used to Measure Them According to Meta-Analysis Studies

Targeted learning outcomes	Assessment/measurement
Content knowledge domain Acquisition of knowledge (concepts and principles that link concepts) Application of knowledge (skill-based)	• Knowledge-based test (often standardized multiple-choice test or teacher/researcher-made multiple-choice test and in some cases concept maps • Skills-based (application) test—e.g., problem situations (essay items) • Observation with clinical ratings • Patient simulation and elaboration assessment such as essay questions or case studies • Performance assessment; complex scenario test; portfolio; simulations; products and oral examinations
Cognitive domain Thinking skills (reasoning, problem solving and critical thinking) Creativity Motivation (self-efficacy, perceived demands of the task and perceived attraction of the task)	• Novice vs. expert thinking—using rubrics with paper-and-pencil instruments for cognitive process and reasoning or problem-solving skills using thinking out loud or verbal protocols • Planning and monitoring (PBL process) • Self-report surveys and logs • Self- and peer assessment • Attrition rate and residency interest
Intrapersonal and interpersonal domain Self-regulation, metacognition, and flexibility Collaboration, communication, and leadership	• Questionnaires • Self-report surveys

Wolfhagen, & Vander Vleuten, 2006), the majority of the PBL investigators did not monitor or assess in greater detail the processes and mechanisms whereby PBL achieves its learning outcomes (Yew & Goh, 2016). Table 5.5 summarizes a list of the learning outcomes and instruments used to measure them according to the results of the meta-analysis studies.

As Table 5.5 suggests and based on the literature, it is difficult to measure the effectiveness of PBL by identifying only one or two core elements of student learning outcomes. In other words, while adopting a PBL approach is unlikely to lead to improvement in student factual knowledge, positive student attitudes, retention of knowledge for a longer period of time, and development of enhanced critical thinking and problem-solving skills are often seen. Thus, assessment of a broad range of student learning outcomes, valid and reliable assessments of deeper learning, better instruments for measurement of problem-solving competencies, such as intra- and interpersonal skills, and use of technology-based assessment (for assessing and monitoring both process and product) are needed to determine the effectiveness of PBL on student learning outcomes. Furthermore, traditional assessments such as professional standardized tests (e.g., state standardized tests in K–12) are unable to measure the full range of complex cognitive competencies. Performance-based assessments are suitable, but scalable, valid, and reliable assessments must be developed. Recently some progress has been made in the development of computer-based assessment instruments that allow for the measurement of different levels of proficiency and different facets of problem solving at a scalable level (Funke & Greiff, 2017). However, heavy reliance on self-report data to evaluate instructional innovation in PBL is still a concern. There need to be observable measures of PBL design principles established to monitor the process of complex problem solving. Finally, as assessment is mainly for teachers and researchers to collect data, there is a need for students also to be involved in the assessment process as they may also benefit from the process.

Summary of Research on Effectiveness of PBL

The results of the current research on the effectiveness of PBL regarding achievement of learning outcomes in higher education settings suggest that the effects of PBL differ according to the levels of knowledge structure being assessed (Albanese & Dast, 2014; Dagyar & Demirel, 2015; Gijbels et al., 2005; Strobel & van Barneveld, 2009; Walker & Leary, 2009). The following summarizes the findings of this research.

- The most positive effects are observed when the focal constructs being assessed are at the level of understanding the principles.
- Short-term knowledge acquisition and retention tend to favor a traditional approach, but when asked for free recall, as in remembering a topic or elaborating on a topic, the results favor PBL.
- Long-term knowledge retention tends to favor PBL.
- Performance or skill-based assessment measured by observation with clinical ratings tends to favor PBL.
- Mixed knowledge and skills assessment tends to favor PBL.
- When student assessment is close to graduation, the results show a higher positive effect size for PBL.

The results of PBL research in K–12 education are summarized in two general categories: school-based reform models and other K–12 studies (Condliffe et al., 2015; Thomas, 2000). The implementation of school-based PBL reform models shows dramatic gains in student achievement (measured by a standardized test for basic skills). It also reveals improvement in school climate and student motivation; an increase in teachers' beliefs in their ability to teach students with different abilities; and improvement in student attendance. The results of other K–12 studies suggest a positive relationship between PBL approaches and the quantity and quality of student learning. Furthermore, studies conducted specifically in mathematics and science middle and high schools show significant increases in problem-solving skills between pre- and posttest for experimental groups; equal or better performance on items that require rote knowledge; and an increase in critical thinking skills measured by the California Critical Thinking Instrument.

Recommendations for Future Researchers and Instructional Designers

This chapter analyzed and synthesized the literature on the effects that PBL practices have on various student learning outcomes including knowledge acquisition, and higher-order thinking skills. The results suggest that assessing multiple learning outcomes particularly complex problem-solving skills are difficult to measure. Learning outcomes are also influenced by many variables such as clarifying what approach is being used; in what setting and for what age groups it is used and how learning outcomes are defined and measured. The PBL researchers and designer should be cautioned that the large variation in PBL practices makes the analysis of its effectiveness more complex. The following is a list of recommendations for researchers, designers, and practitioners of PBL practices.

- Consider expanding the definition of PBL to include the analogous PBL practices.
- Define a broad range of outcomes of learning.
- Reflect on how one can conduct research if considering the dynamic and adaptable nature of the concept of PBL.
- Consider adopting a better research methodology given that PBL shows more success when implemented at the program and institutional levels.
- Ponder what it means for PBL approach when learning technology requires different forms of support for students and teachers or facilitators.

Finally, there are arguments that when instructional reforms, such as PBL, become overly prescriptive, they can hold back innovation. PBL researchers and designer, therefore, should ask themselves how these arguments affect the design of PBL research.

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6

Effects of PBL on Critical Thinking Skills

Nada Dabbagh

The Effects of PBL on Critical Thinking Skills

Problem-based learning (PBL) has been shown to foster the development and improvement of critical thinking skills such as problem solving, analytic thinking, decision making, reasoning, argumentation, interpretation, synthesis, evaluation, collaboration, communication, and self-directed learning (Abrami et al., 2015; Clark & Mayer, 2016; Dabbagh, 2002; Kumar & Refaei, 2017; Kumta, Tsang, Hung, & Cheng, 2003; Loyens, Jones, Mikkers, & van Gog, 2015; McKeachie, Pintrich, Lin, & Smith, 1987; Muller, Schafer, & Thomann, 2017; Tiwari, Iai, So, & Yuen, 2006; Wilder, 2015; Yuan, Williams, & Fan, 2008). Critical thinking skills have consistently made the cut as desirable higher education student learning outcomes when government and consumer agencies call for education reforms that will ready graduates for professional and societal responsibilities (Koh, Chai, Wong, & Hong, 2015; Markle, Brenneman, Jackson, Burrus, & Robbins, 2013). In a 2013 Educational Testing Services (ETS) report, Markle et al. identified critical thinking as one of seven key domains common to twenty-first-century skills and defined critical thinking skills as "thinking critically, solving problems, synthesizing information, and sense-making" (p. 14). Additional established descriptors of critical thinking include "the ability to think deeply about an issue, consider evidence for and against a proposition, and apply reasoning skills and logical inquiry to arrive at conclusions" (Nargundkar, Samaddar, & Mukhopadhyay, 2014, p. 92).

However, there is wide variation in the literature as to what constitutes critical thinking. For example, Markle et al. (2013) found that critical thinking, problem solving, and decision making were reported as distinct skills across seven higher education frameworks of student learning outcomes while having similar core descriptors. Specifically, critical thinking, problem solving, and decision making were identified as important features of K–16 education curricula worldwide as evidenced by the attention given to these competencies on large-scale assessments such as the National Assessment of Educational Progress (NAEP) and the

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Program for International Student Assessment (PISA). Further elaboration by Markle et al. (2013) describes critical thinking, problem solving, and decision making as “one’s ability to reason effectively, use systems thinking and evaluate evidence, solve problems, and clearly articulate the result of the inquiry and exhibit” (p. 14).

While problem solving and decision making have been coupled with critical thinking in the 2013 ETS report, problem solving has its own prominence as a key cognitive process that must be cultivated to enable individuals to be productive members of society. Jonassen (2011) argued that problem solving is the most authentic and relevant learning activity that students can engage in, and that knowledge gained in the context of problem solving is better comprehended and retained, and therefore more usable and transferrable. Jonassen (2011) defined problem solving as a process that has two critical attributes: the ability to form a mental representation or mental model of the problem and the ability to test the mental model in order to generate a solution to the problem. As such, problem solving can be described as a heuristic process requiring the ability to form a hypothesis, find and sort information, think critically about information, ask questions, and reach a viable resolution or solution to the problem. In a 2012 National Research Council (NRC) report, Pellegrino and Hilton (2012) found that *the ability to solve problems* is one of the most important twenty-first-century skills sought by employers. Further elaboration on this skill resulted in the following descriptors: problem solving, creativity, innovation, critical thinking, analysis, reasoning, argumentation, interpretation, decision making, adaptive learning, or executive function (Clark & Mayer, 2016, p. 344).

It is clear from this overview that problem solving, decision making, and critical thinking are interdependent and not mutually exclusive skills. Rather, critical thinking can be perceived as an overarching or broad set of skills that encompass several competencies including problem solving and decision making. The question then becomes: how effective is PBL in supporting critical thinking skills? And are there specific PBL processes or principles that influence critical thinking skills more than others?

PBL is a pedagogical model that engages learners in a complex problem-solving activity in which the problem drives all learning and no formal prior knowledge is assumed in the content area for which the problem is intended (Barrows & Tamblyn, 1980; Dabbagh & Bannan-Ritland, 2005). In PBL, instruction begins with a problem to be solved rather than content to be mastered (Barrows, 1985). Students are introduced to a real-world problem that is ill-structured (Jonassen, 1997) and engage in an iterative heuristic problem-solving process that supports causal reasoning, problem solving, and decision making. The PBL process typically involves working in small groups to formulate the problem space (identify what the problem is), identify learning needs, determine a plan of action, and eventually find a viable and cogent solution to the problem (Grabowski, McCarthy, & Koszalka, 1998). Tutors or teachers are assigned to each group and act as mentors and coaches facilitating the problem-solving process and providing appropriate resources and scaffolding.

Although there are numerous pedagogical models that use problems as an advance organizer for learning (e.g., situated learning, case-based learning, inquiry-based learning, goal-based learning), PBL is the most extensive and complex in "putting the problem to use." As such, PBL is defined as "the learning that results from the process of working toward the understanding or resolution of a problem" (Dabbagh, Jonassen, Yueh, & Samouilova, 2000, p. 60). The major goals of PBL are to help students develop critical thinking skills (Barrows, 1985). This chapter provides a synthesis of the research that demonstrates the effectiveness of PBL in supporting critical thinking skills in order to better understand how these skills are engendered, what skills are specifically targeted, and how these skills are measured. The chapter also provides implications for implementing PBL to ensure that students are engaged in critical thinking. These implications focus on pedagogical principles and the characteristics of ill-structured problems that frame learning in PBL and how these problems are presented.

Research on PBL and Critical Thinking Skills

Research on PBL and its effectiveness in fostering critical thinking skills spans decades and its scope encompasses multiple disciplines and contexts. The studies presented here begin with the most recent (2017) and end with a study conducted in the year 2000 representing almost two decades of research. In terms of discipline and context, these studies include using PBL in an intermediate English composition course at a 2-year college, a Master of Science (MSc) ultrasound Program in Ireland, a capstone course at a Portuguese Business University, a psychology program at a Dutch university, a required business course with third-year students at an undergraduate university, a 3-week orthopedic surgery rotation, and an introductory instructional design course in a graduate program. The breadth of these studies allows for an examination of the effects of PBL on critical thinking skills across disciplines and contexts.

Critical Thinking in English Composition Course

Kumar and Refaei (2017) investigated whether PBL in an intermediate composition course at a 2-year college supported the development of student critical thinking skills as reflected in their writings (N = 60). Using a pre- and postassessment, the researchers graded student artifacts based on an adapted rubric from Paul and Elder (2006), which focused on *six aspects of critical thinking: audience, purpose, content, support rationale, conclusion, unity, and coherence.* This adapted rubric was used to evaluate student writings before and after the course's PBL instruction. Preassessment writing samples were collected at the beginning of the course based on a traditional writing prompt assigned by the instructor to review the knowledge learned from previous coursework. Following this assignment, students were introduced to PBL and challenged to address three different problems. These included contemplating human rights and why they were important, drafting a letter to the editor about a human right they felt should be defended, and a group assignment to draft a "white paper" about how all the group's identified rights should be protected. The letter to the editor was used as the postassessment artifact since it was written by the individual students and reflected a moment in the course wherein the students had been exposed to PBL. Both pre- and postintervention artifacts were scored using the same rubric and were compared. The findings of the study revealed that PBL contributed to statistically significant improvements in students' critical thinking compared to the initial rhetorical prompt. The findings also revealed that the PBL curriculum supported the development of critical thinking skills in five out of the six categories of critical thinking measured in this study. The only category that did not demonstrate a statistically significant shift was in the writing of the conclusion. The findings indicated that students struggled to *synthesize* the overall value of their writing and its importance to the audience, suggesting that more scaffolding prompting reflective thinking or situational awareness is needed to support this aspect of critical thinking.

Critical Thinking in MSc Ultrasound Program

Stanton, Guerin, and Barrett (2017) conducted semi-structured telephone interviews with graduate students in an MSc ultrasound program based in Ireland (N = 16) to understand whether or not the PBL curriculum had an impact on how sonographers interact with their fellow colleagues and patients. The researchers were also interested in understanding whether or not the skills gained in the coursework translated to the students' real-world clinical practices. Following an inductive qualitative analysis of semi-structured telephone interviews, the researchers discovered that the PBL program supported increased *situational awareness and thinking*, and *enhanced communication practices* with both patients and colleagues, and an *increased professed proactivity* in enhancing patient care. In addition to the aforementioned changes in thinking, communication, and practitioner actions, students also described how the program encouraged new behaviors, which had contributed to their clinical practice. These new behaviors included *searching, evaluating, and synthesizing the literature, sharing knowledge with peers, explaining and listening to explanations based on the problems provided, and discussing how best to communicate with patients*. Students reported increases in *knowledge sharing, teaching, enhanced patient communication, evidence-based clinical practices*, and a continually growing interest in learning more about sonography following the program. The researchers argue the positive results in the aforementioned areas address problems stated in the 2014 Irish Health Service Executive's report regarding the most common patient complaints (e.g., communication and information failures, safe and effective care, etc.).

Critical Thinking in Capstone Business Course

Using structural equation modeling, Carvalho (2016) investigated student satisfaction and perceptions of transferable skill development following a PBL capstone course at a Portuguese Business University. Noting commonly espoused organizational complaints that students are ill-prepared for workforce roles, the course sought to pair student groups with companies in order to provide learners the opportunity to solve problems within an authentic organizational context. This study was specifically designed to measure whether or not PBL supported the development of transferable skills into real-world contexts. To measure the perceived accumulation of transferable skills, students (N = 120) were surveyed on whether or not they felt their learning experience supported the development of transferable skills in several areas to include *problem-solving skills, self-directed learning, flexible knowledge, interpersonal skills, teamwork, conflict management, and communication skills*. Other course elements evaluated in this study included teamwork, interaction with tutors, interaction with companies, and the existing assessment models. The results indicated that PBL is viewed as a satisfying and valuable pedagogical approach to effectively develop transferable skills for upcoming practitioners at a statistically significant level, primarily with regards to *information-seeking and teamwork skills* but also for *interpersonal and communication skills*. Student perceptions of the effectiveness of PBL in fostering transferrable skills were attributed to the positive interaction with the tutors, having defined teamwork rules, and the quality of the interaction with the company.

Critical Thinking in Psychology

Loyens et al. (2015) examined the extent to which PBL could support conceptual change compared to lectures and self-study groups. Conceptual change occurs when a student becomes aware of the cognitive conflict between their existing knowledge and the scientific evidence or explanation of a phenomenon they are studying resulting in restructuring their conceptual understanding of the phenomenon. More specifically, *conceptual change is a critical thinking ability in that it prompts students to become metacognitively aware of the cognitive conflict and to seek additional information to resolve the cognitive conflict* (Kowalski & Taylor, 2006). Focusing on Newtonian Laws, the researchers of this study randomly assigned 77 psychology students from a Dutch University into one of three groups that represented different instructional methods (a PBL group, a lecture-based group, and a self-study group). In the PBL group, students were placed into smaller groups with seven to nine other students and began their lesson by completing a pretest with their small group. Following the pretest, students were presented with three problem challenges. The first challenge was to maximize the length of a jump from a swing, the second involved predicting the position of a bird whose droppings landed on someone's head, and the final challenge required students to predict the path of a coyote falling off a cliff. Once the problem scenarios were presented, students were provided a text on Impetus Theory and given 20-min to review the materials. This was followed by a period of discussion and clarification among the group members and the class. Finally, the immediate posttest was administered. In the lecture-based condition students also began the class with a pretest, however this was completed individually. The pretest was followed by a 60-min lecture on Newtonian Laws and Impetus Theory. Following the lecture, each student completed the immediate posttest. In the self-study group, students were also individually tasked to complete the pretest. Following the completion of the pretest, the text on Impetus Theory was handed out. Each student was instructed to study the text for the next 60-min and encouraged to take notes. After the study period, student notes were collected and the immediate posttest was administered. All groups were then assigned a delayed posttest the following week.

Conceptual change was measured by the change in students' scores from pre- to immediate post- to delayed posttest. In a repeated measures analysis of variance (RM-ANOVA), the researchers found that students in the PBL group performed significantly better than students in the lecture and self-study groups in the immediate post- and delayed posttests. No difference was found in the results between immediate posttest results for the lecture and self-study groups. Also, while each condition experienced a drop in overall scores from the posttest to the delayed posttest, the difference in the scores was not significant for any of the groups. The findings of this study suggest that PBL is an effective pedagogical model for supporting conceptual change.

Critical Thinking in Required Business Course

Nargundkar et al. (2014) implemented a guided PBL approach to learning in a required business course for third-year students at an undergraduate university. Arguing that most required courses in the business program are characterized by low student interest, the researchers employed PBL to increase student motivation as well as support the development of critical thinking skills. Recognizing that a purely constructivist implementation of PBL might not be the right approach for their students, the researchers utilized a reverse order textbook as the intervention in the course. This textbook introduced challenges prior to any associated theories or mathematical approaches to solve the problem in order to activate prior learning, base the challenge in an authentic context, and enable exploration of potential solutions. Students were aware that the answers to the challenges were in the back of the book, however were instructed to try to solve the problems in the spaces provided before looking at the solutions. The researchers differentiated this technique from case study instructional methods by pointing out that case studies typically are for advanced students, whereas the students in this course were less versed in the topics involved in the instruction.

To measure the effectiveness of the reverse order textbook on student learning, the instructors compared departmental exam and project scores of students enrolled in the course prior to the intervention (N = 154) and following the intervention (N = 114). The results revealed a statistically significant improvement on scores for students who took the course with the guided PBL intervention. Exam scores improved by 9% overall, and scores that focused solely on critical thinking questions increased by 24%. Critical thinking in this study was defined as "the ability to solve problems, collect and analyze evidence, and use the analysis for decision making" (p. 93) and was measured using Bloom, Englehart, Furst, Hill, and Krathwohl's (1956) taxonomy. The results imply that guided PBL interventions significantly improve students' critical thinking skills. Additionally, although not empirically measured, anecdotal feedback from surveys administered in this study suggest that improvements in critical thinking skills may stem from increased student motivation and interest in the coursework.

Critical Thinking in Orthopedic Surgery Program

Kumta et al. (2003) evaluated the effectiveness of an online PBL multimedia program in supporting student development of critical thinking skills, in particular *clinical reasoning, logical thinking, analytic ability, and problem-solving ability*, during a 3-week orthopedic surgery rotation. To measure the effectiveness of the online PBL approach in supporting these critical thinking skills, the researchers compared the pre- and posttest scores of a multiple-choice exam between participants in a control and experimental condition. A ward examination (practical exam in the authentic context of the hospital) in which students were assessed for their clinical examination skills, critical thinking abilities, and context-specific factual knowledge based on curricular requirements was also administered. These examinations have been accepted as a validated measure of clinical reasoning and logical thinking ability. Students in the control condition were instructed through didactic lecture, bedside tutorials, ward attachments, and outpatient clinics as well as given supplementary materials (e.g., PowerPoint slides, lecture-based materials). Students in the experimental condition were exposed to an online PBL multimedia program. This program reflected common real-world practitioner challenges through clinical case simulations while also offering students opportunities for reflection and feedback regarding their choices. These students also met three times a week to participate in structured group conversations led by a facilitator. The web-based materials in the experimental group required students to make actionable decisions for their mock patients as well as justify their choices. Participants (N = 163) were randomly assigned into either the control or experimental condition in clusters of 15 students. The findings of this study revealed that students in the experimental condition performed significantly better on the posttest scores than students in the control group. The findings also revealed that students in the experimental condition spent significantly more time in the wards beyond bedside tutorials. The researchers concluded by saying that the PBL approach fostered clinical and critical thinking skills in medical students and allowed them to engage in complex problem-solving tasks without endangering patient safety.

Critical Thinking in Instructional Design

Dabbagh et al. (2000) examined the impact of PBL on teaching instructional design skills. The argument made is that instructional systems design (ISD) is a dynamic process of problem understanding and problem solution and therefore ISD is an ill-structured problem-solving process defined by the context of the problem, the knowledge and skills of the instructional designer, and the quality of available resources. This suggests that ISD instruction should focus more on the problem attributes and not on the generality of the systems approach model with its context-free rules. Hence, PBL was used as the pedagogical approach for a graduate level introductory ISD course at a large university in the U.S. that lasted 6 weeks. Students (N = 11) interacted with an ISD problem in two groups and worked through the PBL hypothetico-deductive reasoning process proposing problem hypotheses, identifying learning facts (what we know about the problem) and learning needs (what we need to know about the problem), developing action plans, and revisiting the problem hypothesis until a viable solution was reached. Each group had a tutor to scaffold the problem-solving process and facilitated group discussions four times a week for a period of 3 hr each time. The tutors collaborated on every issue related to the administration and the teaching of the course to ensure that the PBL pedagogy was effectively implemented and consistent across the two groups. Students were also provided with a *master action list* (Barrows, 1985). The master action list for this course contained a comprehensive set of actions and techniques that seasoned instructional designers apply to instructional design problems.

Using the case study research method, the researchers examined 6 weekly group reports and 36 individual student reports. The group reports were shaped by the weekly action plan and the master action list and were a result of student application of instructional design skills to iteratively solve the problem. Individual reports, termed self-reflection statements, assessed the students as self-directed learners, as group learners, and as problem solvers through questions that prompted reflection on these processes. As a final evaluation strategy, the students were provided with a new instructional design problem in the form of a take-home final and were asked to apply what they had learned (individually) to solve this novel problem. The contents of this final evaluation were assessed based on how well the student was able to extend, reorganize, and refine their knowledge of instructional design skills. The results of this study demonstrated that students in a PBL environment acquired the necessary skills of ISD through direct experience and interaction. There was evidence that throughout the learning process students gained a great deal of ISD content knowledge and skills and that learning resulted from *problem solving, collaboration, and reflection*, a process referred to by Schön (1987) as *knowing-in-action*. The results also demonstrated that students were able to adopt self-directed learning strategies and become skilled in group learning as a result of improved *communication skills and self-monitoring skills*. Specifically, students were also able to reflect collaboratively on the feedback provided by the tutors on each of the group reports and restructure the feedback in light of the new information gathered about the problem demonstrating *conceptual change*. This resulted in a final comprehensive, professional-looking document that incorporated the five processes of the systematic approach to instructional design and development (analysis, design, development, implementation, and evaluation). The researchers concluded that PBL is an effective approach for teaching courses that involve problem-solving processes and critical thinking skills such as instructional design.

This sampling of studies demonstrates that PBL has a significant effect on fostering critical thinking skills such as problem solving, communication, collaboration, self-directed learning, reflection, clinical reasoning, analytic thinking, logical thinking, decision making, and conceptual change among others. These findings are not surprising. Since the origins of PBL, researchers (e.g., Barrows & Kelson, 1995) have consistently emphasized that the goals of PBL are to develop critical thinking skills and competencies necessary to operate effectively in professional and private life. However, what this sampling of studies also demonstrates is that PBL implementation varies across disciplines and contexts making it difficult to replicate how these outcomes are realized. For example, Nargundkar et al. (2014) used a guided PBL approach dubbed a reverse order textbook in which challenges were introduced prior to the content but students were aware that answers to these challenges were in the back of the book. This suggests that the challenges were well-defined with clear solutions and solution paths, while Dabbagh et al. (2000) used an ill-structured problem and the hypothetico-deductive reasoning process to cycle students through collaborative problem solving. Kumta et al.(2003) used an online PBL multimedia program that exposed students to real-world practitioner challenges through clinical case simulations followed by structured group conversations and opportunities for reflection and feedback; and Kumar and Refaei (2017) challenged students with three different writing prompts on human rights, two of which did not require collaboration. Additionally, different measures were used to assess critical thinking skills in these studies revealing that in some cases student perceptions were used to determine whether PBL fostered the development of critical thinking, while in others content knowledge and problem-solving knowledge were used to assess critical thinking.

Implications for Practice

Research has shown that PBL implementation varies across disciplines and contexts, and issues such as problem selection and representation, problem-solving processes, student expectations and readiness to engage in a self-directed form of inquiry, team roles and interactions, facilitator roles and interactions, and assessment processes, remain challenging areas. As Dos Santos (2017) suggests, the adoption of PBL is not an easy task particularly when transitioning from a traditional teaching approach. The research reviewed in this chapter reveals that, while PBL resulted in improved critical thinking skills, a number of difficulties were detected. For example, Carvalho (2016) found that PBL teams struggled with defining and following team roles, and emphasized the importance of training instructors and tutors in guiding team dynamics as well as team development throughout the PBL experience. Wilder (2015) argues that PBL has a learning curve that requires student acceptance of their central role in the learning process and that longer interventions may be necessary for students to gain the necessary skills and attitudes to engage in PBL, and for practitioners to gain a true appreciation for the impact PBL has on learning outcomes. Wedelin and Adawi (2015) suggest that students should be trained in problem-solving skills before entering a PBL program so that they understand the power of *learning by exploration* and are ready to handle ill-structured problems. Dos Santos (2017) adds that the PBL approach requires a lot of flexibility and dynamism from all involved and that management processes that offer a full view of the planning, implementation, monitoring, and evaluation stages of these processes are needed to ensure the authentic implementation of PBL throughout its lifecycle.

In order to effectively implement PBL and ensure that critical thinking skills are engendered and fostered, the following learning design principles should be incorporated (Dabbagh & Bannan-Ritland, 2005; Newman, 2005):

- Curricular design principles:
  - PBL must be the pedagogical base in the curriculum and not part of a didactic curriculum.
  - Learning in PBL should integrate a wide range of disciplines or subjects reflected through the problem(s).
- Problem design principles:
  - PBL problems must be ill-structured and allow for free inquiry.
  - PBL problems must promote ownership of the learning process; the context of the problem should motivate students to "own" the problem; students must define the problem.
  - PBL should not assume that students have formal prior knowledge in the content area(s) for which the problem is intended.
- Problem-solving design principles:
  - PBL must emphasize problem solving as the primary learning goal by allowing the problem to serve as the center for instruction.
  - PBL should support recursive and iterative cycling through a reasoning process until a solution to the problem is reached.
  - The PBL process should allow students to generate hypotheses, set their own learning goals, apply their own learning strategies, and solve the problem through searching for and identifying relevant resources.
  - The PBL process should allow learners to integrate, use, and reuse newly learned information in the context of solving the problem.
  - A closing analysis of what has been learned from working toward a resolution to the problem and a discussion of what concepts and principles have been learned is essential.
  - What students learn during their self-directed learning must be applied back to the problem with reanalysis and resolution.
- Pedagogical design principles:
  - The learning activities carried out in PBL must be those valued in the real world.
  - PBL should promote a student-centered, group learning environment in which collaboration is essential.
  - PBL should promote facilitation and scaffolding through instructor guidance; the instructor serves as tutor or coach.
  - PBL should promote self-directed learning (students should set their own learning goals and strategies for achieving those goals).
- Assessment design principles:
  - PBL should promote self-reflection as the primary assessment tool.
  - Self- and peer assessment should be carried out at the completion of each problem and at the end of every curricular unit.
  - Student examinations must measure student progress toward the goals of PBL.

This list of principles clearly conveys that all learning in PBL centers on the problem and that the problem must be ill-structured in order to support these principles. For example, it would not (should not) be possible for a student to provide a viable solution or resolution to an ill-structured problem on their own, nor would it (should it) be possible for students to solve such problems without a pedagogical expert's facilitation. Additionally, it would not (should not) be possible to solve such problems in one problem-solving cycle; rather, multiple problem-solving cycles are needed to come up with a viable, feasible, and justifiable solution. So what exactly is an ill-structured problem and what features and characteristics of ill-structured problems instantiate the PBL principles that foster the development of critical thinking skills? The answer to this question is provided in the next section of this chapter.

Ill-Structured Problems

Jonassen (2011) defines ill-structured problems as problems that occur in the everyday world, are complex, emergent, and interdisciplinary, and have multiple solutions and solution paths. More specifically, ill-structured problems possess the following features or characteristics (Chen & Li, 2015, p. 920):

- The goal of the problem is vaguely stated and requires analysis and refinement in order to make the particular issue tractable.
- The constraints of the problem are not typically found in the problem statement; instead, the problem solver needs to retrieve and examine the constraints during the problem-solving process.
- In most cases, the solver's solution is divided into a representation and a solution phase; however, different solvers may vary considerably in the nature and contents of each of these phases. This is because ill-structured problems may be approached in different ways, according to the solver's knowledge, beliefs, and attitudes.
- Solutions to ill-structured problems typically are not right or wrong, and not valid or invalid; instead, solutions usually are regarded in terms of some level of plausibility or acceptability. Furthermore, solution evaluation may be a function of the evaluator's knowledge and beliefs regarding the issue at hand.

Additional characteristics of ill-structured problems include the following (Barrows, 1985):

- The problem is messy when first encountered.
- The problem requires elaboration, organization, and analysis through inquiry and reasoning.
- The problem is likely to change as more is learned.
- The problem requires decisions even if data are missing, in conflict, or involve conflicting value positions.
- The problem may be resolved through alternative solutions.

In a study (Dabbagh & Dass, 2013) that examined the characteristics of ill-structured problems through a comparative analysis of 51 case problems used in five problem-based pedagogical models, the results revealed that ill-structured problems varied across six themes: problem complexity, nature of problem topic, problem task, problem product, problem-solving activity, and type of effort. More specifically, problems used in PBL were characterized as open-ended and multifaceted, task- and product-centric, and global and community-focused in that they addressed issues and topics such as toxic waste, natural disasters, and public health informatics. With respect to problem-solving activity and type of effort, the results revealed that PBL problems allowed the integration of different forms of reasoning and problem-solving skills, prompted multiple interpretations, required problem framing and scoping, required iterative problem-solving, promoted more explicit, overt, and collaborative problem-solving activities, and supported self-directed inquiry and research.

Barrows (1985) identified a problem design process for an ill-structured PBL problem that starts with "brainstorming an idea to explore its potential" and the degree to which this idea provides the following four criteria (p. 390):

1) an effective vehicle to bring students into contact with significant subject-matter content, and an opportunity to gain experience with a process of rational, reflective, reasoning;
2) appropriate issues for inquiry at a level of complexity that is engaging without being frustrating;
3) an authentic ill-structured problem that can be managed within the instructional time to be devoted to the unit;
4) an opportunity to accomplish normally required curriculum objectives.

More specifically, Barrows suggests constructing a brainstorming map of the concepts and skills that students might encounter if they met an ill-structured problem based on the idea in order to help determine if the idea fulfills these four criteria. If the result of the brainstorming exercise is plausible, the next step in the problem design process would be to develop a role for students to assume and a situation through which they will meet their ill-structured problem. The final step in the problem design process is to draft a description of the problem. In essence, what Barrows is suggesting is to perform a content and task analysis of the idea, dilemma, decision, process, issue, or problem to determine if it can be used as a trigger for learning in PBL. Hung (2006) proposed a conceptual framework to guide problem design in PBL known as the 3C3R PBL problem design model as well as a nine-step PBL problem design process (Hung, 2009). The 3C3R model focuses on aligning proper affordances of the problem with the learning outcomes of PBL. Therefore, in PBL, there is a problem design process and a learning design process. Tables 6.1 and 6.2 demonstrate how these two processes intersect by mapping the characteristics of an ill-structured problem to the learning principles of PBL. Table 6.1 provides an example of an ill-structured problem and related learning outcomes, and Table 6.2 maps the characteristics of this ill-structured problem to the learning design principles of PBL provided earlier in this chapter.

Table 6.1 Example of an ill-Structured Problem—The Forensic Pathology Examiner

Naming John Doe: The Forensic Pathology Examiner

Television, detective novels, and the media have glamorized the profession of forensic pathology. So much so that high school students interested in seeking a career in this field have no realistic appreciation of its methods or its role in crime solving. Investigative agencies like the FBI have a need for skillful dedicated forensic pathologists, and have developed a workshop to introduce high school seniors with a strong science background to the realities and challenges of the field of forensic science.

Students participating in this workshop will be divided into small groups and given an authentic case of a "John Doe"—the skeletal remains of an unidentified person. The case, background, and resources will be presented via the web. A software assistant, "Dr. Y.C. Bones," will provide students guidance as they research the case. After completing their background research, the high school students will visit an FBI crime laboratory, where they can perform a "forensic examination" using a skeletal mock-up and diagnostic equipment. A forensic examiner will guide the groups through the examination process. The groups will then present their findings to the class and their mentor forensic examiner. Required findings include determining gender, approximate age, height, and ethnicity of the deceased, and estimating the time of death. Based on their findings the students must select a likely positive identification of the deceased from a mock list of missing persons. The examiner and the class will critique each finding and allow the groups to defend their conclusions. Students will also be required to explain their reasoning process that led them to the solution of the case.

Learning Outcomes

Students completing the workshop will:

- Develop a realistic appreciation of the role of the forensic pathologist
- Understand the processes, methods, tools, and equipment used to gather and analyze criminal evidence related to skeletal remains
- Comprehend the relevance of sciences such as biology, physiology, and anthropology to forensic science
- Utilize appropriate methods of data gathering and documentation
- Collect and analyze supporting evidence needed to make a positive identification of skeletal remains and to link the remains to missing persons
- Develop critical thinking skills by critiquing the findings of their fellow students and reflecting on their own findings based on such critiques

The Naming John Doe scenario engages students in critical thinking through the provision of an authentic learning activity (identifying the skeletal remains of John Doe). Students are provided with background information about the case, relevant resources, investigative tools, and expert coaching to help them *solve* the problem. Additionally, problem-solving activities promote collaboration among peers, encourage a sense of community, and emphasize approaching the problem from different directions and multiple perspectives.

Problem Posing and Representation

In addition to PBL problems possessing the characteristics of ill-structured problems, research has shown that problem posing and representation makes a difference in supporting authentic PBL implementation. For example,

Table 6.2 Mapping the Learning Design Principles of PBL to the Features of the Problem

Promote ownership of the learning process (the problem context motivates students to "own" the problem, students must define the problem)

- *The problem context is authentic and related to students interests (students who enroll in this workshop are already thinking about a career in forensic science) and therefore the problem context should motivate them to own the problem*

Assumes no prior knowledge in the content area(s) for which the problem is intended

- *Students have no prior knowledge in forensic science*

Promote a student-centered, group learning environment in which collaboration is essential

- *Students can complete all the proposed activities in groups and engage in group discussions about the problem issues*

Promote self-directed learning (students should set their own learning goals and strategies for achieving those goals)

- *Since the case, background, and resources are presented via the web and Dr. Y.C. Bones will provide guidance, students can individually research the case information setting their own learning goals and strategies to achieving those goals (e.g., which resources to browse, in what order, what additional information they determine is needed, etc.)*

Promote authentic learning through real-world problems that are ill-structured; the learning activities carried out in PBL must be those valued in the real world

- *The problem is certainly a real-world problem and there are no apparent solutions. Based on how each group of students analyzes the case information and the results of their forensic examination, different solutions and solution paths may be formulated. The problem is therefore ill-structured*

Emphasize problem solving as the primary learning goal by allowing the problem to serve as the center for instruction

- *The scenario certainly emphasizes problem-solving skills. Students learn about forensic pathology while researching the problem information and using the tools of the trade to arrive at a viable solution*

Promote self-reflection as the primary assessment tool

- *This characteristic may not be as apparent as the others from just reading the brief scenario introduction; however, the fact that students are gathering information and performing investigative tasks to solve the problem implicitly means that students are reflecting on their findings as they proceed with the investigation and critically judging the results. Additionally, when students are asked at the end to explain to their peers and mentor their reasoning process that led to the identification of the skeletal remains, they are reflecting on their learning process and on how they arrived at their final solution*

Allow students to generate hypotheses, set their own learning goals, apply their own learning strategies, and solve the problem through searching for and identifying relevant resources

- *This scenario certainly lends itself to this characteristic. Students are generating hypotheses individually and in groups each time they research the problem data and perform related tasks. This is one of the hallmarks of PBL*

Allows learners to integrate, use, and reuse newly learned information in context

- *Again, this scenario lends itself well to this characteristic, allowing students to integrate information from several sources and to reuse information relative to the hypothesis generated. Students are continuously revisiting the hypothesis in light of the new information collected or derived*

Support recursive, iterative cycling through a reasoning process until hypothesis is reached (provide scaffolding for learning a reasoning process)

- *This characteristic is supported in this scenario for the same reasons as the one above. The final solution is reached inductively through a recursive process of reasoning through the data collected*

Promote facilitation and scaffolding through instructor guidance (instructor serves as tutor/coach)

- *The scenario allows for two coaches. A computer coach (Dr. Y.C. Bones) and a human coach (the mentor forensic examiner). Both of these experts act as coaches, guiding the students in the problem-solving process* research has demonstrated that heterarchical or network-like web-based representations of ill-structured problems can have a significant effect on critical thinking skills such as increasing collaboration, thinking critically about the problem content, facilitating expert-like solutions to the problem, and a more comprehensive and decisive information-seeking behavior. In a series of studies (Dabbagh, 2002; Dabbagh & Denisar, 2005; Dabbagh & Williams-Blijd, 2009) that examined students' information-seeking and problem-solving behaviors while interacting with two types of web-based representations of an ill-structured PBL problem, hierarchical (HI) (tree-like representation) and heterarchical (HR) (network-like representation), the results revealed three key findings. The first was that team exploration or information-seeking behavior in the HR problem design is more comprehensive (more links were visited) and decisive (minimized uncertainty with respect to the usefulness of the visited links in solving the problem) than team exploration in the HI problem design problem. The second finding revealed that team-based solutions developed in response to the HR problem design scored higher overall on both product and process problem-solving criteria than did team-based solutions developed in response to the HI problem design. The third finding revealed that the HR teams demonstrated considerably more expert-like problem-solving behavior than did the HI teams. Overall, these studies suggest that heterarchical web-based representations of ill-structured problems enable or evoke learning interactions and information-seeking behaviors that result in more cogent and viable problem solutions and the articulation of more expert-like problem-solving behavior.

Similarly, Poulton, Conradi, Kavia, Round, and Hilton (2009) examined the impact of interactive (hyperlinked and branched or nonlinear) online virtual patient (VP) PBL cases versus traditional paper PBL cases on student engagement and learning. Online VP interactive cases provided more lifelike representations of patient cases and allowed students to consider options as the case unfolded and to explore the consequences of their actions and decisions. These challenges were delivered to five PBL tutorial groups in a weekly PBL module. While these students regretted the absence of paper cases because they could not take notes as they progressed in their examination of the case, the findings of this study revealed that VP PBL cases allowed students to practice reasoning and decision-making skills and experience the consequences of their decisions. These findings were based on a comprehensive evaluation using questionnaires and interviews with both students and tutors. Additionally, students interacting with the VP PBL cases were more engaged and went through the online case at a reasonable pace allowing them to discuss the case more thoroughly and reflect on their decisions.

Byun, Kwon, and Lee (2014) designed two different ill-structured mathematics modeling simulations using spreadsheet software and a software package called GSP for elementary school students at a Korean Elementary School. The first simulation required students to find the best (optimal) cellular plan for an individual given a variety of cell phone plans and attributes. The second simulation challenged students to determine the best locations for security cameras for a real-world situation that had relevance to the students. Using pre and post results from the Mathematics and Technology Aptitude Scale (MTAS), the researchers found that 8 out of 20 items showed significant increases in learners' attitudes toward mathematics and technology. For instance, interaction with the modeling software resulted in significant increases in student attitudes toward learning mathematics with technology, confidence using technology, behavioral engagement, and mathematics confidence. The researchers suggest future research should focus on further development of computer-based modeling tools and mathematical simulations using PBL pedagogies.

Chen and Li (2015) argued that problem representation, argumentation skills, monitoring, and evaluation are primary requirements for ill-structured problem solving and that using concept mapping software to help students visualize the semantic and structural relations between task-relevant information and subject-matter knowledge can support cognitive processing and complex problem solving in an e-learning context. Specifically, these researchers suggest that using advanced computer-based concept mapping tools to facilitate student access to conceptual knowledge, content knowledge, and information resource knowledge by embedding hyperlinks in concept nodes that connect abstract concepts with related resources. This is similar to the approach that Dabbagh et al. (Dabbagh, 2002; Dabbagh & Denisar, 2005; Dabbagh & Williams-Blijd, 2009) used to represent ill-structured problems in a web-based or e-learning context. However, the hyperlinks in the Dabbagh et al. studies were embedded in the actual narrative description of the ill-structured PBL problem, whereas Chen and Li (2015) suggest that concept maps be used as a cognitive tool that augments or supplements the narrative representation of the ill-structured problem. Both approaches address some of the challenges that students face when solving ill-structured problems by using technology to provide access to more salient problem information and foster cognitive interactivity that facilitates problem solving without increasing nonessential extraneous processing load.

Smith (2014) advocated for the use of concept maps in conjunction with PBL during all phases of the problem-solving process to support critical thinking skills and deep learning. Smith posited that concept maps can be used to foster and assess students' conceptual change before, during, and after engagement in a PBL curriculum or contextualized instruction. As described earlier in this chapter, conceptual change is a critical thinking ability and research has shown that PBL is a pedagogical model that supports conceptual change (Dabbagh et al., 2000; Loyens et al., 2015). Smith suggests several methods for implementing concept maps in conjunction with PBL activities to promote conceptual change. One such method is modeling to students how to develop causal concept maps that foster the understanding of the relationships between concepts they are learning as they work toward a resolution of the PBL problem. Another method is allowing small groups to collaboratively develop a concept map of the

PBL problem space and negotiate how the concepts should be displayed, or allowing individual students to develop a concept map of the PBL problem space and share this map with their peers in their small groups. Smith argues that peer feedback on concept maps challenges students to "critically rethink" the concepts and relationships on the map enabling social negotiation and conceptual change.

These studies demonstrate that problem posing and representation in PBL is a key factor in initiating the problem-solving process and engaging students in critical thinking. As Hung (2006) posits, PBL problems are not just a trigger to start the learning at the beginning of the PBL process, rather, they are a critical and significant component of the instruction throughout the PBL process. Hence, it is imperative to ensure not only the ill-structuredness of these problems, but also the manner in which they are presented or communicated to students particularly in an e-learning context where technology provides a variety of options for conveying instructional materials. Begg, Ellaway, Dewhurst, and Macleod (2007) posit that a well-designed PBL problem should elicit and support a wide range of cognitive activities in order to be sufficiently effective as a learning tool, and that simulation technology can enhance the posing and presentation of a PBL problem by allowing role playing and gamified activities to achieve this objective (e.g., the VP cases described earlier). Clark and Mayer (2016) describe BioWorld, a multimedia environment used in a PBL context to teach high school students critical thinking skills. In addition to the patient case narrative, the learner is provided with options to drag and drop relevant phrases from the case narrative into an evidence table, select an initial hypothesis from a pull-down menu, order diagnostic tests from a pull-down menu, access resources from an online library, prioritize the evidence, and compare priorities to those of an expert. Essentially, the design of BioWorld is prompting or triggering Barrows (1985) hypothetico-deductive PBL reasoning process of: what we know about the problem, what the problem hypothesis is, what we need to know about the problem, what the action plan is, and how the results of our action plan support the initial hypothesis.

Aligning PBL Problem Characteristics and PBL Pedagogical Principles to Support Critical Thinking Skills

Ultimately, and in order to ensure the authentic implementation of PBL, problem design and learning design should occur simultaneously to support and foster critical thinking skills. Table 6.3 illustrates how the PBL problem characteristics identified in this chapter could be aligned with the PBL pedagogical principles identified in this chapter in a three-phased mapping approach to promote critical thinking skills.

Table 6.3 Aligning PBL Problem Characteristics With PBL Pedagogical Principles to Promote Critical Thinking Skills

PBL problem characteristics	PBL pedagogical principles	Critical thinking and problem-solving skills
Phase I—Problem Posing and Representation		
• Problem lacks the needed information for being defined or resolved when first encountered (problem is messy) • Goal of the problem is vaguely stated and requires analysis and refinement in order to make the particular issue tractable • Constraints of the problem are typically not found in the problem statement; the problem solver needs to retrieve and examine the constraints during the problem-solving process	• Learning activities carried out in PBL must be those valued in the real world • Learning in PBL should integrate a wide range of disciplines or subjects reflected through the problem • PBL should promote self-directed learning by allowing students to generate hypotheses, set their own learning goals, apply their own learning strategies, and solve the problem through searching for and identifying relevant resources • PBL should promote a student-centered, group learning environment in which collaboration is essential • PBL should promote facilitation and scaffolding through instructor guidance; the instructor serves as tutor/coach	• Self-directed learning • Logical thinking • Causal reasoning • Analytic ability • Information-seeking skills • Problem-solving ability • Communication skills • Collaboration skills • Situational awareness and thinking • Searching, evaluating, and synthesizing • Interpersonal skills • Group and chairperson skills • Time management • Strategic thinking
Phase II—Problem-Solving Process		
• Problem requires elaboration, organization, and analysis through inquiry and reasoning • Problem requires decisions even if data are missing, in conflict, or involves conflicting value positions • Problem is likely to change as more is learned through inquiry	• PBL should support recursive and iterative cycling through a reasoning process until a solution is reached (provide scaffolding for learning a reasoning process) • PBL should allow learners to integrate, use, and reuse newly learned information in the context of solving the problem • PBL should promote facilitation and scaffolding through instructor guidance; the instructor serves as tutor/coach	• Analytic ability • Causal reasoning • Knowledge sharing • Clinical reasoning • Problem-solving ability • Decision making • Flexible knowledge • Conflict management • Argumentation • Interpretation • Searching, evaluating, and synthesizing

Table 6.3 (Continued)

PBL problem characteristics	PBL pedagogical principles	Critical thinking and problem-solving skills
Phase III—Problem Resolution and Reflection		
• Problem may be resolved through alternative solutions • Problem may be approached in different ways, according to the solver's knowledge, beliefs, and attitudes • Solutions typically are not right or wrong, and not valid or invalid; instead, solutions usually are regarded in terms of some level of plausibility or acceptability	• What students learn during their self-directed learning must be applied back to the problem with reanalysis and resolution • A closing analysis of what has been learned from working toward a resolution to the problem and a discussion of what concepts and principles have been learned is essential • PBL should promote self-reflection as the primary assessment tool; self- and peer assessment should be carried out at the completion of each problem and at the end of every curricular unit • Examinations must measure student progress toward the goals of PBL	• Reflection skills • Self-monitoring skills • Conceptual change • Problem-solving ability • Enhanced communication practices • Explaining and listening to explanations based on the problems provided (articulation) • Knowledge transfer • Interpretation • Self-assessment

Conclusion

This chapter demonstrated through research evidence that PBL fosters the development of critical thinking skills such as problem solving, analytic thinking, decision making, reasoning, argumentation, interpretation, synthesis, evaluation, collaboration, effective communication, and self-directed learning (Abrami et al., 2015; Clark & Mayer, 2016; Dabbagh, 2002; Kumar & Refaei, 2017; Kumta et al., 2003; Loyens et al., 2015; McKeachie et al., 1987; Muller et al., 2017; Tiwari et al., 2006; Wilder, 2015; Yuan et al., 2008). The chapter also provided implications for practice including learning design principles, problem design principles, and examples of problem posing and representation that ensure the authentic implementation of PBL and the achievement of critical thinking skills. Critical thinking is one of the seven key domains that are defining desirable higher education student learning outcomes and is defined as thinking critically, solving problems, synthesizing information, and sense-making (Markle et al., 2013). PBL is a pedagogical approach that engages students in critical thinking, problem solving, synthesizing, and sense-making through ill-structured problems. Ill-structured problems must be carefully selected, generated, and presented to prompt a problem-solving process that is iterative, recursive, and collaborative resulting in critical thinking as a desired outcome.

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7

Effects of Problem-Based Learning on Motivation, Interest, and Learning

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Introduction and Background

Students sitting in class. It is a regular class in a regular school. A school, like so many schools nowadays, that has been through twenty-first-century upgrades, such as state-of-the-art network computers and an electronic whiteboard/projector combo. What has not changed though is the style of instruction: the teacher is still talking and the students are still listening—well, some of them are listening. Others scribble something on a piece of paper, occasionally staring out of the window. How long until this lesson is over? Yawn—how boring! The tragedy here is that the lesson is *boring*, not because the topic is by definition boring, but because of how it is offered to the students.

Problem-based learning (PBL) was supposed to change all this, with students being engaged, active participants in the learning process, who take charge of their learning. Confrontations with exciting real-life problems and puzzling phenomena were intended to make the topic more relevant—and above all—more interesting. But has this instructional approach held up to its promise? What do we know about the motivating and interest-arousing potential of PBL some 50 years later?

When the "founding fathers" at McMaster University conceived PBL in the late 1960s, they were convinced that this new instructional approach would be more motivating for students to study (Spaulding, 1969). They assumed that exposing students to authentic clinical problems early on in their curriculum would be perceived as motivating because students would immediately immerse themselves in the professional context of a doctor rather than studying isolated foundational subjects, as it is the case during the initial stage of many conventional medical curricula. In addition, it was assumed that integrating the basic medical sciences (e.g., physiology, anatomy, biochemistry) with the clinical sciences would have a motivational effect on students because it would make clear *why* these basic sciences were relevant to the study of medicine.

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Despite the fact that the encouragement of student motivation was an explicit motive for developing this new instructional approach, and its subsequent embracement by many medical schools, not much systematic research has been devoted to examining whether the premise that PBL results in enhanced student motivation is true. It appears as if those involved have taken the potentially motivating effects of PBL for granted, thus not seeing a need to subject it to empirical investigation. A quick search on Thomson Reuters' Web of Science reveals that there are less than 30 out of 3,000+ papers on PBL that are specifically devoted to the study of motivation in PBL. Moreover, most of these studies measured motivation in a highly generic manner; that is, a questionnaire was administered in a PBL curriculum inquiring about the students' general level of motivation.

The objective of this book chapter is threefold. First, we will provide an overview of the research in which motivation was measured at the general curriculum level. Second, we will provide an overview of specific characteristics of PBL, such as the problem, the tutorial group, and the tutor, that contribute to students feeling more motivated to study. Third, we will home in on the central role of the problem in PBL as the instructional tool responsible for arousing students' interest in the topic at hand.

What is Known About PBL and Motivation? Results From Curriculum-Level Studies

First of all, it is important to highlight that the number of studies investigating motivation in PBL is limited and thus it is difficult to draw generalizable conclusions about this line of research (Hmelo-Silver, 2004; Thomas, 1997). Second, the manner in which "motivation" is defined and operationalized differs greatly among studies. For instance, some researchers operationalize motivation as student satisfaction, or how enjoyable the curriculum is as a whole (Schmidt, Van der Molen, Te Winkel, & Wijnen, 2009; Vernon & Blake, 1993). Others treat motivation as intrinsic interest in engaging with the learning materials (Reeve, 1989; Ryan & Deci, 2000), and how competent/self-efficacious students perceive themselves to be (Bandura, Freeman, & Lightsey, 1999; Zimmerman, Bandura, & Martinez-Pons, 1992). Yet others equate motivation to curiosity or situational interest (Rotgans, 2009; Rotgans & Schmidt, 2012b). This diversity in definition and operationalization makes it difficult to directly compare findings and draw general conclusions about the role of motivation in PBL. Therefore, there is a need to impose some order upon these studies. A first manner in which to classify studies is to separate those that treat motivation as the *independent* variable versus those that treat motivation as the *dependent* variable.

Studies that treat motivation as an independent variable are typically cross-sectional studies in which a motivation questionnaire is administered as part of a PBL course (Rotgans & Schmidt, 2009). Subsequently, the scores obtained from the motivation questionnaire are correlated with an outcome measure for this course to examine how well motivation predicts academic achievement.

Araz and Sungur (2007) conducted such a study with secondary school students who participated in a PBL genetics course. They administered a questionnaire, which measured four motivational constructs (control of learning beliefs, task value, intrinsic goal orientation, and self-efficacy). In addition, a measure of prior knowledge, reasoning ability, and an academic achievement measure were included. A path model was tested to examine how the variables are related to each other. The results of their study revealed that none of the motivational constructs was a significant predictor of achievement. Prior knowledge and reasoning ability were significant predictors of performance. A similar cross-sectional study was conducted by Rotgans and Schmidt (2012a) with polytechnic students who were enrolled in a PBL curriculum. At this polytechnic, all the courses (i.e., the entire curriculum) were taught using PBL and students were given one problem each day (Rotgans, O'Grady, & Alwis, 2011; Rotgans & Schmidt, 2012b). In the study, a motivation questionnaire was administered consisting of six motivational subscales (intrinsic goal orientation, extrinsic goal orientation, task value, control beliefs for learning, self-efficacy, and test anxiety). In addition to the motivational subscales, nine subscales were administered tapping into students' learning strategies and study management (e.g., critical thinking, metacognitive self-regulation, and time and study management). Similar to the previous study, they also used path analysis and the results revealed that motivation was not a direct predictor of academic achievement, but the relationship was mediated by the use of learning strategies. Overall, these studies generally provide limited evidence that motivation is a significant predictor of academic achievement in PBL. Why this may be the case will be dealt with in later sections of this chapter.

Other studies treat motivation as the dependent variable. For instance, a study by Dunlap (2005) examined whether undergraduate computer science students' self-efficacy beliefs would change as a function of being exposed to PBL during a 16-week course in software engineering. The results revealed a significant increase in self-efficacy over the 16-week period, suggesting that being exposed to PBL increases students' self-efficacy for the topic in question. A limitation of this study is that no control group was used to examine if the effects are due to the PBL pedagogy or other factors. This brings us to studies that directly compared whether student motivation differed between PBL and more conventional instructional approaches, such as direct instruction or lectures. Such a study was conducted by Wijnia, Loyens, Derous, and Schmidt (2014), in which they examined whether there are differences in terms of motivation between PBL and a lecture-based approach. In their study they operationalized motivation in terms of autonomous and controlled motivation. The results revealed that there were no significant differences in motivation between PBL and lectures.

Overall, these findings suggest mixed results regarding the relationship between PBL, motivation, and achievement. The question is then: why is this so? We suggest three reasons. The first is that in some studies motivation is treated as the dependent variable (e.g., Wijnia et al., 2014), while in others it appears as the independent variable (Araz & Sungur, 2007). As a consequence, the results of these studies cannot easily be compared because there is a difference when motivation is treated and interpreted as the outcome of the PBL process or when it is treated as the input variable of the process. Comparing the findings between these two types of approaches is like comparing apples with pears. Second, researchers tend to use different definitions and operationalizations of motivation (e.g., task value, self-efficacy, controlled motivation, situational interest), making it difficult to compare findings of multiple studies and synthesizing generalizable conclusions. The most important shortcoming of some of these studies is that they measure motivation at a general level, without specifying which elements in the problem-based context cause motivation to increase. The next section of this chapter will review studies that did just that. These studies looked at specific elements of PBL and tried to understand how these elements would affect motivation to learn.

PBL-Specific Characteristics That Enhance Motivation

A number of features of PBL separate this instructional approach from more conventional pedagogies, such as direct instruction. First and foremost, in PBL students are presented with a problem that contains one or more phenomena in need of explanation (Sockalingam, Rotgans, & Schmidt, 2011). Confronted by the problem, students activate their prior knowledge (what do I know about this problem?) and formulate hypotheses that can explain the problem. This is not done in isolation, but collaboratively within a group supervised by a tutor (or facilitator). The formulation of hypotheses leads to learning issues that specify what students need to study during independent study. Students then spend a considerable amount of time engaged in such self-study. Subsequently, they share their findings with the group and try to make sense of the phenomena presented in the problem. From this description it is apparent that several of these PBL-specific features have the potential to have a positive effect on student motivation.

We will discuss the role of the tutor here first. The assumption is that the direct interaction and support of a tutor may have a motivating effect on student learning. Unlike conventional pedagogy, the teacher is not predominantly a source of information but a source of stimulation and encouragement. Since tutorial groups tend to be small, tutors are in a better position to build mutual trust and engage in close personal relations with their students (Schmidt & Moust, 2000). These factors are considered conducive to student motivation.

Three tutor characteristics have consistently been linked to better learning—and recently to enhanced motivation. These three characteristics are: subject matter expertise, social congruence, and cognitive congruence (De Grave, Dolmans, & van der Vleuten, 1999; Lockspeiser, O'Sullivan, Teherani, & Muller, 2008; Schmidt & Moust, 1995). Findings from these studies suggest that good tutors have sufficient subject matter expertise, are socially congruent with their students (i.e., they show genuine concern for their students), and are cognitively congruent (i.e., they demonstrate the ability to express themselves in a language that students can understand, using concepts they comprehend, and explaining concepts in ways easily grasped by students). If a tutor has these characteristics, studies have shown that students performed significantly better in the tutorial group than with tutors who displayed fewer of these characteristics (Lockspeiser et al., 2008; Williams, Alwis, & Rotgans, 2011; Yew, Chng, & Schmidt, 2010).

But do these characteristics also affect student interest? It is conceivable that how the tutor behaves, e.g., asking questions, encouraging students to participate,

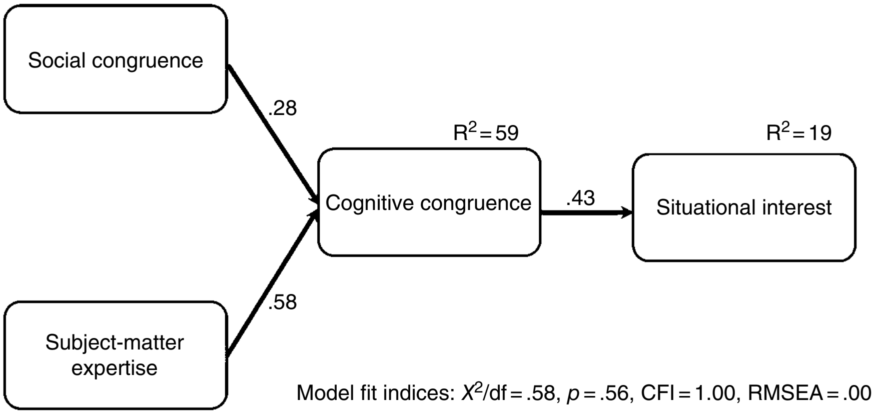


Figure 7.1 Subject-Matter Expertise, Social Congruence, and Cognitive Congruence as Predictors of Situational Interest in PBL.

and clarifying misconceptions, influences students' interest in the topic at hand. To explore this possibility, we conducted a study to address this question by examining how these three tutor characteristics influenced students' "situational" interest in PBL. As the name suggests, situational interest is considered a fleeting type of interest that can change from one moment to the other. We used path analysis to examine how much of the variance in situational interest can be explained by the particular tutor characteristics (Rotgans & Schmidt, 2011c). The results revealed that not all three components directly predicted situational interest. Subject matter expertise and social congruence were input variables for cognitive congruence, explaining about 60% of the variance. See Figure 7.1 for a visual overview of the path model.

Cognitive congruence was in turn a significant predictor of situational interest, explaining almost 20% of the variance. These findings suggest that the way the tutor conducts their role has a substantial influence on their students' interest in subject matter during PBL.

Recently, Wijnia et al. (2014) conducted a study in which they examined whether tutors' autonomy-supportive or controlling instructional styles had a significant effect on motivation and performance in PBL. They used an innovative simulated group discussion in which tutor instructions were systematically manipulated to be autonomy-supportive or -controlling. Their results revealed that controlling tutor instructions led to higher motivation. Paradoxically autonomy-supportive instructions did not relate to student motivation and performance. These findings contradict suggestions that experiencing more autonomy in the classroom would result in more intrinsic motivation (Deci & Ryan, 2004; Reeve, 2004).

Collaborative learning in small-group tutorials is another source of motivation (Järvelä, Volet, & Järvenoja, 2010; Springer, Stanne, & Donovan, 1999). In PBL students work together to identify learning issues for self-study and help each other in attaining a thorough understanding regarding the problem at hand by sharing their insights gained through self-study. In the group, students try to reach a shared understanding of the issues presented in the problem and they are to a certain degree dependent on each other's (prior) knowledge (Dolmans & Schmidt, 2006). Studies specifically geared toward motivation and small-group work in PBL are however largely absent. The only experimental study that we were able to uncover was conducted by De Volder, Schmidt, De Grave, and Moust (1989). They investigated what the effects are of group discussion on intrinsic interest for a specific topic. Half of the participants were given a problem about osmosis, whereas the other half received a problem about another subject. Immediately after the students discussed their respective problem in their tutorial groups, both groups were asked whether they were interested in receiving information about the topic of osmosis. The results of the study revealed that the students who had discussed the problem on osmosis reported higher intrinsic interest in receiving information about the topic of osmosis, immediately after the discussion and even after reading a text about osmosis as compared with the group who had discussed the other problem. According to the authors, these findings suggest that the tutorial group discussion has a positive effect on interesting students in the topic they discussed.

There are studies that examined the other end of the spectrum by exploring under which conditions the tutorial groups are *less* effective. For instance, Hendry, Ryan, and Harris (2003) identified the three most frequent problems in the tutorial group, which are (a) quiet students; (b) lateness or absenteeism; and (c) dominant students. Hitchcock and Anderson (1997) conducted a study to explore how differences in tutorial groups can be resolved. They proposed that tutorial groups should first establish ground rules about how the tutorial groups should function and tutors should establish a positive collaborative atmosphere in the group. If conflicts arise however, they should be dealt with immediately. Although these studies provide valuable insights into what makes a tutorial group dysfunctional and how to deal with it, they do not directly provide insights into what motivates them. Further research is needed to get a better understanding of how groups and their dynamics have a motivating effect on learning in PBL.

Finally, a number of studies tested the causal interrelationships among PBL-specific characteristics and how they affect student motivation (e.g., Gijselaers & Schmidt, 1990; Schmidt, 1999; van Berkel & Schmidt, 2000). Using program-evaluation data from a large number of courses, these studies tested a hypothesized causal model of PBL by examining to what extent students' prior knowledge, the quality of the problems presented, tutor performance, and tutorial group functioning influenced time spent on individual study, intrinsic interest, and academic achievement. The better these characteristics of PBL were implemented, the higher student motivation. The results of these studies suggest that students' prior knowledge, the quality of the problems, and the quality of the way the tutorial group functioned directly influenced intrinsic interest in the topic at hand. Tutor performance (and problem quality) had an indirect effect on interest through group functioning: the better the tutor supported the students (and the better the problem), the better the group functioned, leading to higher levels of interest. See Figure 7.2 for a graphic depiction of the findings of the original

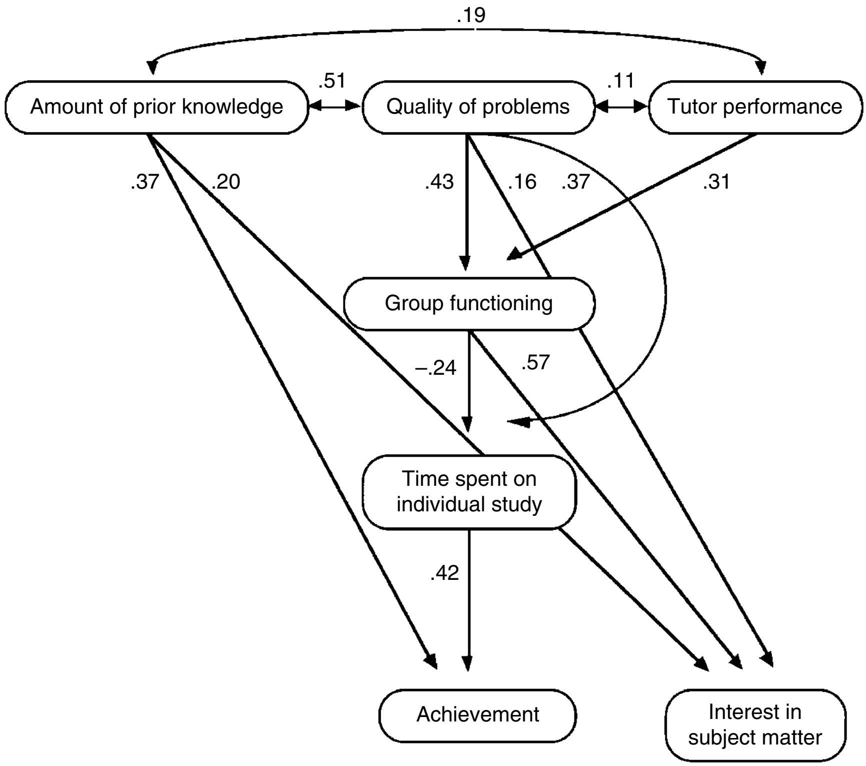
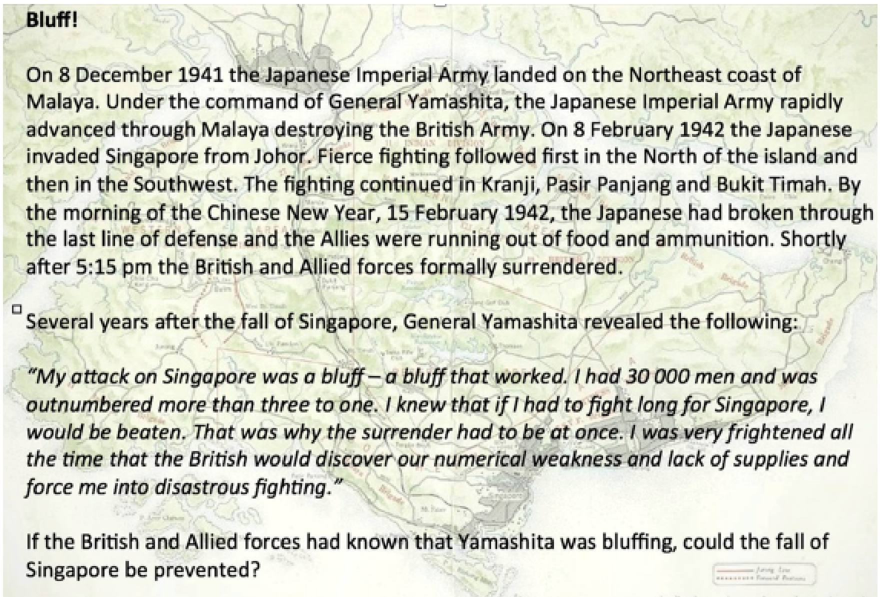


Figure 7.2 Schmidt (1999) Causal Model of PBL.

Schmidt study (Schmidt, 1999). These studies suggest the importance of good problems as a source of student motivation. We will discuss the role of problems in enhancing interest in more detail in the next sections.

Problems as a Crucial Source of Motivation in PBL

Why do problems have such a significant effect on motivation in PBL? Hmelo-Silver (2004) suggests that "Because learning issues arise from the problem (in response to students' need to know), intrinsic motivation should be enhanced" (p. 259). Norman and Schmidt (1992) propose that "…when students work on problems perceived as meaningful to them, they show interest in issues relevant to those problems that goes beyond merely studying to pass an examination" (p. 558). Schmidt (1993) suggests a possible underlying mechanism. He proposes that intrinsic motivation should be considered as "…a kind of curiosity that drives the subjects into knowing more about the topic" (p. 427). He furthermore proposed that problems in PBL create a knowledge gap in students, which results in exploratory behavior to find out more about the problem and thus close the knowledge gap (Schmidt, 1983, 1994).



Bluff!

On 8 December 1941 the Japanese Imperial Army landed on the Northeast coast of Malaya. Under the command of General Yamashita, the Japanese Imperial Army rapidly advanced through Malaya destroying the British Army. On 8 February 1942 the Japanese invaded Singapore from Johor. Fierce fighting followed first in the North of the island and then in the Southwest. The fighting continued in Kranji, Pasir Panjang and Bukit Timah. By the morning of the Chinese New Year, 15 February 1942, the Japanese had broken through the last line of defense and the Allies were running out of food and ammunition. Shortly after 5:15 pm the British and Allied forces formally surrendered.

Several years after the fall of Singapore, General Yamashita revealed the following:

"My attack on Singapore was a bluff – a bluff that worked. I had 30 000 men and was outnumbered more than three to one. I knew that if I had to fight long for Singapore, I would be beaten. That was why the surrender had to be at once. I was very frightened all the time that the British would discover our numerical weakness and lack of supplies and force me into disastrous fighting."

If the British and Allied forces had known that Yamashita was bluffing, could the fall of Singapore be prevented?

Figure 7.3 Example Problem Fall of Singapore During World War II.

Research to test this hypothesis was only sporadic at the time when it was conceived and only substantiated two decades later, when we subjected the "knowledge gap explanation" to further empirical investigation. We were particularly interested in unraveling what the underlying psychological mechanism is that triggers interest in students when they are presented with a problem, such as the example depicted in Figure 7.3.

We used this problem in several studies with students in Singapore and despite the fact that this history topic about the fall of Singapore is generally perceived as boring, this problem is typically very successful in arousing students' interest. Why does this problem about the fall of Singapore arouse interest in students? We believe it is because the problem contains known and unknown information that creates a realization of a knowledge deficit—a knowledge gap regarding the topic at hand. This is because it is to be expected that most Singaporean children know that Singapore was invaded during World War II. There are numerous World War II memorials scattered around Singapore and there are numerous signs indicating battle sites that were important during the invasion. However, what most of the students do not know is that the attack on Singapore was a bluff by the Japanese General Yamashita. This missing piece of information, that despite being outnumbered they succeeded in overrunning the British and Allied defenses, is expected to create an expectancy violation in students, which results in an awareness of a knowledge deficit regarding the topic at hand. This awareness, we propose, in turn results in heightened interest and an urge to find out more about the specific topic to close the knowledge gap.

This phenomenon is referred to as the "knowledge-deprivation hypothesis of situational interest" and we subjected it to a series of empirical tests. However, before we can present the findings of these studies, we need to elaborate for a moment on the "issues of measurement" with conventional measures, as described in the studies earlier that employed generic measures of motivation/interest. Once we have clarified this issue, it will become apparent why we operationalized our studies as we did.

Issues with Conventional Measurements

When one intends to conduct a detailed analysis of how a problem affects student motivation, measurement at the course or curriculum level, such as in the studies discussed before, are less suited to obtaining detailed information about what is going on in the situation. For instance, asking students about the quality of problems by means of an end-of-semester questionnaire or program evaluation would yield information that is too general because students would provide "averaged impressions" of all problems they had encountered; one problem may have been more motivating than the other and thus an averaged impression would be reported that conveys information that is too general. To address this problem, one has to measure student motivation during much shorter timeframes, such as one PBL session. But even then, having only one measure, say at the end of the PBL session, would still result in an "averaged impression" of what went on during the session. In order to capture what is going on in situ, i.e., when a problem is presented to students, one has to measure *repeatedly* before and after the problem to get an adequate measure of the effect of the problem on student motivation. To adequately describe this approach, we adopted the term "micro-analytical measurement" (DiBenedetto & Zimmerman, 2010; Rotgans, 2009; Rotgans & Schmidt, 2011a; Zimmerman & Kitsantas, 2005).

As mentioned before, motivation can be operationalized in many ways and to do justice to this more detailed measurement approach, we chose to use situational interest as an indicator of student motivation (Schraw, Flowerday, & Lehman, 2001; Schraw & Lehman, 2001). This type of interest is different from the stable, trait-like type "individual interest," which only slowly develops over time (Krapp, 1999). For instance, developing an individual interest in science takes many years to cultivate, whereas situational interest in science can emerge spontaneously when presented with an intriguing problem. We devised and validated a short self-report measure of situational interest, which can be administered in under 1 min to reduce interferences during class. See Table 7.1 for an overview of the items.

Application of the Micro-Analytical Measurement Approach

We first applied the micro-analytical measurement approach in a study in which we measured situational interest five times at critical moments during a 1-day PBL session about economics (Rotgans & Schmidt, 2011b). We administered the questionnaire before and after students received a problem, immediately after

Table 7.1 Six-Item Situational Interest Questionnaire

1	I want to know more about this topic.	1 *Not true at all*	2 *Not true for me*	3 *Neutral*	4 *True for me*	5 *Very true for me*
2	I enjoy working on this topic.	1 *Not true at all*	2 *Not true for me*	3 *Neutral*	4 *True for me*	5 *Very true for me*
3	I think this topic is interesting.	1 *Not true at all*	2 *Not true for me*	3 *Neutral*	4 *True for me*	5 *Very true for me*
4	I expect to master this topic well.	1 *Not true at all*	2 *Not true for me*	3 *Neutral*	4 *True for me*	5 *Very true for me*
5	I am fully focused on this topic; I am not distracted by other things.	1 *Not true at all*	2 *Not true for me*	3 *Neutral*	4 *True for me*	5 *Very true for me*
6	Presently, I feel bored.	1 *Not true at all*	2 *Not true for me*	3 *Neutral*	4 *True for me*	5 *Very true for me*

Please indicate, on a scale from 1 (*not true at all for me*) to 5 (*very true for me*), how true the statements are for you **right now**.

initial discussion of the problem, after self-study, and finally after elaboration on what was learned during self-study. We then examined the growth trajectory of situational interest as a function of the PBL process. The data revealed an interesting trend in how situational interest develops over a PBL session. Situational interest first increased when a problem was introduced and students engaged in discussing it. However, as the students gained more knowledge about the problem in question, situational interest significantly decreased. The data suggest that situational interest progresses over the course of a PBL session in an inverted U-shape fashion.

In studies that followed, we were able to replicate these findings that situational interest significantly increases as soon as a problem is introduced and then significantly decreases as students gain more knowledge (Rotgans, 2009; Rotgans & Schmidt, 2012b; Schmidt, Rotgans, & Yew, 2011). In addition, in one study we were able to directly compare PBL vs. direct instruction in which students did not work on problems—all else being equal (Schmidt et al., 2011). The findings of this study demonstrated that no significant change in situational interest occurred for the direct instruction group, whereas for the PBL group, situational interest developed in the typical inverted U-shape fashion.

The fact that situational interest increases when students are confronted with a problem makes intuitive sense, but why is there a significant decrease in situational interest as they progress with learning? We propose the knowledge-deprivation hypothesis of situational interest as a theory that can explain this phenomenon of an initial increase and subsequent decrease in situational interest.

The Knowledge-Deprivation Hypothesis of Situational Interest

To explain the inverted U-shape pattern in situational interest during PBL, the work of Berlyne is particularly relevant (Berlyne, 1954, 1962, 1978). Berlyne did not use the term situational interest but wrote about "epistemic curiosity," which is curiosity for knowledge. Epistemic curiosity and situational interest, however, seem to play similar roles in education: they are both aroused by instructional interventions, and both are supposed to motivate the acquisition of knowledge. According to Berlyne (1954), the emergence of situational interest is the result of a gap between what one knows about a particular topic and what seemingly needs to be known; situational interest from this point of view is triggered by the experience of a knowledge deficit (see also Schmidt, 1993). Berlyne referred to this process as a need for new information that motivates exploratory behavior and knowledge acquisition. In accordance with his work, we have proposed a drive-reduction explanation of situational interest, the "knowledge-deprivation hypothesis of situational interest" (Rotgans & Schmidt, 2014). Our proposal of how situational interest is aroused and satisfied has four elements. See Table 7.2 for a summary.

First, confronted with a problem not immediately understood, a student engages in an attempt to retrieve knowledge from their long-term memory that may help them to interpret the problem. Second, if the retrieval from long-term memory fails, the student experiences a gap between what they know and what they need to know to understand the problem at hand. Third, this conscious realization of a knowledge deficit leads to the arousal of situational interest for information that may help eliminate the deficit ("I don't know this. Interesting! Let's find out more!"). Aroused situational interest is therefore a motivational indicator of the preparedness of the person to engage in exploratory behavior to find information and processing such information. Fourth, the acquisition of new knowledge satisfies the drive to learn. If the knowledge gap is closed with

Table 7.2 Overview of the Four Elements of the Knowledge-Deprivation Hypothesis

Sequence	Descriptor	Mechanism
1	Problem confrontation	Retrieval attempt from long-term memory to make sense of the problem
2	Knowledge-retrieval failure	If knowledge retrieval attempt fails, the individual becomes consciously aware of his or her knowledge deficit regarding the problem at hand
3	Situational interest arousal	The awareness of one's knowledge gap leads to situational interest arousal and a willingness to engage in information-seeking behavior to close the knowledge gap
4	Arousal reduction of situational interest	Exploratory behavior that results in knowledge acquisition and closing of the knowledge gap leads to an arousal reduction of situational interest

regard to the problem, there is no further impetus to find out more about it. Hence, situational interest decreases and may even disappear.

In our proposal, the failed attempt to retrieve relevant knowledge, necessary for understanding the problem, is crucial to the emergence of situational interest. We propose that the unsuccessful retrieval also may lead to a more extensive search for new information. The problem acts hereby as a catalyst: it makes the organism aware of a possible discrepancy between its understanding of the world and how the world really is. Since such a discrepancy can have negative consequences for the organism, the drive to reduce the knowledge gap is, we suspect, a biological given (Kang et al., 2009). Situational interest is the red flag that signifies this undesirable state of affairs and is lowered when the informational needs are satisfied.

Empirical Evidence Supporting the Knowledge-Deprivation Hypothesis

We conducted three studies to empirically test the knowledge-deprivation hypothesis of situational interest (Rotgans & Schmidt, 2014). The first study was an experiment in which we presented Singapore secondary school students with the history problem depicted in Figure 7.3, about the fall of Singapore during World War II. Prior to the problem, half of the participants received a text providing an explanation for this problem. The other half received unrelated information. As such, we manipulated their prior knowledge regarding the problem. Situational interest was measured both before and after the presentation of the problem. The participants who did not receive the explanatory information reported a significant increase in situational interest in the topic after the problem was presented. The group that was given the prior knowledge necessary to understand the problem beforehand did not show such change in situational interest. In our view, this outcome demonstrates that situational interest is only aroused by a problem when a knowledge gap exists between what the learner knows about the problem and what needs to be known to understand it.

In a second study, participants were informed about a topic they were going to study (i.e., coastal erosion of the Singapore shore) after which we measured both students' self-reported knowledge about this topic and their situational interest. We then presented them with a coastal erosion problem and recorded their self-reported knowledge and situational interest for a second time. See Figure 7.4 for a depiction of the problem.

Students who perceived the largest knowledge gap after introduction of the problem were shown to experience the largest increase in situational interest. These results suggest that participants have to be *consciously aware* that a gap exists between what they know and what they need to know to understand the problem at hand, to provoke situational interest.

In a third study, we investigated the trade-off between situational interest and knowledge acquisition over the duration of three lessons in a natural classroom setting. In this study, we administered measures of situational interest and knowledge acquisition repeatedly, which enabled us to observe how both develop

Singapore is disappearing

On a weekend you plan to go to the beach with your friends. Your destination is West Coast Park. Once you arrive there, you all notice that the beach has been cordoned off and a big danger sign warns people from going too close to the shoreline (see picture below).

You ask a passerby what is going on and he tells you that the beach in West Coast Park has receded by at least 3 meters in some parts in the past 2 years.

You wonder how is this possible and what can be done to prevent the situation from worsening?

Figure 7.4 Problem on Coastal Erosion of the Singapore Shore.

over the course of a learning event. The same problem was used as in the first study about the fall of Singapore during World War II. The results of the study confirmed and extended the findings from the first two studies. Initially, when the problem was presented, participants responded with a significant increase in situational interest. See Figure 7.5 for a visual overview of these data.

Subsequently however, while participants gained knowledge during self-study and knowledge consolidation, their situational interest in the topic decreased significantly. We believe that this outcome supports the idea that situational interest emerges from lack of knowledge and disappears when sufficient new knowledge is acquired as the knowledge-deprivation account predicts (Rotgans & Schmidt, 2014).

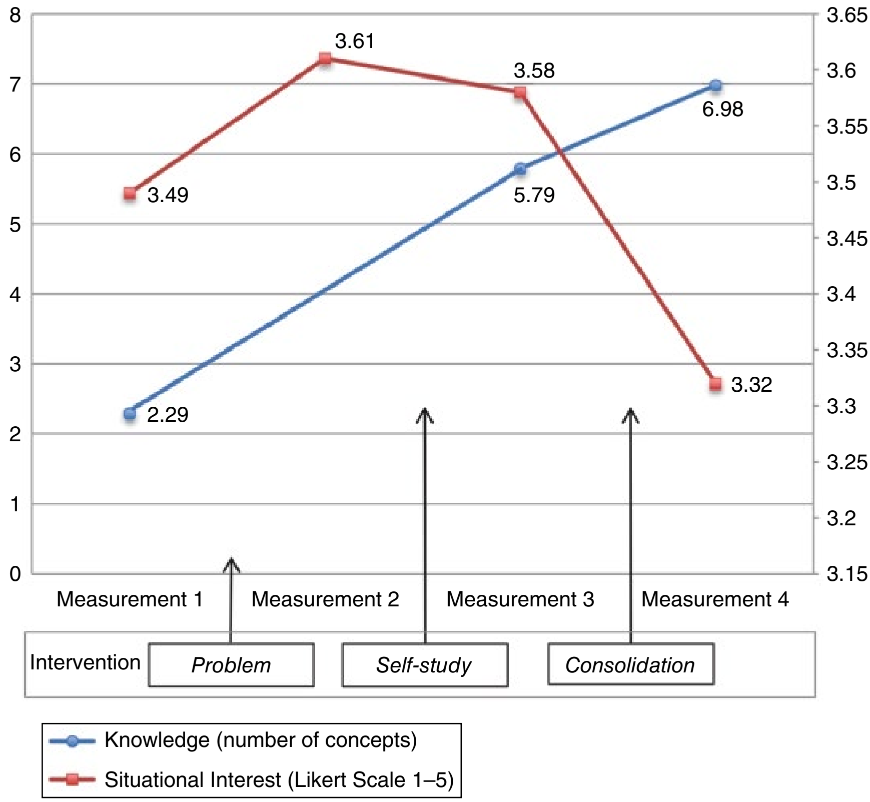


Figure 7.5 Relationship Between Situational Interest and Knowledge Acquisition.

After having explored the mechanism responsible for situational interest and knowledge acquisition, we shifted our attention to the question of what are the long-term effects of subjecting students repeatedly to interest-arousing problems. In a PBL curriculum students are not exposed to only one problem as it was the case in our research studies, but repeatedly to many problems that revolve around a study subject. Besides the obvious effects on knowledge acquisition, are there any other significant educational byproducts that emerge out of the repeated exposure to problems?

We hypothesized that repeatedly experiencing intriguing problems—particularly if school subjects are concerned that are generally perceived as less attractive—may gradually develop into a liking and more stable interest for the subject in question. Put simply, repeated arousal of situational interest may develop into increased individual interest for the subject in general (Krapp, 2003). Needless to say that if this were the case, it has significant educational implications because it would suggest that one can manipulate students' long-term individual interest for school subjects for which they may have less affection and interest (e.g., abstract topics in mathematics, complex principles in science).

This proposal constitutes a significant deviation from attempts in education to align study subjects with students' individual interests (Lent, Brown, & Hackett, 1994; Silvia, 2001). Rather than aligning study subjects with individual interests, we propose that all is needed is to present students with intriguing problems that arouse their situational interest and if one succeeds in reinforcing it over a longer period of time (as it is the case in PBL), it will gradually and somewhat automatically change their individual interest in the subject in question.

Our proposal originated from numerous observations of our students when they worked on our problems. They frequently stated "…I generally do not like this subject, but this problem is really interesting and I would like to find an answer for it." We figured that if we reinforce the experience of having an urge to know ("Hey that is interesting, let's figure it out") and then actually figuring it out and developing a deeper understanding of the topic, this will attach positive feelings and value to the subject in general, and in the long run changes their attitudes and interest for the subject at large.

Long-Term Effects of Interest-Arousing Problems on Individual Interest in PBL

We explored the possible long-term effects of repeated arousal of situational interest on individual interest development in a recently conducted study, in which we presented primary school science students with four problems over the duration of 4 weeks (Rotgans & Schmidt, 2017). One problem was presented each week over the duration of 4 weeks (see Figures 7.6–7.9 for an overview of the four problems on the science topic "properties of light").

Each week students met during two sessions each of 1-hr duration. During the first session they discussed the problem and then engaged in self-study. They continued self-study when they met during the second session and then presented/discussed their findings at the end of the second session. The next week they were given the second problem and they engaged in the same process again. This continued for 4 weeks. A measure of individual interest was devised and validated (Rotgans, 2015). An overview of the individual interest measure with its items is depicted in Table 7.3. During each week we administered one individual interest and two measures of situational interest before and after they received the problem.

Measuring both situational and individual interest over 4 weeks enabled us to determine (a) if the problems aroused students' situational interest and (b) whether the arousal had an effect on changing students' individual interest for the subject. The data were analyzed using latent growth curve modeling (Duncan, Duncan, & Strycker, 2013). This statistical approach enables the researcher to examine how situational interest arousal (i.e., the different scores of situational interest before and after the problem) influences the intercept and slope of individual interest. The influence of situational interest on the slope is of particular interest since it represents the growth trajectory of individual interest over 4 weeks.

The results of the analysis revealed that all problems were successful in arousing situational interest. More importantly, latent growth curve modeling revealed that situational interest arousal had a positive and significant effect on the slope, or growth trajectory, of individual interest. In other words, repeated exposure to

The secret cave of Pulau Ubin

Not many people know this, but there is a hidden cave on Pulau Ubin, which was used during the Japanese occupation in WWII as a secret hideout. After the war most people forgot about it and since it is so well hidden nobody found it ever since.

Two good friends, Elaine and Teck Seng, who heard stories about the cave from Elaine's grandpa, decided to go out and find the cave. According to their grandpa, there are some treasures hidden in it—left behind by the people who were hiding from the Japanese.

After a long and very exhausting search through the mangrove forests of Pulau Ubin, Elaine and Teck Seng finally found it (see picture).

At first, Teck Seng is a bit scared to go in because it is a very deep cave and he does not know what they will find, but in the end his curiosity wins and he is determined to explore the cave.

Just when he wants to enter, Elaine says: *"wait a minute Teck Seng, did you bring the torchlight, without it we cannot see in the dark cave!"*
Teck Seng replies: *"No need for a torchlight our eyes will get used to the dark and we will be able to see, no worries."*
Elaine protests: *"without a torchlight we will not be able to see; I will not enter the cave without it!"*

Who do you think is right?

Figure 7.6 Problem 1: The Secret Case of Pulau Ubin.

intriguing problems had a significant effect on increasing students' liking and value of the school subject in general.

We conducted a second study in which we replicated the first and extended the research by exploring if the problem is indeed the significant factor in arousing situational interest and responsible for the change in individual interest over time. Strictly speaking, it is possible that other factors, besides the problems, may have positively influenced the increase in individual interest over time (tutors, growing rapport with peers in the tutorial group, etc.). In this study we randomly assigned four primary school science classes to either a problem condition or a

Mysterious moonlight
Sometimes at night you can observe a full moon, shining bright in the sky lighting up the landscape. For instance, see the photograph below, which was taken at midnight

Isn't it surprising that the moon, which is NOT a light source itself, can shine so bright at night so that we can see all the things around us? Where is the light coming from?

Figure 7.7 Problem 2: Mysterious Moonlight.

Keep the rays out
As we all know, Singapore is a hot place to be. As a result of this, there are many efforts to keep the sun out of buildings to keep it cool inside.
You may be surprised to find out how many different materials can be used to prevent sunrays from entering buildings through the windows. A key feature to consider is of course not to seal off the windows entirely so that it is too dark inside and you need to switch on the lights to be able to see.
What kind of materials do you think would be best suited to keep it cool inside and have sufficient light to see?

Figure 7.8 Problem 3: Keep the Rays out.

Amazing shadows
After dinner, you are on your way home from the local food court. It is already dark and you are on your bicycle. While cycling on the street you notice that when you approach a street lantern, your shadow gets first longer, then shorter when you close in and longer again when you have passed the lantern.
You wonder how is this possible?

(Students are then shown a video that exemplifies the above description of the phenomenon).

Figure 7.9 Problem 4: Amazing Shadows.

Table 7.3 Individual Interest Questionnaire

1	I am very interested in science.	1 *Not true at all*	2 *Not true for me*	3 *Neutral*	4 *True for me*	5 *Very true for me*
2	Outside of school I read a lot about science.	1 *Not true at all*	2 *Not true for me*	3 *Neutral*	4 *True for me*	5 *Very true for me*
3	I always look forward to my science classes because I enjoy them a lot.	1 *Not true at all*	2 *Not true for me*	3 *Neutral*	4 *True for me*	5 *Very true for me*
4	I have been interested in sciences from a young age.	1 *Not true at all*	2 *Not true for me*	3 *Neutral*	4 *True for me*	5 *Very true for me*
5	I watch a lot of science-related TV programs.	1 *Not true at all*	2 *Not true for me*	3 *Neutral*	4 *True for me*	5 *Very true for me*
6	Later in my life I want to pursue a career in science or a science-related career.	1 *Not true at all*	2 *Not true for me*	3 *Neutral*	4 *True for me*	5 *Very true for me*
7	When I am reading something about sciences, or watch something about sciences on TV, I am fully focused and forget everything around me.	1 *Not true at all*	2 *Not true for me*	3 *Neutral*	4 *True for me*	5 *Very true for me*

Please indicate below, on a scale from 1 (*not true at all for me*) to 5 (*very true for me*), how true the statements are for you **in general**.

nonproblem condition. The difference between the groups was that the nonproblem condition received a general instruction by the teacher that contained all the information of the problem, but was not considered a problem per se. For instance, instead of presenting Problem 1 to the students (see Figure 7.6), the teacher provided the following information: "During this week, you will find out why you need a light source to see in the dark. For instance, if you go into a dark cave you cannot see without a light source, such as a flashlight or a flare. Moreover, you will learn what the difference is between light sources, such as the sun or a flashlight and nonlight sources. Finally, you will find out how light enables you to see in the dark—how that actually works."

The results of this study revealed that the students who received problems reported significantly higher levels of situational interest compared with the students who did not work with problems. Moreover, only for the group that received problems, a significant increase in individual interest was observed over the 4-week period. The group that did not receive problems did not report any changes in individual interest for the topic over the 4-week period.

In our view, these findings demonstrate the significant effect of problems on the arousal of situational interest and the positive effect this has on changing students' overall interest and attitudes toward the subject in general. We believe that PBL with problems being the focal point of this instructional approach has a powerful potential to motivate students to engage with school subjects that are generally perceived as less appealing, and is capable of positively changing their individual interest in the subject in general.

Concluding Remarks and Future Research

PBL is believed to have a motivating effect on students. This makes intuitive sense, but evidence for this assumption is scarce and more systematic research is needed to establish why that is the case and what causes it. Conducting generic studies that measure general motivational constructs in a PBL curriculum is not the best way forward since this line of research lacks context specificity. Instead, micro-analytical measures seem to be more promising since they have adequate grain-size to determine which specific feature of PBL is responsible for enabling and supporting student motivation. The specific features we identified in this chapter are the problems, the tutor, and group discussion. Although this may not be a comprehensive and conclusive list, it is probably a reasonable start for prioritizing research on motivation in PBL.

Most research to date revolves around the role of problems in PBL. This is justified considering that working on problems is the most distinctive feature of this instructional approach and it makes sense that problems draw students in by creating a need to know, which fuels learning and performance. The knowledge-deprivation hypothesis represents an account that can explain the underlying psychological mechanism, but needs further testing and replication with a variety of problems covering a range of subject domains and contexts. The same is the case for the role of the tutor in motivating students in PBL. Although it is known that cognitive congruence has a significant effect on students' situational interest, further micro-analytical studies need to explore at which phase or stage in the PBL process the role of the tutor is most critical—is it during group discussion of the problem, clarifying misconceptions, asking questions, or encouraging students to participate?

Finally, more research is needed to explore why the group interaction in PBL has an effect on student motivation. According to the available studies, choice and autonomy support seem to play a less significant role in PBL than in conventional curricula. As a consequence, we need to broaden our search in finding more PBL-specific features that can explain why group interactions have a positive effect on student motivation. Is it because students in PBL depend more on each other, feel more socially connected since they have to work together consistently and over a long period of time, and maybe feel more obliged to engage in thorough self-study because they report to each other and not to the teacher?

Investing research efforts into these three areas will help to paint a more complete picture of the effects of PBL on motivation, interest, and learning.

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8

Self-Directed Learning in Problem-Based Learning: A Literature Review

Heather Leary, Andrew Walker, Mason Lefler, and Yu-Chun Kuo

Introduction

Problem-based learning (PBL) is described throughout the literature as an inquiry-based approach to learning that is student-centered and provides the means for gaining problem-solving and lifelong learning skills (Becker & Maunsaiyat, 2004; Blumberg, 2000; Chen, Chang, & Chiang, 2001). PBL begins with the presentation of an ill-structured problem to be solved that has potentially multiple solutions. Teachers act as facilitators throughout the process, guiding learners with metacognitive questions as they actively construct knowledge by defining learning goals, seeking information to build upon prior knowledge, reflecting on the learning process, and participating in active group collaboration (Barrows, 1998). The majority of PBL research and practice is in medical education and focuses on the cognitive domain, but PBL has branched out into all disciplines (Savery, 2006; Walker & Leary, 2009). More research is now focusing on understanding the conative and affective domains in PBL, specifically self-directed learning, metacognition, self-regulation, and lifelong learning.

The purpose of this review is to focus on self-directed learning both as an integrated process of PBL and as a meaningful outcome associated with its use. As a process, self-directed learning is embodied by asking students to take charge of what they are learning (Barrows, 1986; Bidokht & Assareh, 2011). This process of transferring the responsibility of instructional guidance from the teacher to the student is heavily guided by different aspects of the learning environment. Part of that guidance comes from the careful selection and sequencing of problems (Barrows, 1996), whereas guidance also comes through the form of metacognitive questions posed by a facilitator, which keeps the discussion going until students bring up all of the important topics necessary for the solution to the

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problem to become apparent (Hmelo-Silver & Barrows, 2006). Over time, teachers fade their guidance and students take more and more ownership over the facilitation of their own learning. In addition to problem sequence and teacher guidance, peer collaboration (Nelson, 1999) also plays a key role in PBL and helps to promote self-directed learning. As part of the small-group process learners identify key issues to explore, conduct independent research, and then bring what they learn back to the group. This process motivates students to hold each other accountable for the quality and relevance of the information as well as the information's utility in contributing to the problem solution. As an outcome, self-directed learning is a benefit to PBL learners in providing transformational learning and preparation to be a lifelong learner (Hmelo-Silver, 2009).

Self-Directed Learning

Self-directed learning is generally known as an increase in learners' awareness, initiative, and acceptance of personal responsibility for their own learning with the acquisition of resources and skills to enhance their learning experience (Abraham, Hassan, Damanhuri, & Salehuddin, 2016). In addition to a learning theory orientation, self-directed learning includes prescriptive instructional theory components. Prescriptive self-directed learning involves individual best practices for learning; specifically, what learning techniques or pedagogical approaches maximize learning (e.g., knowledge acquisition and comprehension), how to prepare for a new level of knowledge acquisition, and how to learn outside formal educational classrooms (Bolhuis, 2003).

Origin and Development of Self-Directed Learning

Beginning with and building upon the work of Houle (1988), Knowles (1970, 1975), and Tough (1978, 1979), self-directed learning as a learning theory purports that people can indeed learn on their own without instructional interventions while discovering their own learning process. Research on self-directed learning increased dramatically in the 1970s when scholars began investigating the characteristics and attributes associated with someone who is self-directed, how to harness the goals of self-direction for improved learning, and how to assess, teach, and identify self-direction in learning (Grow, 1991; Guglielmino, 1977; Oddi, 1986).

There are three goals associated with self-directed learning: (a) to enhance the ability of learners to be self-directed in their learning, (b) to foster transformational learning (process of reflection and awareness that leads to changes), and (c) to promote emancipated and social action learning (Brockett & Hiemstra, 1991; Brookfield, 1985; Knowles, 1970; Mezirrow, 1985, 1990; Tough, 1978, 1979). There are many models and theoretical formulations that intersect with self-directed learning and that share some main characteristics including motivation, self-monitoring, self-management, interest, commitment, and self-evaluation (Candy, 1991; Garrison, 1997; Grow, 1991; Guglielmino, 1977; Oddi, 1986). It is important to note that self-directed learning is also known as independent learning, self-instruction, self-study, and discovery learning (Guglielmino, 1977). For the purpose of this review, self-directed learning is defined broadly as assuming responsibility for learning while recognizing the following items in regard to learning: value placed on learning, attitudes toward learning, motivations, willingness, and actions.

Self-directed learning is both a process and a measurable outcome (Candy, 1991; Leary, 2012), both of which are a focus of this review. In terms of knowledge domains, self-directed learning includes both affective and conative components. As a process, self-directed learning's primary function for learners is in planning, carrying out, and evaluating learning experiences while they are experiencing the learning. Conversely, as an outcome, self-directed learning functions as an acquired skill where the learner can acknowledge with confidence the ability to, in the future, apply the skills learned while continuing to engage in and refine self-directed learning skills (Knowles, 1975; Merriam, Caffarella, & Baumgartner, 2007).

Note that there is a wider context for self-directed learning that can be explored. We considered both self-regulated learning and metacognition before ultimately landing on self-directed learning and its relationship to PBL. Self-regulated learning implies control over learning with a learner directing cognition, being motivated, and involving the process of metacognition. Self-regulated learning stems from cognitive psychology and, although it shares many similarities with self-directed learning, including defining tasks, goal setting, planning and enacting strategies, monitoring outcomes, self-evaluation, active participation, goal-directed behavior, activating metacognitive skills, and intrinsic motivation, historically they are different. Self-regulated learning focuses on narrow micro-level constructs with tasks typically set by a teacher in a formal learning environment, while self-directed learning stems from adult education and involves broader macro-level constructs initiated by students (Loyens, Magda, & Rikers, 2008; Saks & Leijen, 2013). Zimmerman and Lebeau (2000) contend that in the context of PBL, that self-regulated learning and self-directed learning are highly similar and oftentimes the literature uses the terms interchangeably.

Metacognition is knowledge, understanding, and regulatory skills for thinking as part of cognitive, affective, or conative experiences (Mayer, 2001). This is an important area for cognitive outcomes in knowledge development and cognitive behavior modification. Metacognition also provides a means for building and recognizing affective or conative elements, for instance self-regulation and value for learning. Learners with metacognitive skills are able to discern and monitor their knowledge and know when they are not understanding a concept, making metacognition essential to cognitive, affective, and conative effectiveness (Mayer, 2001). It is important to note that metacognition has a role across all three domains and is mentioned by Barrows (1986) as well as Hmelo-Silver (2009) as an element promoted by PBL. While meta-cognition is certainly well aligned and probably merits a similar review of its own we decided to stay with self-directed learning in part because it is specifically described as part of the components of PBL (Barrows, 1986).

Self-Directed Learning in PBL

Like many areas of scholarship, the origins of PBL are complex and include parallel efforts. As PBL was being developed, a need was observed in students to not only understand content, but to "learn to learn" (Barrows & Tamblyn, 1980, p. 8), become lifelong learners (Barrows, 1986), and be more autonomous and responsible for their own learning (Brockett & Hiemstra, 1991; Knowles, 1975). Clinical cases as described by Jones, Beiber, Echt, Scheifley, and Ways (1984), or their simulated patient counterparts (Barrows & Tamblyn, 1976), were not just about problem solving or discipline specific clinical reasoning in medical education, they provided students with skills that would allow them to navigate the constantly evolving knowledge base in medicine (Savery, 2006). Thus PBL had a new vision of education, where students would not only meet their future practice with the right knowledge but also with the right volition and skills to use that knowledge. In order to move away from traditional rote learning and toward lifelong learning in a constantly evolving discipline, PBL promoted self-directed learning which would allow students to take ownership in identifying what they needed to know and be able to do in order to solve the problems at hand.

Cognitive, Affective, and Conative Domains

Historically, cognitive psychology focused only on the cognitive domain, but that has recently changed and the field of psychology is encompassing more areas of research, including the affective and conative domains, to advocate active learning and to view students more holistically (Bruning, Schraw, Norby, & Ronning, 2004). The three domains represent separate but interactive areas of knowledge, connection, perceptions, and behavior related to learning. It is important to note that a more inclusive picture of a learner is provided when the three domains are represented. Since PBL advocates and purports it knowledge and process building as well as self-directed learning (which provide a more well-rounded picture of a learner), it is important to include information about all three domains and how they relate to PBL. The cognitive domain is widely associated with Bloom's (1980) taxonomy, where learning builds upon each step, beginning with knowledge and moving to comprehension, application, analysis, synthesis, and evaluation. Cognition includes knowing, understanding, storing, retrieving, and processing information.

The affective domain also builds upon the early work of Bloom (1980), where he and his co-authors concentrate on a learner's sensitivity to certain phenomena (Krathwohl, Bloom, & Masia, 1973). This domain involves the interpretation of feelings, emotions, attitudes, values, and awareness related to learning. Krathwohl and colleagues provided a taxonomy of categories including receiving (awareness, interest), responding (acknowledging potential value, appreciating), valuing (attitudes), organizing (attitude adjustment), and characterization (change in attitude or values). Affect, in general, encompasses the passion and feelings that accompany learning. The conative domain, in contrast, is concerned with the activation and connection of behavior or actions related to knowledge and affect (Huitt & Cain, 2005). There are many terms that comprise this domain, including goals, directed efforts, follow-through, self-direction, and self-regulation. To recap, the conative domain strives to activate internal intentions. Cognition looks at what is learned, the affective domain emphasizes feelings about what is learned and the learning experience, while the conative domain underscores actionable behavior, with a willingness and desire to learn. While self-directed learning leads to cognitive gains it is most directly associated with the affective and conative domains.

Related Learning Theory and Instructional Theory

PBL has drawn criticism for having imprecise ties to learning theory (Colliver, 2000). To a certain extent we agree. As a fundamentally pragmatic solution to pressing problems in medical education early work in PBL was not necessarily created with existing learning or instructional theory in mind. That does not mean that post-hoc connections to theory cannot be drawn, which is an effort undertaken by Albanese (2000), and one that we will expand on here as it pertains to self-directed learning. Since self-directed learning is both a learning theory and a prescriptive instructional theory we consider both instructional and learning theories as part of our review below.

Both Colliver and Albanese eschew *contextual learning theory*, which is a prescriptive instructional theory rooted in constructivism and overlapping with situated, social, and distributed cognition (Borko & Putnam, 1998). Contextual learning theory places an emphasis on providing multiple contexts for learning, recognizes the importance of problem solving, promotes learners engaging in self-regulation, and calls for authentic assessment. While all of these overlap with key principles of PBL, there are concerns about the quality of the basic research associated with contextual learning theory (Albanese, 2000; Colliver, 2000). For the context of this review, the best match in contextual learning theory to self-directed learning is self-regulation, which is a better match to motivation. While motivation is an important PBL outcome and instructional theories of motivation are closely related to self-directed learning, it is not the focus here.

Information processing theory at a surface level has a good alignment. As a computer model analogy of not just human memory (working, short-term, long-term) but processes for the interpretation, encoding, and placement/retrieval of information (Anderson, 1990). While it certainly has prescriptive work associated with it, information processing is a learning theory. As pointed out by some authors, specific elements of information processing theory are present in PBL (Schmidt, 1983) including activation of prior knowledge when identifying knowledge gaps and learning issues, using learning situations similar to eventual practice to promote encoding specificity, and meaningful reflection built into things like closed-loop PBL (Barrows, 1986). While this is a great theoretical foundation for structured content knowledge and perhaps even reasoning processes, both of which are important to PBL, the ties to self-directed learning are less clear.

One potential bridge is provided with situated cognition. There is a fundamental acknowledgment that learning is not only social and contextualized but actually an elevation of those concepts. Learning does not happen within a context but rather learning is an integral part of both social activity and practice (Lave & Wenger, 1991). Situated cognition offers overlap with cooperative learning in the sense that there are communities of practice that negotiate norms, tools as mediational means for achieving goals, and even the very language used to discuss practice. As a theory, situated cognition offers a radically different perspective from information processing theory. According to situated cognition, attempting to come up with an objective conceptualization of knowledge implies an artificial distinction between individuals that are fundamentally connected, and fails to account for individuals who are acting and engaging in meaningful inquiry within their communities of practice. Despite this level of overlap, there are certainly disconnects with much of the PBL literature.

Situated cognition has long looked for models outside of traditional and formal schooling (Lave & Wenger, 1991). In part because by design these formal institutions strip away meaningful context, focus on the individual, assess discrete knowledge, and generally shy away from learning being social, participatory, and negotiated (Wenger, 1998). Yet, to the extent that PBL is used in formal settings it faces similar challenges. Asking learners to take a leadership role in small-group tutorials is an exercise so uncomfortable that some tutors have found themselves conducting mini-lectures despite being trained otherwise (Moust et al., 1990). PBL has been used in a wide range of contexts from very discrete activities to entire curricula. While a single-class PBL intervention bears little resemblance to situated cognition, an entire PBL curriculum, paired with adult/continuing education is taking steps that are closer to cultivating communities of practice. For a more extensive review of PBL, situated cognition, and their common philosophical roots, see Hung (2002).

We see the promotion of practice, emergent practice, and the negotiation of what communities value and even how they communicate as described in situated cognition as being closely aligned with principles of self-directed learning. Tutors play the role of more central members of a community and PBL learners are inherently inbound (Wenger, 1998), bringing with them what they already know—perhaps even from related communities of practice. These inbound learners may take on the role of legitimate peripheral participants, and are constantly negotiating with themselves as well as with other group members and the tutor what it means to be part of the community that is ideally central to their PBL experience.

PBL Goals

The PBL literature provides detailed definitions for the learning objectives and goals in PBL. Some PBL educational objectives were rooted in medical education, while others take into consideration the movement of PBL into more disciplines or the importance of self-directed learning (Barrows, 1986; Hmelo-Silver, 2004, 2009; Loyens et al., 2008; Norman & Schmidt, 1992). These goals include:

1) Structuring of knowledge for use in clinical contexts.
2) Developing an effective clinical reasoning process or problem-solving skills.

3) Development of effective self-directed learning skills or lifelong learning skills.
4) Increased motivation for learning (develop intrinsic motivation).
5) Constructing flexible knowledge.
6) Being a good collaborator.

Among the educational objectives and goals listed, the cognitive, affective, and conative domains are included.

Cognitive Goals

Knowledge is at the heart of cognition, and PBL improves student knowledge. Barrows (1986) wrote that the structuring of knowledge for use in clinical contexts focuses on information recall and application. The development of an effective clinical reasoning process complements the acquisition of structured knowledge. In contrast with structured knowledge, clinical reasoning involves developing problem-solving skills through practice. This represents one of the key shifts of PBL as compared to more traditional pedagogies. While PBL shares common ground in terms of authentic practice with several problem-centered pedagogies it is particularly well-positioned with respect to self-directed learning.

Roger Schank (1995) makes the claim that by verbalizing experiences learners will structure their knowledge in a way that promotes later recall and meaningful use of what they have gleaned. One of Schank's many points is that listening to the stories of others is not in itself a meaningful experience, rather, learning comes from either actively interpreting the stories of others, or better yet, having to both experience and then frame what you have learned in a way that would make sense to others. Both interpreting or living and telling your own experiences require a level of intentional action on the part of learners that overlaps with both problem-based and self-directed learning.

Intentional action is embodied with elements like the collaborative independent study of problem-based groups where learners have purposefully identified their learning issues in relation to the provided problem then sought out the necessary information, processes, and techniques that are best applied toward a meaningful solution. For self-directed learning the intentionality described here is about taking personal responsibility (Abraham et al., 2016), and while PBL is a planned pedagogy, the immersion in authenticity is in some ways a better fit with informal learning that occurs outside of traditional classrooms (Bolhuis, 2003).

In PBL, students construct their reasoning process through generating a hypothesis, information seeking, analysis, synthesis, and making decisions while acquiring information. As noted above, self-directed learning for the purpose of this review is both a measurable outcome as well as a process (Candy, 1991; Leary, 2012). As an executive function problem-based learners are self-directed in that they intentionally plan, refine, carry out, and subsequently evaluate their learning experiences. One of the best ways these core elements of self-directed learning are revealed is through the work of Hmelo-Silver and Barrows (2006). Rather than adopting the typical pattern of a teacher initiating a question, getting a student response, and evaluating their response, learners engage in a far more self-directed approach. Learners identify a preliminary hypothesis and then engage in a backward-driven reasoning process. That process illuminates the expected roots of observable phenomena (e.g., a patient who the learners think is about to go into diabetic shock may have labored breathing as well as a fruity odor on their breath). The fruity odor is a potential sign of ketoacidosis caused by a shortage of insulin. A test for high blood sugar could make sure of the root cause and by reasoning backward through their preliminary hypothesis a group of PBL learners has shifted to making, and discussing their own knowledge claims. Further, their exploration of other plausible hypotheses (such as anorexia nervosa) that also may present with a fruity odor on the breath can help them differentiate between these differential diagnoses.

Affective and Conative Goals

Motivation is a strong element in the conative domain and helps fuel learning in the cognitive domain. As an essential part of PBL, learning through the challenge of solving problems coupled with its perceived relevance is often motivating for a learner. Perceived relevance is central to the affective domain, with learners placing value on the content and context of the learning. Hmelo-Silver (2009) referred to motivation as being an intrinsic element that involves students working on a task for their satisfaction or interest and determining what is engaging or that the goal is important. Motivation is a very strong element of self-directed learning. It has the power to propel a student forward quickly and helps them in acquiring the skills and resources needed to enhance their learning as well as increasing awareness and acceptance of learning processes.

The development of effective self-directed learning skills includes self-assessment and flexible knowledge so that the student understands their personal learning needs and where to find and use appropriate information for problem-solving (Barrows, 1986; Loyens et al., 2008). Two characteristics in the affective domain, knowing what a student values in learning and recognizing their attitude toward learning, and a student's directed efforts from the conative domain will be promoted in a PBL environment. Students must know what they do and do not know. They need to set goals and be able to identify their knowledge gaps, strategize how to reach their goals, implement the plan, and assess if they have reached their goal. The collaborative part of self-directed learning encompasses all aspects of working in a group and, as students commence work in PBL environments, working through problems they build their self-directed learning skills. Establishing common ground, negotiation, resolutions, actions, and agreement require open communication from all members. This goal incorporates the items of caring, valuing, attitudes, actions, willingness, directed efforts, and the desire to assume responsibility, all of which are part of the affective and conative domains.

The goals of PBL place value on and imply that PBL promotes learning outcomes in the cognitive, affective, and conative domains. According to Krathwohl et al. (1973), all domains are important for effective learning and each plays an important role in student outcomes. Research shows that learning encompasses cognition, metacognition, the affective and conative domains (Martin & Briggs, 1986). Although it is important to study them individually, they should also be synthesized together as none of them should be singled out as more central to learning than another (Bloom, 1980; Bruning et al., 2004; Krathwohl et al., 1973; Mayer, 2001). Together they provide learners with the opportunity to receive and use knowledge, motivation to gain knowledge (Anderson, Greeno, Reder, & Simon, 2000; Lave & Wenger, 1991; Smith & Ragan, 1999), and the skills to understand their own learning (Duell, 1986).

Self-Directed Learning Studies Review

Blumberg (2000) uses an organizing framework to consider self-directed learning. *Learning processes* is about the ability to define what to learn, planning and operationalizing learning, time management, seeking and evaluating resources, and evaluating self-directed learning skills. The second dimension, *learning strategies*, focuses on the methods that students use to process information, and *learning outcomes* refer variably to immediate (short-term) or years after a PBL intervention (long-term). Blumberg summarizes that PBL fosters self-directed learning skills, that PBL students are active library users, that PBL students engage in deep-level processing, and the development of self-directed learning skills is recognized by the student and the teacher. This framework includes some of the basic elements of self-directed learning. Learning process and learning outcomes fit well within the cognitive domain (knowledge and awareness), with learning strategies aligning well with the conative element of skill acquisition to enhance learning.

Loyens et al. (2008) builds on the previous literature review by Blumberg and includes similar and succinct categories to characterize self-directed learning in PBL. *Learning issues* refer to what the student needs to do to gain a better understanding of the problem as they rely on their prior knowledge and pursue resources (learner awareness in self-directed learning; cognitive domain). *Time planning and self-monitoring* is a student's capability to plan and monitor their time (skills to enhance learning in self-directed learning; conative domain). In *information-seeking behavior* students make decisions on what materials and resources to use, and these behaviors differ between first-year (rely on reference literature, content in tests, and lectures) and senior students (rely on tutorial group discussions) (skills to enhance learning in SDL; conative domain). In line with information-seeking behavior, *student perceptions of self-directed learning* were less certain for beginning students, while seniors acknowledged the importance of being self-directed (acceptance in self-directed learning; affective domain). They also indicated that they needed support from a teacher to gain these skills. This review highlights that conceptual clarity of what is self-directed learning provides guidance for teachers and students to foster their self-directed skills development.

The only dissertation reviewed was a meta-analysis focused on self-directed learning, comparing lecture-based classrooms with problem-based classrooms (Leary, 2012). This analysis was the first synthesis with quantitative data from multiple disciplines and studies that support the claims that PBL promotes aspects of self-directed learning. The overall effect size was in favor of PBL classrooms, with a medium effect size of $g = 0.45$. Using the structure of self-directed learning provided by Candy (1991), the meta-analysis divided self-directed learning into four components: (a) learner control of instruction, (b) self-management in learning, (c) personal autonomy, and (d) independent pursuit of learning. These components reported positive summary effects in favor of PBL. Additionally, the data support the concept that self-directed learning in PBL is a process (within an intervention) as well as an outcome (result of the intervention). Process refers to gaining and using self-directed learning skills while in the method of learning, while outcomes refer to a skill the student walks away with that could be transferred to another learning opportunity.

To understand the characterizations of self-directed learning from the remaining recent empirical and theoretical literature, we have taken a very condensed and simplified approach using categories and ideas from Blumberg (2000), Loyens et al. (2008), and Leary (2012) as well as what emerged from the literature. We propose five high-level categories for characterizing self-directed learning in PBL: (a) learning process, (b) learning outcomes, (c) perceptions, (d) teacher support and environment, and (e) learning models. The five categories include important elements of self-directed learning, from learner awareness and initiative in diagnosing and carrying out their learning needs to the acquisition of skills and resources to enhance learning. These categories highlight the process of self-directed learning and outcomes associated with it as well as parts of the cognitive, affective, and conative domains.

Learning Process

Learning process encompasses everything that has to do with learners understanding topics, self-learning, motivation, learning actions, planning, goal setting, strategies and assessment skills, deep approaches to learning, reflection, using resources, and making choices (Abraham et al., 2016; Demirören, Turan, & Oztuna, 2016; Kek & Huijser, 2011; Malan, Ndlovu, & Engelbrecht, 2014; Rimal, Paudel, & Shrestha, 2015; Shankar & Nandy, 2014; Silien & Uhlin, 2008; Statham, Inglis-Jassiem, & Hanekom, 2014; Yew & Schmidt, 2012). As a very large category, the learning process encompasses actions (conative domain). In a previous study, students remarked about the process of learning that "…as PBL is assessed, it demands more understanding of topics, and requires more self-learning" (Abraham et al., 2016, p. 17), which is part of the process but also triggers learning and stimulates interest, leading to linking concepts and stimulating more learning (part of the cognitive and conative domains) (Abraham et al., 2016).

In many ways, this category is very large and quite broad. It highlights so many aspects of self-directed learning that align well with PBL. One element of the learning process, finding and using resources is an important aspect of PBL. How students use resources varies. Shankar and Nandy (2014) indicated that new students used resources inside and outside the classroom differently than more seasoned students, showing a shift in more elegant planning and use of resources for seasoned students. Other elements in the learning process include goal setting and planning. Demirören et al. (2016) reported gender differences in planning and goal setting (female students do this better). Yew and Schmidt (2012) summed up the PBL learning process as "one that encourages active processing and organization of information through co-constructions and elaborations in small group discussions" (p. 393).

Learning Outcomes

In the meta-analysis by Leary (2012), specific mention of what we consider *learning outcomes* was made. This category refers to encouraging students to be more interactive in their learning to potentially lead them down the path of being a lifelong learner (Rimal et al., 2015). Leary (2012) describes a learning outcome as measuring the level or ability to engage in self-directed learning after the instruction (fostering transformative learning or making connections with prior knowledge and applying that in new learning environments and situations). As opposed to self-directed learning as a process (a formative outcome), the focus for a self-directed learning outcome is more summative and transformational. Ferriera and Trudel (2012) indicate an increase in problem-solving skills in a high school science classroom after using PBL and indicate the students left the classroom as active learners, ready to be transformational in their learning. Being able to interpret what this means for an individual learner (affective domain) and then act on it (conative domain) are high-level skills in self-directed learning. Designing learning opportunities with outcomes in mind would enhance a learning experience.

Perceptions

Individual beliefs about the capability to learn, perform a certain behavior, to change, or to grow encompass *perceptions*. Beliefs can develop from direct experience, observing others, reactions, or persuasion (Demirören et al., 2016). The *learning process* and *learning outcomes* can be affected by *perceptions*. Malan et al. (2014) indicated that the sustainability of learning (both as a process and as an outcome) is hindered if the belief in the approach does not support the activity. Perceptions and interpretations (affective domain) are very powerful in building self-directed learning skills. Students perceive many things about their learning processes and outcomes, and PBL teachers/facilitators have their own perceptions (Statham et al., 2014). This idea leads directly into the next category of *teacher support and environment*.

Teacher Support and Environment

English and Kitsantas (2013) indicate that PBL students must take responsibility for their own learning and development of self-directed learning skills, but that the teacher or facilitator as well as the learning environment must be designed to support them. They believe that self-directed learning skills will grow when certain environmental features and teaching practices are used. Specifically, that in the beginning of a PBL class, teacher involvement and direction should be high and then decrease as the class continues forward in time to end with low amounts of teacher involvement and high amounts of student self-direction. Kek and Huijser (2011) believe that to develop self-directed learning skills in students, a teacher must be actively involved and engaging students to participate in questioning, explaining, and evaluating ideas. Along with this, self-directed learning skills develop when a healthy student–teacher relationship is present (which can often be an emotional connection in the affective domain), making PBL not a fully independent student activity (Timmons, 2008). Statham et al. (2014) found that the main beliefs and perceptions from a PBL module were different for the students and the teacher. One group of students focused on improving clinical reasoning, information gathering, and organization while the other group of students focused on seeing students take responsibility for their own self-directed learning. In the study by Frambach, Driessen, Chan, and van der Vleuten (2012), year one medical students exposed to an independent PBL learning environment without adequate guidance became overly dependent on tutors and rote learning to survive, which prevented them from developing self-directed learning skills. The *environment* teachers and students dwell in as well as the *support from a teacher* impacts all of the previous categories and can impact the development of self-directed learning skills in a positive or negative direction (Demirören et al., 2016). This also makes situated learning more attractive as a theoretical model for PBL. An institution looking to promote self-directed learning is going to need to cultivate a community of practice (Wenger, McDermott, & Snyder, 2000) that extends beyond the PBL classroom.

Learning Models

Several articles provided *learning models* to use and follow when implementing PBL and striving to support the development of self-directed learning skills. English and Kitsantas (2013) describe learning environment features and teaching practices. In terms of learning environment there are many factors (classroom environment, student processes, teacher direction, and self-learning). As students progress through the phases of the class and self-learning, the teacher direction decreases and student direction increases. For teaching practices, Silen and Uhlin (2008) developed two thinking models aimed at promoting self-directed learning. In the first (Model A) inquiry in the tutorial session emphasizes that there should be varying and different inquiry processes during a tutorial session. In the second (Model B), the relationship between tutorial sessions and self-study stresses an ongoing self-directed process while connecting what is learned with tutorial sessions. Strohfeldt and Grant (2010) introduce a model for self-directed learning in PBL that keeps a high standard with curricular goals while lowering staffing resources, which can be a challenge when implementing PBL courses (Leary, Walker, Shelton, & Fitt, 2013). The model uses case studies and repeated steps to reinforce the PBL process and critical thinking, which fall into the categories of the learning process and learning outcomes. These models provide the unifying ideas of opportunities for stimulating and engaging students while raising them to their responsibility as learners without compromising curricular integrity or the PBL process.

Reviews and Meta-Analyses of Self-Directed Learning in PBL

The literature on PBL covers empirical studies to literature reviews to meta-analyses. Since its inception, many meta-analyses have been conducted to analyze the effectiveness of PBL for cognitive outcomes (Albanese & Mitchell, 1993; Dochy, Segers, Van den Bossche, & Gijbels, 2003; Kalaian, Mullan, & Kasim, 1999; Vernon & Blake, 1993; Walker & Leary, 2009). Several have shown positive gains in affective and conative outcomes such as motivation, student satisfaction, and self-directed learning (Albanese & Mitchell, 1993; Vernon & Blake, 1993). Although some claim that affective and conative outcomes should develop through the use of PBL (Albanese, 2000; Hmelo-Silver, 2009), only one systematic review focuses on self-directed learning (Leary, 2012) and through meta-analysis provides evidence that PBL does indeed promote and support the development of self-directed learning as a process and transferable outcome for learners.

Narrative portions of prior reviews have examined both affective and conative outcomes such as motivation, student satisfaction, and self-directed learning skills (Albanese & Mitchell, 1993; Vernon & Blake, 1993). Students in the PBL treatments showed improvements in their interest, attitude, and behavior with respect to learning. Albanese and Mitchell found that PBL students exhibited different study behaviors when compared to a traditional lecture-based environment, including an increase in studying for deep meaning and understanding as well as for the "sheer joy" (p. 61) of learning. Students in PBL curricula were more likely to study by reflecting on the material, and they tended to have a more positive orientation toward the content and process of learning. Vernon and Blake (1993) found that PBL students had positive attitudes toward their programs.

Conclusions

Recent literature reviews and a meta-analysis have focused on understanding self-directed learning in PBL. Both PBL and self-directed learning have a great deal of stand-alone scholarship looking at first proving the efficacy and then engaging in refinement over time. This review aims at further elaborating the connections between PBL and self-directed learning. From existing reviews to primary research, and all the way down to related instructional theory and learning theory clearly those connections exist. We have reported that data support the claims that PBL promotes self-directed learning both as a process within PBL and as an outcome of effective PBL interventions. Further, self-directed learning is mediated heavily by student and teacher perceptions, by environmental factors, and by underlying models that are used (or not) as part of a larger intervention.

While this is a good start, much work remains. The empirical literature on self-directed learning on PBL is still relatively new. Albanese (2000) mused early on that some of the best PBL outcomes might be noncognitive in nature. As a construct that is cognitive, affective, and conative, self-directed learning is clearly an effective outcome and key ingredient in PBL. Yet making that case is only part of the necessary work. We hope that future scholarship will look at ways to refine and improve on self-directed learning in PBL, perhaps exploring further the role of teacher and student perceptions, the surrounding environment, and even connections to situated cognition. In order to facilitate that work, self-directed learning faces several measurement challenges. The rather large reliance on self-report makes for a challenge to show both reliable and stable measures. Scholars should look for a mix of self-reported data and evidence of self-directed learning subscriptions to educational sources, attendance or the kinds of professional development choices made, choice of profession or type of practice (such as preparing the next generation of practitioners) as potential evidence of self-directed learning in conjunction with PBL. We also acknowledge the close proximity and overlap between self-directed learning and motivation, both of which are important outcomes of PBL. A future review exploring motivation in the context of PBL will be an important part of understanding and potentially refining PBL as it relates to self-directed learning.

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9

Group Work and Group Dynamics in PBL

Herco T. H. Fonteijn and Diana H. J. M. Dolmans

Introduction

Small-group work is a cornerstone of problem-based learning (PBL), yet groups have not always been at the forefront of discussions of the merits of PBL. Some researchers believed groups simply provide an environment that facilitates individual knowledge acquisition (cf. Eva, 2002). Others argued that high functioning groups boost intrinsic motivation for studying course content and test performance (De Volder, Schmidt, De Grave, & Moust, 1989). By explaining, discussing, and negotiating content in the tutorial group, students share, elaborate, integrate, and apply knowledge that is acquired by individual members (e.g., Schmidt, Rotgans, & Yew, 2011; Visschers-Pleijers, Dolmans, de Leng, Wolfhagen, & van der Vleuten, 2006). Studies on tutorial group work have focused on cognitive processes elicited by small-group discussions on the quality of problems, effects on achievement, and the influence of the tutor on group learning (Chiriac, 2008).

Small-group work is also associated with social–emotional, motivation-enhancing qualities. Tutorial groups would help students to develop friendships, while close contact between tutors and students can help build an academic community (e.g., Cockrell, Caplow, & Donaldson, 2000; Schmidt, Rotgans, & Yew, 2011). In PBL, a student is pushed by peers to exert effort because of presumed outcome interdependence: for a student to succeed, the group must succeed. When team spirit develops, students will want to help their peers.

Azer and Azer (2015) recently reviewed studies on group interaction in PBL in health sciences and concluded that group interaction was affected by student and tutor perceptions, subject-matter expertise of tutors, group dynamic skills of the tutor, and training students in group dynamics. However, there was limited evidence for an effect of group interaction on learning. In addition, process losses can be daunting.

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This chapter will review factors affecting group work and group dynamics in PBL, being group resources such as composition and diversity, learning task and processes, the learning context, but also structural and interpersonal losses and possible remedies.

Factors Affecting Group Work and Group Dynamics in PBL

In PBL, the task or problem is the focus of all group-based activities. It gives rise to learning goals and task-based exchanges of interdependent group members. However, to a large extent the acquisition of knowledge and skills in a tutorial group is based on individual learning. Therefore, PBL group discussions are constrained by the resource pool (i.e., individual differences and capabilities of group members). As group processes unfold over time, various states emerge that are typically studied by asking members to quantify perceptions of cognitive and motivational group-level constructs (e.g., satisfaction, cohesion, or group efficacy; cf. Kozlowski & Ilgen, 2006). These states can impact group learning behaviors. For instance, perception of psychological safety has been shown to affect group learning behaviors like seeking feedback, asking for help, and discussing misconceptions (Edmondson & Lei, 2014). This section focuses on the resource pool, the learning task and group learning behaviors, and ends with an overview of contextual factors that affect group work and group dynamics.

The Resource Pool

The size of the tutorial group, individual differences, and abilities of its members as well as diversity all belong to the resource pool that constrains PBL group work.

Group size

Although the immediate impact of size on group work is difficult to determine (Stewart, 2006; Webb & Palincsar, 1996), large groups would benefit from increased resources brought in by members, but tend to suffer from coordination or process losses. For example, Lohman and Finkelstein (2000) found more evidence for self-directed learning in PBL tutorial groups of six students than in groups of nine students. Unfortunately, small-size tutorial groups (with low student–tutor ratios) have high delivery costs.

Individual differences

Individual differences and abilities also affect group work. For instance, *personality* factors like extraversion, conscientiousness, agreeableness, and dominance relate to (attitudes toward) group work (Driskell, Goodwin, Salas, & O'Shea, 2006). Holen et al. (2015) showed that PBL was appreciated by extravert, curious, agreeable, and conscientious students, and by some students high on neuroticism. Students high on conscientiousness disliked group work, while students scoring low on agreeableness showed more negative preferences for PBL. Apart from personality, relationship status affected attitudes toward PBL: students living in symmetrical relations (e.g., peers, partners) were more in favor of PBL than students living in asymmetrical relations (e.g., with parents or relatives). The authors also found that female students demonstrated less negative PBL preferences.

Ability

Although cognitive ability and skill levels of team members boost team performance (Stewart, 2006), Woolley, Aggarwal, and Malone (2015) found that average and maximum intelligence of individual group members was only moderately correlated with collective intelligence (i.e., the group intelligence that emerges from collaboration between its members). Excellent students may be valuable team resources and help some group members perform, but they may also demotivate other group members (Rogers & Feller, 2016). Woolley et al. (2015) conclude that social perceptiveness, percentage of women in a group, and the distribution of speaking turns have higher predictive power for collective intelligence.

Experience

Familiarity with group work will also affect PBL outcomes. Students face difficulties when they leave a passive, instructor-directed role and embrace a learner role that calls for self-direction or self-regulation (Henry, Tawfik, Jonassen, Winholtz, & Khanna, 2012). Indeed, the scaffolding that a PBL environment can offer more strongly affects learning behavior of first-year students than learning behavior of senior students, who seem to be more ready for self-directed learning (Dolmans & Schmidt, 2006).

Rotgans and Schmidt (2011) found that students in an applied science PBL curriculum differ in feelings of autonomy and situational cognitive engagement, which they assume would progress with students' knowledge acquisition in PBL, rather than with changes in task demands. Cognitive engagement relates to other types of *motivation* (self-efficacy, grit, growth mindset) that add to the resource pool. Various studies on motivation in PBL (e.g., Dolmans, Wolfhagen, & Van der Vleuten, 1998; Singaram, Van der Vleuten, Van Berkel, & Dolmans, 2010) suggest that motivated students elaborate on discussion content and correct contributions from peers, thus enhancing learning. Apart from epistemic motivation, or the willingness to expend effort to achieve a deep understanding of the group task, pro-social motivation—being preferences for joint outcomes, cooperation, and fairness—may also improve group outcomes. Pro-social motivation can boost team cohesiveness and collaboration and create a safe and open climate for communication (cf. Randall, Resick, & DeChurch, 2011). Lack of pro-social motivation, evidenced by sponging, free-riding, or withdrawing behaviors, lowers resources and frustrates collaboration.

Diversity

Heterogeneity may also add to the group resource pool. While cognitive diversity is believed to improve the quality of information elaboration, demographic diversity may interfere with group performance. Demographic differences can affect PBL outcomes by making heterogeneous groups vulnerable to faultlines: dividing lines that subdivide a group in subgroups and that are based on alignment of demographic attributes (Lau & Murnighan, 2005).

The Categorization-Elaboration Model (Van Knippenberg, De Dreu, & Homan, 2004) states that information elaboration and social categorization processes interact, such that intergroup biases, triggered by social categorization, disrupt the elaboration of task-relevant information. For instance, a focus group study by Singaram, Van der Vleuten, Stevens, and Dolmans (2011) showed that medical students in South Africa working in heterogeneous groups learned more from each other because of their differences in language and academic preparedness. Yet, groups were less productive when students segregated in the tutorial groups along racial lines. Jiang, Jackson, Shaw, and Chung (2012) found that faultlines based on educational specialty in interdisciplinary project teams reduced information sharing, whereas faultlines based on nationality reduced off-task social interactions. Demographic faultlines can have positive effects on task performance and elaboration, when team members have high levels of task motivation and hold pro-diversity beliefs (Meyer, Glenz, Antino, Rico, & González-Romá, 2014). Heterogeneous teams with strong prosocial motivation may also interact well, provided adequate guidance can help the group make sense of what happens (Randall et al., 2011). Overall, however, sharing similar backgrounds seems more conducive to information sharing and team effectiveness (DeChurch & Mesmer-Magnus, 2010).

These diversity-related effects in heterogeneous teams suggest group members should try to understand both the task and the group processes, including knowledge of "who knows what" so relevant expertise can be brought in at the right time (cf. Hung, 2013; Van den Bossche, Gijselaers, Segers, Woltjer, & Kirschner, 2011).

The Learning Task and Group Learning Processes

Characteristics of the problem or task affect group work, as do both sociocognitive learning processes (e.g., co-construction, mutually shared cognition, constructive conflict, and reflexivity) and interpersonal processes (social cohesion, psychological safety, interdependence, group potency; cf. Van den Bossche, Gijselaers, Segers, & Kirschner, 2006; Van den Bossche et al., 2011).

The learning task

Sockalingam, Rotgans, and Schmidt (2011) noted that problem clarity led to more group discussion than problem familiarity. However, students did not value problems for stimulating elaboration and promoting teamwork, but preferred interesting problems from which learning goals are easily derived (Sockalingam & Schmidt, 2011). Conversely, problems that do not provide adequate challenges for learning new knowledge and skills can trigger "ritual" behaviors; that is, a situation in which students keep the appearance to be actively involved (Dolmans, Wolfhagen, van der Vleuten, & Wijnen, 2001). Apart from *meaningfulness* and clarity of problems, *interdependence* is a strong driver of PBL group dynamics. Group perceptions of interdependence can affect cooperation in a group and produce a greater shared responsibility (Van den Bossche et al., 2006). Researchers distinguish between outcome interdependence (i.e., personal benefits depend on successful performance of other team members) and task interdependence (i.e., interconnections between subtasks so that performance on one assignment depends on the quality or completion of another subtask or assignment; cf. Wageman, 1995). Task interdependence leads to more communication and information sharing. Given interdependent tasks, groups will build shared knowledge of the task and the team (e.g., transactive memory or shared mental models, cf. Hung, 2013). Outcome interdependence in PBL relates to assessment. Cooperative learning in PBL would be effective if tasks were properly designed and the tutorial group tried to achieve shared learning goals while each individual is accountable for their learning (cf. Slavin, 1991). Instructors can trigger different interactions patterns, as they strike a balance between group assessment and individual assessment. For instance, Kamp, Dolmans, Van Berkel, and Schmidt (2013) found evidence for causal relations between a student's constructive activities and their unit test score and between a student's collaborative activities and the group assignment score.

Autonomy

Autonomy is a third key driver for group interactions. In PBL, need for autonomy figures in the debate on the respective merits of self-regulated and self-directed learning. In self-directed problem-based learning, students have a stronger voice in the selection and evaluation of learning materials than in self-regulated learning (Loyens, Magda, & Rikers, 2008). Empowerment of students is presumed to increase motivation and group potency (Vansteenkiste, Sierens, Soenens, Luyckx, & Lens, 2009; cf. Rousseau & Aubé, 2013). Verkoeijen, Rikers, Te Winkel, and Van den Hurk (2006) showed that a student group who generated their own learning goals studied more materials and spent more time on individual study and group discussion than a student group who were given learning goals.

Group climate

The teamwork literature suggests various team-level constructs and beliefs influence PBL group learning processes (Van den Bossche et al., 2011). For instance, group potency (an overall belief about the group ability to be effective; cf. team efficacy) may foster team confidence and hence help teams persevere. Task cohesion (shared commitment to achieve group goals) also relates to team learning behaviors, unlike social cohesion (emotional bonds of friendship), which can lead to groupthink, but predicts team viability. Psychological safety has been shown to affect group learning by assuring members that dissenting ideas can be voiced without harm (Edmondson & Lei, 2014). Team psychological collectivism boosts prosocial motivation, which benefits information sharing (Randall et al., 2011). Van den Bossche et al. (2006, 2011) also argued that acquisition of mental schemas is influenced by social outcomes listed above (but see Woolley et al., 2015). For instance, a qualitative study by Robinson, Harris, and Burton (2015) showed that chairs can negatively impact group learning if they fail to manage rapport, especially when students have little prior knowledge about the subject matter and team members feel pressures to save face while they share learning with others.

Team learning behaviors

Successful PBL groups establish interaction processes that help share and co-construct knowledge, for example, by asking exploratory questions, cumulative reasoning, and handling conflicts (cf. Visschers-Pleijers, Dolmans, Wolfhagen, & van der Vleuten, 2004, 2005a, 2005b; Visschers-Pleijers et al., 2006; Yew & Schmidt, 2009). A key skill for building mutually shared cognition is negotiation: team members achieve agreement through constructive conflict on how a problem is interpreted. They then develop mutually shared cognition by accepting co-constructed understanding of a problem (Van den Bossche et al., 2006, 2011).

A study of 89 first-year medical students in six problem-based learning groups (Draskovic, Holdrinet, Bulte, Bolhuis, & Van Leeuwe, 2004) found that knowledge elaborations mediated the relationship between task-oriented interactions and knowledge acquisition. Elaborations benefited the acquisition of metacognitive understanding and relational knowledge more than the acquisition of factual knowledge. Similarly, Chernobilsky, Dacosta, and Hmelo-Silver (2004) found that students involved in problem-solving groups showed increased ability to use the specialized language of the discipline to analyze problems. Again, learning was related to participation in co-constructive group activity.

A recent review comparing effects of PBL on deep versus surface approaches to learning also showed mixed results with small positive effects of PBL on deep learning and little effect on surface learning (Dolmans, Loyens, Marcq, & Gijbels, 2015). This aligns with meta-analyses suggesting that group work in PBL can benefit learning, showing small differences between PBL and traditional methods for knowledge acquisition, typically at the principle and application level of assessment, and substantial differences for acquisition of skills (e.g., Gijbels, Dochy, Van den Bossche, & Segers, 2005; Walker & Leary, 2009).

Van Blankenstein, Dolmans, Van der Vleuten, and Schmidt (2013) tried to disentangle elaboration during group discussion and prior knowledge of members by having students observe a problem-based discussion while a tutor asked either elaborative or superficial questions. Elaborative questions had no main effect on recall, but there was an interaction with prior knowledge: elaboration is helpful for students with more prior knowledge, but harmful for students with less prior knowledge.

The Learning Context

Context can affect PBL group processes in various ways, even within a module. This section focuses on the context of learning.

Discipline

Disciplines can impact pedagogical methods (cf. Shulman (2005) on signature pedagogies), for instance because cognitive competence profiles vary between professions (Lehman, Lempert, & Nisbett, 1988). Hence, PBL group work varies with disciplinary contexts, for instance incorporating elements of research-based or project-based learning. In some disciplines or courses, more directive content specialists may add greater value as a tutor than process coaches (e.g., statistics for social sciences, cf. Budé, van de Wiel, Imbos, & Berger, 2011). Engineering students seem more convinced of the value of co-creation than other students (cf. Dahlgren & Dahlgren, 2002; Mitchell & Smith, 2008). Certain disciplines have been known to attract students with different appetites for group work (e.g., business students and psychology students have different social value orientations, cf. Van Lange, Schippers, & Balliet, 2011). Finally, Walker and Leary (2009) present evidence suggesting that PBL may be more effective in areas other than medicine (e.g., teacher education and social sciences).

Culture

A wide range of studies suggests culture impacts group work in PBL. Holen et al. (2015) found that medical students from Nepal were less enthusiastic about PBL than students from North Dakota and concluded that the nonauthoritarian and self-directed learning format may be culturally unfamiliar to some Nepalese. In India, medical students were bothered by the fact that not all group members participated equally and wanted formal assessment of performance of peers (Nanda & Manjunatha, 2013). Imafuku, Kataoka, Mayahara, Suzuki, and Saiki (2014) suggest that appropriate behavior for Japanese students in a PBL tutorial is shaped by the place, the relative status of members, and one's relationship to those people. Although an Asian emphasis on group interest before individual interest aligns with small-group learning, Choon-Eng Gwee (2008) also saw a potential conflict between PBL pedagogy and Asian cultural reticence paired with blind respect for teachers. In culturally diverse groups, some students may find the experience of working with peers threatening, because transparency in PBL groups provides less opportunity to save face (Robinson et al., 2015). Faultlines based on nationality can also reduce off-task social interactions (Jiang et al., 2012).

Qualitative research by Frambach and colleagues (Frambach, Driessen, Beh, & van der Vleuten, 2013; Frambach, Driessen, Chan, & van der Vleuten, 2012) suggests that cultural factors like uncertainty avoidance, power distance, competitiveness, and need for achievement affect small-group interaction (e.g., inhibition, unwillingness to challenge peers or the tutor, reluctance to share information, or a desire to save face). For instance, uncertainty and tradition challenged Middle Eastern students' acceptance of self-directed learning. Hierarchy and tutor focus challenged Hong Kong students in a hybrid PBL curriculum. Both Middle East and Hong Kong students seemed more achievement oriented, more competitive, and less willing to share than Dutch students (Frambach et al., 2012).

Socialization and training

Students' initial perceptions of effective PBL group work tend to differ (e.g., De Grave, Dolmans, & Van Der Vleuten, 2002; Visschers-Pleijers et al., 2006). PBL group work perceptions and norms develop early both inside and outside tutorial groups. Outside tutorial groups, students connect to peers on social media to make sense of the academic climate, or in small independent study groups that serve as back-up or substitutes for regular tutorial groups. Hendry, Ryan, and Harris (2003) found that 86% of students had been part of such a group in the first years of their study. Groups consisted of four to six members who helped each other feel motivated, supported, and who helped clarify difficult concepts.

Students' initial perceptions of group work can also be affected negatively by hyperbonding (Watts, 2013): some groups or entire cohorts can develop nonproductive student behaviors (e.g., group absenteeism, sharing old exams and summaries via social media, or off-task behavior), resulting in peer groups that disrupt learning. First-year students may suffer from the absence of a framework for learning. Therefore, management of student expectations should start before the first day of class. A cohort charter with recommendations for student collaborations may help students reflect. Norms can be negotiated during the first tutorial. Norms can relate to active learning, to being prepared, to being on time, to interrupting one another, the role of the tutor, use of ICT tools, etc. Norms and other group arrangements can also be written down in a team charter (Cox & Bobrowski, 2000; Mathieu & Rapp, 2009), which can register "who knows what" and how tasks and responsibilities are distributed, so a group may be better prepared for task and team interdependence in PBL.

Reflection is an important element of introductory training in PBL skills. Without adequate monitoring of group work, groups may adopt one individual's opinion rather than constructing consensus, or its members may confuse quantity with quality of contributions. Students bringing in many ideas may have to be convinced to pause and defend their ideas, while students who are reticent may need to develop skills to advocate ideas. Keville et al. (2013) analyzed the reflective reports of a group of medical psychology students experiencing PBL for the first time. Students avoided difficult conversations and conflict because of their emotional impact. Lack of familiarity with the PBL process and poor preparation for self-directed learning may also cause distress and uncertainty (De Boer & Otting, 2011; Hmelo-Silver, 2004; Hung, Harpole Bailey, & Jonassen, 2003). Guided reflexivity could improve group performance (Gurtner, Tschan, Semmer, & Nagele, 2007). Reflexivity (a deliberate process of discussing group goals, processes, or outcomes) can be triggered by videos of critical incidents in other groups while a chair or tutor stimulates discussion on what can be learned from the incident (cf. Diwas, Staats, & Gino, 2013). Since groups tend to settle for surface reflexivity, creating a meta-norm of reflexivity very early in the group's life, and taking time-outs, will help deep reflexivity (Schippers, Edmondson, & West, 2014).

Tutor/facilitator

In PBL, the tutor or facilitator directs interaction among students, typically by asking probing questions, or validating student contributions in line with course goals (Hmelo-Silver, 2004; Hung et al., 2003; De Grave, Dolmans, & Van der Vleuten, 1999). Novice learners tend to spend more time on problem interpretation, but do worse in defining a problem, which may leave them in need of tutor support as they brainstorm, identify solutions, and choose among them. Tutors may also help students understand the importance of reflecting on the outcomes of group discussion, and bring closure to a session (Ertmer & Stepich, 2002). Students also expect the tutor to intervene when the group lacks motivation (De Grave et al., 2002). After reviewing studies investigating the tutor role in PBL in medicine, Dolmans et al. (2002) conclude that content experts tend to rely on subject-matter expertise to guide discussion, whereas noncontent expert tutors tend to rely on process facilitation expertise to guide discussion. The authors argue that a tutor should be both an expert in the subject matter under discussion and an expert in facilitating student learning. Yet, Yew and Yong (2013) emphasize the relative importance of social congruence between tutor and students, and a relationship between tutor content expertise and student learning was not established in a meta-analysis by Leary, Walker, Shelton, and Fitt (2013).

Structural Losses and Remedies

Various factors can impede successful group functioning in PBL. This section will highlight structural losses in PBL group work, and suggest some remedies. The next section will focus on interpersonal losses.

Lack of elaboration/superficial learning

Superficial learning results when students merely state the main results from their self-study, and ignore differences in viewpoint between students or sources. Or they defer to minority opinions or opinions of most talkative peers with little critical thinking (De Grave et al., 2002; Dolmans et al., 2015; Hendry et al., 2003; Moust, van Berkel, & Schmidt, 2005). Superficial learning may result from erosion of the curriculum or from a failure of process. For instance, students may fail to build on and apply previous knowledge when they approach a new problem, as Mitchell and Smith (2008) noticed when they analyzed group work of engineering students. Robinson et al. (2015) related superficial discussions in the tutorial group to avoidance of face threatening acts, for example, by a chair who refuses to single students out for a contribution or by students who fail to correct one another. Avoidance would result from poorly developed communication skills and social and emotional perceptiveness, and a lack of confidence. The authors suggest facilitators need to build in opportunities for socialization and make students' obligations and rights explicit. Simple time-outs at a course's midpoint asking group members to engage in counterfactual thinking can be effective, unless reflexivity also remains superficial and is routinely intended to seek comfort. Since groups often maintain positive illusions about performance, individual reflection may be more effective (cf. Gurtner et al., 2007). Facilitators may themselves hinder deep learning by giving explanations rather than encouraging students to elaborate on conflicting ideas (Aarnio, Lindblom-Ylänne, Nieminen, & Pyörälä, 2013). Tutor training on when (not) to give direct explanations is recommended (cf. Leary et al., 2013; Yew & Yong, 2013).

Common knowledge effects during discussion

Information sharing in groups suffers from the fact that relevant information held by a minority is overlooked (cf. Mesmer-Magnus & DeChurch, 2009). Framing a task as an open problem without a correct solution, time pressure, skewed participation, group homogeneity, and large group sizes exacerbate this loss. Cross-understanding of how members represent a problem, team reflexivity (e.g., making students aware of common knowledge effects), and introducing asymmetries in prediscussion information may help a group identify relevant information (cf. Straus, Parker, & Bruce, 2011). Alternatively, a group might be given more time to discuss, access to information sources during discussion, instructions not to form a priori judgments, and explicit assignment of roles based on prior knowledge (cf. Schippers et al., 2014). PBL groups can for instance increase cognitive diversity by having students prioritize learning goals differently or by assigning members to serve as devil's advocate. Moust, Roebertsen, Savelberg, and De Rijk (2005) divided tutorial groups of 12 students into small groups of three or four students who collaborated during self-study and prepared a presentation. The study teams increased cognitive diversity and offer members benefits of small-group interaction (e.g., more balanced discussion). Increasing cognitive diversity may result in greater constructive conflict and reduced cohesion (e.g., De Dreu & Weingart, 2003).

Pressures toward conformity, confirmation bias

In PBL groups, conflicting ideas should arise easily and new knowledge should be constructed and tested through negotiation. Yet, Visschers-Pleijers et al. (2005a, 2005b, 2006) showed that second-year medical students felt dissatisfied with the level of exploratory questioning and cumulative reasoning and believed that handling conflicts (e.g., negations or counterarguments) was not contributing to perceived group productivity. Students may experience confusion when conflicts arise. Normative peer pressure toward conformity would inhibit dissent, reduce benefits of diversity, and may cause group polarization. Working under time pressure increases normative peer pressure. Pressure toward conformity can be reduced by encouraging group members to consider information simultaneously rather than sequentially (e.g., by group mind mapping), by challenging them to consider more alternatives, and by sharing their uncertainty at the beginning of a group meeting (cf. Straus et al., 2011). Postmes, Spears, and Cihangir (2001) showed that groups with critical norms of open expression, disagreement and a safe climate performed better and valued unshared information more than groups with consensus norms.

Unproductive brainstorm

While brainstorming, interacting groups produce fewer ideas than nominal groups. Exposure to ideas of others may stimulate productivity (e.g., Rentsch, Mello & Delise, 2010), but in orally interacting groups production blocking will cause losses. Task procedures that do not require turn taking can limit productivity losses in brainstorming (e.g., brainwriting, in which members exchange written ideas simultaneously, and electronic brainstorming, cf. DeRosa, Smith, & Hantula, 2007). Changing group composition, using aids like mind mapping software and idea browsers, removing time pressure, and training tutors how to facilitate brainstorm sessions may also improve results. Facilitators could promote separation of idea generation from evaluation, discourage unnecessary elaboration of ideas, invite all students to participate, and limit evaluation apprehension by encouraging members to contribute without criticism (cf. Straus et al., 2011).

Interpersonal Losses and Remedies

Collaboration will suffer when perceived interdependence is low, especially in homogenous groups, as this student quote illustrates: "I really didn't talk to many other people about our problems that we were given. But a lot of us are on the same page, like if I did talk to them, they knew just as much as I did" (Henry et al., 2012, p. 55). However, students may also lack skills for integrating contributions. Many researchers recommend teaching content together with group skills for collecting and scrutinizing information from team members (e.g., Henry et al., 2012; Ochoa & Robinson, 2005; Schippers et al., 2014). In a noneducational setting, Woolley, Gerbasi, Chabris, Kosslyn, and Hackman (2008) found that groups that received training in effective collaboration strategies outperformed untrained groups. Interestingly, teams with high expertise benefited most from the training, suggesting training is needed to help members recognize expertise in the group. Collaborative preplanning (MacMillan, Entin, & Serfaty, 2004) and team charters (Cox & Bobrowski, 2000; Mathieu & Rapp, 2009) can be implemented to support reflexivity and better prepare students for task and team interdependence in PBL. Worked examples showing how students can integrate information from different resources can provide additional support for self-directed learning (Wijnia, Loyens, van Gog, Derous, & Schmidt, 2014). Students can also produce peer feedback to stimulate reflection on collaboration. Renko, Uhari, and Soini (2002) introduced a peer consultation model to help students engage with problems during group meetings. Kamp and colleagues (Kamp et al., 2013; Kamp et al., 2014) used a peer rating scale to test whether midterm peer feedback on cognitive, collaborative, and motivational activities improved quality of individual contributions to the PBL tutorial group. Feedback was only effective for students with low scores on a pretest. Peer feedback seems effective when an explanation of the peer judgment, prior training, and cues for behavior change are provided. A tutor can also make formative and summative assessments of how student participate in PBL groups. Reviewing various methods for assessment of professional behavior, Van Mook et al. (2009) favor combining multiple methods, assessing longitudinally, including multiple realistic contexts, triggering conflict, and offering immediate feedback and suggestions for improvement.

Social categorization

Group biases flowing from social categorization can also disrupt collaboration (Van Knippenberg et al., 2004). For instance, cultural factors may create a divide between students or between a tutor and the group. Singaram et al. (2011) suggest teachers need special diversity training to deal with heterogeneous groups and the tensions that arise. Choon-Eng Gwee (2008) proposes teachers promote a "karaoke" culture of nonjudgmental empowerment to adapt PBL in Asia. Remedios, Clarke, and Hawthorne (2008) tried to frame collaboration differently as a balance between listening and speaking after noticing that Asian students were worried that they were among the quietest in their groups, and were preoccupied with their ability to speak in the tutorials. The Asian students learned that listening can have a collaborative or noncollaborative intention (e.g., listening for private learning is not collaborative). Similarly, not speaking can be collaborative when students monitor the discussion but do not fill in gaps, because they agree with the group, because they worry they will slow down the group, or because their contributions are blocked by a rapid succession of topics. Interrupting would then be considered as rude, especially in Asian culture.

Valuing diversity has been shown to overcome faultlines. Teams with pro-diversity beliefs can better exploit informational diversity (Homan, Van Knippenberg, Van Kleef, & De Dreu, 2007). Diversity policies and rules can positively affect diversity climate (Böhm et al., 2014). However, general diversity training may not impact accuracy and sharedness of diversity mindsets as much as reflection on the actual diversity students experience within their group (Van Knippenberg, van Ginkel, & Homan, 2013).

Poor adjustment to PBL, difficult incidents

Sharing knowledge of PBL principles, training the roles that students will play, and asking senior students or buddies to share experiences may help smooth the transition to PBL. Training PBL group skills often involves observing videos of critical incidents, so students can give and receive feedback responses about group processes. Abdelkhalek, Hussein, Gibbs, and Hamdy (2010) suggest using team-based learning, a teacher-centered, less resource demanding, small-group learning method, to prepare medical students for future problem-based learning.

Kindler, Grant, Kulla, Poole, and Godolphin (2009) signal a need for enhanced training of both tutor and students on how to tackle difficult incidents in PBL groups. They report that tutor interventions targeting group dynamics (e.g., tensions between tutor and group or within the group) were rarely successful. Interventions in response to difficult incidents related to an individual student (e.g., tardiness, quietness, underachievement) were most successful when another student or the group intervened. Tutor interventions were more successful when they occurred outside the tutorial. Feedback given during the tutorial was rather ineffective. Overall, half of the difficult incidents were dealt with successfully. Students may be motivated to learn teamwork skills when they can appreciate the professional relevance of the topic (e.g., Aarnio, Nieminen, Pyörälä, & Lindblom-Ylänne, 2010).

Unequal participation

Several researchers have studied group dysfunction resulting from unequal participation or tensions between dominant and quiet students (De Grave et al., 2002; Dolmans et al., 2015; Hendry et al., 2003). Diverse teams may suffer from members whose individual goals (e.g., passing the exam using abstracts and old exams) do not match group goals (building a shared understanding). However, De Grave et al. (2002) reported that students felt their learning process suffered more from a lack of motivation, elaboration, and interaction than from unequal participation or quiet/dominant students (but see Woolley et al., 2015).

Mediated communication challenges

The environment of tutorial groups is changing. Use of mobile devices by digital natives triggers worries about cognitive outcomes (Barr, Pennycook, Stolz, & Fugelsang, 2015). In PBL, ICT support for contextual learning and collaborative learning is most widely used (Verstegen et al., 2016; cf. Jin, Bridges, Botelho, & Chan, 2015; Lajoie et al., 2014). Occasionally, instructors offer support for activation of prior knowledge, cognitive elaboration, and structuring of information. For instance, mind maps can be used to trace the development of group discussions, to support knowledge sharing in heterogeneous or interdisciplinary groups

(Imafuku et al., 2014), or to measure problem-space coverage (Hmelo-Silver, 2013). Conditions for optimal use of these tools have not been established, however. Zwaal and Otting (2012) did not find concept mapping led to more or better matching learning goals, nor did it affect time spent on problem analysis, yet students were more satisfied with the group process. In online PBL groups, social perceptiveness and distribution of speaking turns is as important as it is in face-to-face groups (Engel, Woolley, Jing, Chabris, & Malone, 2014). The lack of nonverbal feedback can be challenging for novice learners as well as tutors in online PBL (e.g., Fonteijn, 2015). Tutors experience challenges in establishing social presence and in managing cognitive load when dealing with multiple tasks online (Kear, Chetwynd, Williams, & Donelan, 2012). Yet, facilitated online problem discussions have shown deeper problem space coverage than nonfacilitated discussions (Ertmer & Koehler, 2015).

Time/Routine problems

Duration of group meetings is likely to impact group work, since time pressure is not conducive to learning (cf. Zajac, Gregory, Bedwell, Kramer, & Salas, 2014). Insufficient time for a group meeting leads to a rushed, superficial discussion. In addition, group members will be involved in temporal conflicts due to individual differences (students may value speed over accuracy, short-term over long-term goals). Differences in time valuation might be considered in team charters, so students can cope with various pacing styles. Other temporal aspects in PBL have recently received more attention (e.g., Hommes et al., 2014; Rotgans & Schmidt, 2011). Hommes et al. (2014) noticed students develop psychological safety, interdependence, potency, group learning behavior, social and task cohesion, and transactive memory over the first months of their study. Groups might stay together for longer periods of time, as familiarity has been shown to breed effectiveness (Cooke, 2015). However, toward the end of their programs, PBL students complain about getting stuck in a rut. Perturbation training, combining PBL with other student-centered approaches or adapting PBL (e.g., offering PBL online, self-supervised groups, asking students to identify/design rather than analyze problems, fading support, etc.) may reinvigorate group work.

Losses due to presence or absence of a tutor

The presence of a tutor can negatively impact the perceived sense of autonomy that self-directed PBL promotes (cf. Nanda & Manjunatha, 2013). Students eagerly read a tutor's face to infer relevance of learning goals or materials, or to reduce uncertainty. By removing the tutor from the learning environment, students are forced to take greater responsibility for group learning and to demonstrate they have indeed mastered PBL skills. Without a tutor, students can also prove they have acquired PBL skills. Modern technology can provide access to knowledge no tutor possesses (e.g., Grove, Zald, Lebow, Snitz, & Nelson, 2000).

In experiments with self-supervised groups in a psychology curriculum (Fonteijn, 2015, 2018), students gently acclimatize to autonomy: groups were instructed to deliver a team charter, and mind maps summarizing each group discussion. Teachers provided feedback by selecting exemplary maps and sharing these with all students. In addition, a teacher was available online to answer questions via chat. Students adapted quickly, rarely asked questions via chat, and also claimed to honor the agreements in their team charter. Group attendance, discussion time, final exam performance, course evaluations, and passing rates did not differ between self-supervised groups and tutor-led groups in previous years. Self-supervised groups appeared to be more cohesive and showed more equal participation, but reflection on group processes may need further scaffolding in addition to the team charter (Fonteijn, 2018). These findings align with those of Steele, Medder, and Turner (2000), who reported that students favored tutorials led by a peer (i.e., a group member who was instructed as a tutor) for being more efficient, and more cooperative with less posturing and competition than faculty-led tutorials (cf. Dolmans et al., 2002). However, the authors suspected students took short cuts that may undermine higher cognitive skills. Similarly, Ertmer and Koehler (2015) noticed that students in facilitated online discussions discussed more aspects of the problem space in more detail, and spent more time on relevant instructional design issues and related solutions than students in nonfacilitated online discussions.

Conclusion

Study of group work and group dynamics faces severe challenges. Not surprisingly, most existing studies on PBL group work show large variations in results. Most studies focus on a very small number of groups of students, enrolled in one course, and rarely do justice to the complexity of group interactions (which often involve implicit communication, cf. Robinson et al., 2015). Most studies have used self-report data, yet student perceptions are sometimes flawed. For instance, Lieux (2001) compared a PBL group of students with a group taking lectures and noticed that student perceptions of their work did not match their actual performance: the PBL group perceived that they had learned less than the lecture group, yet both groups of students did equally well in their final exam.

Challenges related to designing adequate measures of group work, to disentangling individual contributions from team contributions or interdependencies between individuals and groups, and to understanding dynamical aspects of group learning have begun to capture the attention of PBL researchers (e.g., Hommes et al., 2014; Rotgans & Schmidt, 2011; Van Blankenstein et al., 2013; Van den Bossche et al., 2006). Rotgans & Schmidt, 2011, for instance, showed that micro-analytical measurement of self-reported cognitive engagement, persistence, and flow of students in an applied science curriculum varied across phases of PBL. Contrary to expectations, situated cognitive engagement did not peak during initial individual study, when students might perceive maximal autonomy, but during group discussion of findings and subsequent individual study. Gorman, Cooke, Mesa, and Guastello (2015) consider these challenges against the backdrop of enormous amounts of data about groups and teams that new technologies and new learning environments will bring. New data will shed more light on how student activities produce group learning and performance. New data could also provide rich feedback on group states that may improve training.

Most research has not focused on relations between group work and academic achievement of either the group or its individual members. Even then, measuring the distribution of knowledge across team members may not be the only interesting outcome of PBL group work. In real life, teams with effective interactions can trump teams with perfect knowledge (Cooke, 2015). By capitalizing on group work, and remedying process losses, PBL can offer an excellent environment for building one of the exemplar twenty-first-century skills: teamwork.

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10

PBL in K–12 Education

Michael M. Grant and Suha R. Tamim

PBL in K–12 Education

Problem-based learning (PBL) is an intricate instructional model. It requires learners to engage with complex problems in order to learn new knowledge and skills, as well as apply and integrate with existing ones. In K–12 education, the goals of PBL parallel other calls for change, for example, improving access and competency in science, technology, engineering, and mathematics (Ostler, 2012); promoting student engagement and authenticity (Jerzembek & Murphy, 2013); and criticizing myopic standardized tests (Ravitz, 2010). PBL has also been as a pathway to achieve curricular reform in K–12 education. Recent standards revisions have encouraged data collection, analysis, and interpretation (e.g., Common Core State Standards for Mathematics; Next Generation Science Standards) and emphases on scientific and engineering practices (National Research Council, 2011; Quinn & Bell, 2013). In addition, PBL and several complementary instructional approaches, such as project-based learning (PjBL), inquiry, and anchored instruction are models on which K–12 curricula and school reform have been based (Cognition and Technology Group at Vanderbilt [CTGV], 1990, 1992; Krajcik & Blumenfeld, 2006; Meyer et al., 2012; Spires, Hervey, Morris, & Stelpflug, 2012).

Most recently, a growing number of public schools have adopted a model of school reform centered on project-based strategies, integrative curricula, extensive technology integration, and approaches for student engagement (Gourgey, Asiabanpour, & Fenimore, 2010; Mosier, Bradley-Levine, & Perkins, 2016; Ravitz, 2008, 2010). These include New Tech High schools, High Tech High, EdVisions Schools, and Envisions Schools. While the numbers of schools have grown rather quickly in the U.S. with implementation in 21 states for the New Tech High school models (Mosier et al., 2016), the research has lagged (Gourgey et al., 2010), focusing on limited case studies and student perceptions. Moreover, while there is growing interest in PBL in K–12 education, the actual implementations have been cautious in number.

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The purpose of this chapter is to provide an overview of the theoretical foundations and research conducted with PBL and complementary pedagogies with children and youth. First, theoretical foundations of PBL will be presented along with complementary pedagogical models. Second, the research on implementing PBL will be discussed. A third section on research in K–12 context will be considered, including a variety of research methods and identification of gaps.

Theoretical Foundations

PBL is an instructional model grounded in social constructivist theories. As such, it is student-centered, characterized by the construction of multiple perspectives of knowledge with multiple representations, within a social activity, and focused on discovery and collaborative learning, scaffolding, coaching, and authentic assessment (Barrows, 2006; Driscoll, 2005; Duffy & Cunningham, 2001). Moreover, it is focused on solving stimulating authentic and ill-structured problems.

While PBL focuses on finding solutions to problems, PjBL emphasizes learning during the construction of artifacts. The project-based science characteristics (Blumenfeld et al., 1991; Blumenfeld, Krajcik, Marx, & Soloway, 1994; Krajcik, Blumenfeld, Marx, & Soloway, 1994; Krajcik & Shin, 2014), the Buck Institute for Education (BIE) characteristics (Larmer, Mergendoller, & Boss, 2015), and Grant's characteristics (2002; 2011) are three examples that describe similar PjBL key features. While PBL and PjBL have both been discussed earlier, two other complementary instructional models are also prevalent in K–12 education: (a) inquiry and (b) anchored instruction. Each of these is briefly described below.

Inquiry Learning

There is no agreed upon definition for inquiry across the education literature. Definitions are contextual, based upon discipline (e.g., science education) and contexts (e.g., higher education, K–12). However, like PBL, inquiry is generally considered a student-centered approach that affords the learner some choice in the content, path of learning, or process of an investigation (Saunders-Stewart, Gyles, & Shore, 2012). In K–12 education, science education researchers define the largest body of knowledge and recommendations for inquiry. In particular, science educators ascribe inquiry to reflect the work of scientists and scientific investigations.

Banchi and Bell (2008) define four types of inquiry that span the continuum of teacher-centered to student-centered pedagogies. The first two levels, confirmation inquiry and structured inquiry, are teacher directed. In both levels, the teacher determines both topic or question and method for investigation. Martin-Hansen (2002) refers to these types of pedagogies as "cookbook lessons" (p. 37), where learners are expected to follow the same procedures to produce the same products. The second two levels, guided inquiry and open inquiry, most closely reflect the characteristics of pedagogies similar to PBL and other pedagogies, such as PjBL. In guided inquiry, the teacher may choose or limit the topic while the learner must determine the path of investigation (Banchi & Bell, 2008; Martin-Hansen, 2002). In open, or full, inquiry, the learner is allowed to choose the topic or driving question and process of investigation. Both guided inquiry and open inquiry require the most self-direction and self-regulation from the learner.

Anchored Instruction

Anchored instruction is similar to PBL such that there is an emphasis on problem solving and learning new knowledge and skills through the problem-solving process. The use of an *anchor* is a contextualized and complex problem, such as a case study or strong narrative (Crews, Biswas, Goldman, & Bransford, 1997). A significant impetus for designing anchored instruction is to prevent inert knowledge; that is, knowledge that cannot be generalized into new situations even though it may be relevant (CTGV, 1990). Four principles of anchored instruction put forth by the CTGV (Bransford et al., 2000; Crews et al., 1997) are: (a) teaching and learning activities should center on an engaging anchor; (b) the learning materials allow for exploration and investigation from multiple viewpoints and multiple instances; (c) all data to solve the problem are presented in the problem case with extraneous data; and (d) learners work in small groups to dialogue, explain, clarify, and consider others' ideas.

Anchored instruction differs most from PBL and other complementary pedagogies with the third principle above. Anchored instruction provides all details of the problem and data to solve the problem within the presented case. The most well-known example of anchored instruction in K–12 settings is likely "The Jasper Woodbury" series created by the CTGV for mathematics education. The CTGV also created "The Voyage of the Mimi" series (CTGV, 1992), which is more focused on science education and interdisciplinary content. More recently, other researchers (Bottge, Rueda, Grant, Stephens, & Laroque, 2010; Lamberg & Middleton, 2009; Shyu, 2000) have investigated the impacts of anchored instruction on mathematics.

Implementations Research in K–12 Contexts

Successful implementation requires the acquisition of skills for both learners and teachers. On one hand, students should demonstrate learning outcomes beyond content knowledge. On the other hand, teachers should adjust to new roles and responsibilities. This section will address research on student learning outcomes and teacher roles and responsibilities. In addition, it will highlight research on barriers and challenges to implementation.

Research on Student Learning Outcomes

Learning outcomes in PBL and complementary pedagogies incorporate not only content knowledge but also lifelong learning skills (Saunders-Stewart et al., 2012). This section will first discuss categories of learning outcomes, followed by specific discussions on self-direction, self-regulation, collaboration, motivation, creation of learning artifacts, and assessing student learning outcomes.

Categories of learning outcomes

Through a process of methodological literature review and categorization, Saunders-Stewart et al. (2012) generated 23 categories of student outcomes for learning through inquiry, such as PBL and complementary pedagogies. These outcomes were defined as "any change that [was] a result of engagement in inquiry, for example, but not limited to, learning contents and skills, or changes in attitudes and motivations" (p. 8). The categories were not considered mutually exclusive to one another. The authors noted that oftentimes the outcomes were not isolated during research, and the empirical support for the categories overlapped as well.

The 23 categories were broadly organized into four groups by which inquiry occurs in a classroom as defined by Saunders-Stewart et al. (2012, pp. 9–14): *process* for activities guided by a learner's interest where generalized skills can be learned; *content* for activities where learners engage with discipline-specific knowledge and application of this knowledge; *strategy* for activities that support problem solving, organization, metacognition, self-direction, and self-regulation; and *context* for engagement with activities that require learners to make meaning from experiences within the learning environment, such as data and resources, motivations, collaborations, and reflection. The four groups and 23 categories are listed in Table 10.1.

This categorization could guide research on PBL effectiveness, which often lacks clarity on how it is being assessed (Wilder, 2015). These categories can provide direction and coherence for future research on student outcomes (e.g., Saunders-Stewart, Gyles, Shore, & Bracewell, 2015) and provide a taxonomy for understanding interactions among students and teachers in PBL and inquiry (e.g., Walker & Shore, 2015).

Self-direction

Research on self-directed learning (SDL) in K–12 settings is scarce. Across all PBL contexts, mixed findings are reported in SDL studies (English & Kitsantas, 2013; Lee, Mann, & Frank, 2010; Loyens, Magda, & Rikers, 2008). First, PBL implementations fluctuate between high fidelity with the Barrow's PBL model and hybrid curricula (Lee et al., 2010; Lloyd-Jones & Hak, 2004). Second, research in PBL is mainly focused on academic outcomes. Wilder (2015) indicated that studies often assessed PBL outcomes through traditional methods, detracting from other skills such as SDL. Third, scholars differ on the operationalizations of SDL and its constructs (Song & Hill, 2007). More consistent direct assessment or evaluation of SDL is needed in order to support claims of improved self-direction (Lloyd-Jones & Hak, 2004).

When studying SDL, researchers must take into consideration variability in students' readiness that is determined by their personal attributes (Fisher, King, & Tague, 2001). This is especially important in K–12 settings where young students lack previous experiences in thinking and reflection, which challenges teachers in their attempts to facilitate SDL (Ertmer et al., 2009). Indeed, Bolhuis and Voeten (2001) observed that secondary school teachers spent very little time if any on process-oriented teaching (guiding students' learning), which

Table 10.1 Categories of Learning Outcomes in PBL and Complementary Pedagogies

Process	Content	Strategy	Context
1) Learning process—the "how to" 2) Construction of knowledge 3) Learning how to learn or lifelong learning 4) Generation of questions and curiosity 5) Emulate professionals and create authentic products 6) Change in the range of teacher and student roles; role diversification; and increased student ownership	7) Acquisition of facts or knowledge 8) Improved achievement 9) Understanding the nature of the content area (e.g., scientific literacy) 10) Understanding the nature and value of inquiry 11) Understanding concepts (vs. memorizing facts) 12) Ability to see concepts as related 13) Development of expertise	14) Development of intellectual or thinking skills 15) Problem-solving skills 16) Development of personal skills (e.g., planning and organization) and habits of mind	17) Application of knowledge or information 18) Positive attitude toward subject or learning 19) Self-esteem, self-confidence, self-efficacy 20) Motivation and task commitment 21) Social nature of learning 22) Enhanced creativity 23) Motivation to be informed citizens and increased social awareness and action.

Adapted from Saunders-Stewart et al. (2012, pp. 9–14).

jeopardized the performance of students with low SDL skills. Similarly, teachers' inexperience with SDL facilitation may negatively impact students' preferences for student-centered learning like PBL (Bassett, Martinez, & Martin, 2014).

Not only is student SDL readiness linked to teachers' support, but it also brings into question issues of measurement. Several researchers focus on validating scales of SDL readiness that can inform curricula, assess students' learning needs, and support teachers in designing instructional strategies (Ayyildiz & Tarhan, 2015; Fisher et al., 2001; Hendry & Ginns, 2009). The challenges of research on SDL explain its inconsistency and scarcity in PBL K–12 settings.

Nonetheless, there are some examples. Ababubakar and Arshad (2015) reported positive findings on the role PBL played in the development of SDL skills for secondary chemistry students. They found that students were able to formulate their learning goals, assess their learning needs, access resources, choose learning strategies, evaluate learning outcomes, and gain information management skills. Similarly, Azer (2009) found that fifth-, sixth-, and seventh-grade students were self-directed in using resources with variations between grades. Also, Van Deur and Murray-Harvey (2005) found that primary school students can learn SDL skills, and those students in high to moderate levels of inquiry-based learning were more engaged and showed improved SDL skills compared to students with low levels of inquiry-based learning. These examples indicate that SDL with PBL and complementary pedagogical approaches in K–12 settings are promoted but need to be taught explicitly to students and facilitated by trained teachers.

Self-regulation and reflection

Closely related to SDL is the concept of self-regulated learning (SRL). Zimmerman (2005) described self-regulation as "the self-generated thoughts, feelings, and actions that are planned and cyclically adapted to the attainment of personal goals" (p. 14). SRL research in K–12 is also scarce (English & Kitsantas, 2013; Stefanou, Stolk, Prince, Chen, & Lord, 2013). Nonetheless, students who find intrinsic value in their learning tend to be more self-regulated (Kingir, Tas, Gok, & Vural, 2013), and when provided with metacognitive prompts, students show more self-regulation (Peters & Kitsantas, 2010). Authors argue that well-crafted driving questions, goal setting, fading instruction, making thinking visible, formative assessment, presentations, reflection prompts, self-evaluation promote students' SRL (English & Kitsantas, 2013; Kingir et al., 2013; Schunk & Ertmer, 2005).

Findings on the effects of PBL on SRL are mixed because SRL depends on multiple variables such as cognition, metacognition, motivation (Schraw, Crippen, & Hartley, 2006), engagement in the learning process, ability to set goals, and the learning environment characteristics (Loyens et al., 2008). Additionally, pitfalls exist, such as variations in PBL implementation, that might constrain SRL (Hung, 2011). Therefore, more focused research is needed with clear distinctions made between SDL and SRL, where students initiate learning tasks in SDL while they select learning strategies for tasks generated by teachers in SRL (Loyens et al., 2008).

Collaboration

Collaboration aims at helping students learn to construct knowledge and solve problems in groups (Hmelo-Silver, 2004). However, in a controlled experimental design for PBL in K–12 settings, Wirkala and Kuhn (2011) found no significant differences in comprehension and application assessment between individual and group PBL in three classes of sixth graders. As PBL researchers, it is critical for us to question whether this context or these contents are unique in this regard or whether this research is generalizable across all of K–12. Barron (2003) explored the influence of group interactions on problem-solving outcomes among sixth graders. She found that the quality of group social interactions impacted learning outcomes. More successful groups, who demonstrated higher performance in problem solving, engaged in discussion of proposed solutions and focused on the topic, whereas less successful groups ignored or rejected peers' proposals and focused their conversations on the topic only half the time. In addition, successful groups showed joint ownership of their work and were better at mediating conflict when less successful groups showed relationship issues.

Group work has its challenges, though. When examining high school collaborative PjBL, Lee, Huh, and Reigeluth (2015) reported that group members experienced three types of intragroup conflicts: task, process, and relationship conflict. Task conflict from negotiations for knowledge construction influenced collaboration positively. Process conflict over the process of collaboration, and relationship conflict relating to personal attributes and negative feelings between members, influenced collaboration negatively. Moreover, they found better levels of group social skills to be associated with better collaboration and less conflict and that both process and relationship conflicts often occurred simultaneously. In order to overcome group conflict, Lee et al. (2015) suggested grouping students together with different interests and perspective and encouraging relevant task conflict. They added that providing proper procedural scaffolding, reducing social loafing, setting individual accountability, and grouping the same students over several projects reduced process conflict. Furthermore, grouping members with low social skills with members with high social skills and offering workshops on these skills increase group-level social skills.

Collaboration enhances learning and help learners acquire metacognitive, negotiation, and communication skills (Cockrell, Caplow, & Donaldson, 2000; Hmelo-Silver, 2004). Making it successful necessitates setting individual accountability to achieve a balanced input from students and proper scaffolding and modeling to resolve conflict (Cockrell et al., 2000; Lee et al., 2015; Mergendoller, Maxwell, & Bellisimo, 2006).

Motivation

Motivation to learn, especially intrinsic motivation, is another PBL goal and the driving force for SDL and SRL (Hmelo-Silver, 2004; Loyens et al., 2008; Savery, 2006; Schmidt, 2000). It is fostered through giving learners choices that are meaningful, relevant, challenging yet tangible, competence enhancing, and provided in an appropriate amount (Evans & Boucher, 2015).

As with SDL and SRL, researching the effect of PBL on motivation is complex. Individual characteristics and instructional elements might affect motivation differently. For example, Meyer, Turner, and Spencer (1997) found different patterns of motivation among fifth- and sixth-grade students in a project-based mathematics unit. These patterns were influenced by the degree of challenge seeking among students, tolerance of errors, flexibility in altering plans, and goal orientation. Similarly, Liu, Olmanson, Horton, and Toprac (2011) reported that students exposed to a multimedia PBL science unit were motivated; they found positive links between motivation, perceived competence, and posttest scores. In addition, the use of anchored instruction with authentic and engaging problem cases improved motivation for elementary Taiwanese students (Shyu, 2000).

On the other hand, teachers' readiness and skills for teaching PBL plays an important role in students' motivation. For example, Morrison, McDuffie, and French (2014) found that the problem-solving, inquiry, and PjBL components of the program were well enacted by teachers and that social interactions and collaboration enhanced motivation and engagement in addition to promoting student learning. Therefore, PBL and complementary pedagogical approaches can increase motivation in the students' learning experiences. However, they require effective facilitation, student choice, and an understanding of students' characteristics.

Creation of learning artifacts

In PBL and complementary pedagogies, learners create artifacts, or representations of their learning. Across the different pedagogies, though, the artifacts may be different and used for various purposes. In PBL, the learning artifacts are typically of two types. The first type is representational artifacts (Lu, Bridges, & Hmelo-Silver, 2014) that are co-constructed in tutorial groups and with the tutor/facilitator. These artifacts may be structured whiteboard notes or learning grids (see, e.g., Hmelo-Silver, 2004; Lu et al., 2014) that help guide learners through issues. In addition, these representational artifacts are an "external memory" (Lu et al., 2014, p. 306) to which the tutorial group can refer. Similarly, with inquiry in middle school, scientific arguments to support decision making are archived within a multimedia environment and have been characterized as learning artifacts such that the arguments as artifacts can be referenced by learners later or shared with other students for comparison (Bell & Linn, 2000).

The second type of learning artifact used in PBL is most closely associated with PjBL. These learning artifacts are external representations that address a learner's understanding of the learning goals (Blumenfeld et al., 1991; Grant, 2011; Krajcik & Shin, 2014). Learning artifacts are often used as referents in reflections, explanations, or documentation (e.g., Grant & Branch, 2005; White & Martin, 2014). For example, White and Martin (2014) describe the use of video clips captured by middle grade students and subsequent mathematical analysis with the video clips. In PjBL, learning artifacts address the driving question or task and reflect achievement of the learning outcomes or goals (Chapman & Stone, 2010; Krajcik & Shin, 2014; Lehman, Rush, & Buchanan, 2006).

In both types of artifacts, two characteristics are common. First, learning artifacts support reflection. For learners, learning artifacts are a means to analyze and evaluate learning progress, successes, areas for improvement or remediation, and knowledge and skills to be generalized (Land & Greene, 2000; Lu et al., 2014). Lehman et al. (2006) found that 18 of 23 teachers in their study used student journals and reflections to document learning and progress. Second, learning artifacts are also limited. While they are indicators of learning, they do not represent all that has been learned (Grant, 2011). For example, during SDL, a learner may need to explore alternative hypotheses but these would most likely not be present in an artifact. Portfolios offer one method to collect multiple artifacts and reflections (Lehman et al., 2006) to better document learning processes and products.

Assessing student learning outcomes

Compared to students in traditional lecture-based settings, researchers have reported that PBL students in K–12 settings:

- demonstrate increased positive attitudes toward learning (Liu et al., 2011; Morrison et al., 2014; Shyu, 2000);
- are more self-directed (Ababubakar & Arshad, 2015; Azer, 2009; Van Deur & Murray-Harvey, 2005);
- improve in problem identification and problem solving (Bottge et al., 2010);
- achieve higher-order levels of learning through the application of knowledge and skill development (Tarhan & Acar, 2007; Wirkala & Kuhn, 2011);
- have greater learning gains in content knowledge assessment, with learning gains more pronounced for middle- to low-ability students (Holm, 2011).

PBL assessment in K–12 settings has room for improvement. Wilder (2015) reported that assessment studies mostly focused on short-term implementations and measured academic achievement in a pretest–posttest design, equating student academic achievement with “student ability to recall conceptual and factual knowledge” (p. 431). She argued that using assessment strategies similar to the ones used in traditional learning environments defeated the goals of PBL.

Research on Teacher Roles and Responsibilities

Teachers experience shifts in their roles and responsibilities when acting as facilitators and guides to the learning experiences of their students. In particular, they face the issues of problem design, transition to facilitator and pedagogical beliefs, scaffolding, challenges with classroom assessment, and uses of PBL. An overview of research on these topics is presented below.

Problem design

Little has been studied or directly reported about the design of problem cases in K–12 research. Instead, authors have primarily reported the challenges and significant time allocated to developing problem cases and driving questions (e.g., Ashgar, Ellington, Rice, Johnson, & Prime, 2012; Lehman et al., 2006). Still other researchers have reported providing K–12 teachers with problems as part of curricular materials or university–school partnerships (CTGV, 1992; Liu, Wivagg, Geurtz, Lee, & Chang, 2012; Marx, Blumenfeld, Krajcik, & Soloway, 1997).

Unfortunately, little description or explanation has been provided about the processes necessary to teach teachers how to develop problem cases or driving questions and tasks (c.f. Goodnough & Hung, 2009). In addition, there has been insufficient reporting of how teachers adjust or calibrate problems for the differing abilities of students, prior knowledge, or prior experiences with PBL and other complementary pedagogies.

Perhaps the most significant works for problem design have been conducted by W. Hung, BIE, and Torp and Sage. Hung (2006) originally developed the 3C3R conceptual model to emphasize the components that must be addressed during the generation of a problem. More recently, Hung (2009) translated the 3C3R model into a design process to generate a problem case. Classroom teachers have demonstrated success with developing problem cases using the design process (Goodnough & Hung, 2008, 2009). BIE (e.g., Hallermann, Larmer, & Mergendoller, 2011; Larmer et al., 2015) has produced teacher professional development in order for teachers to craft open-ended driving questions to frame their units of instruction. Similarly, Torp and Sage (2002) in the second edition of their text focus heavily on providing examples from a variety of disciplines in how problem cases can be generated and developed for PBL.

Transition to facilitator and pedagogical beliefs

Teachers' beliefs about teaching and learning influence their classroom practices. Educational background, pedagogical and content knowledge, prior experiences, self-efficacy, and other factors mold these beliefs, which when added to external elements such as time, student ability, standards, school culture, and resources, shape their ultimate classroom practice (Pajares, 1992; Prawat, 1992; Savasci & Berlin, 2012). Liu et al. (2012) found that middle school teachers are motivated to adopt the PBL approach when it aligns with their pedagogical beliefs, fits well with their curricular need, and has administrative support. However, even when teachers' beliefs support constructivist practices, their actual implementation is not always reflective of these beliefs and the observed practices are less than the perceived implementation. For example, Pecore (2012) reported that some teachers maintained traditional practices such as note taking, worksheets, and mini-lectures even when their beliefs showed support for more constructivist learning environments, such as PBL. Similarly, Savasci and Berlin (2012) identified three trends relevant to PBL teachers: emerging, progressing, and expert constructivist. However, teachers' classroom practices were categorized as transitional, emerging, and progressing constructivist showing that teachers' perceptions were greater than the actual practice.

Grant and Hill (2006) discussed five stressors teachers face when adopting a student-centered pedagogy: (a) accepting the shift in role from conveyer of knowledge and director of learning to facilitator of learning and knowledge construction; (b) becoming comfortable with the fluidity and dynamic nature of student-centered environments; (c) tolerating the ambiguity and flexibility of students investigating ill-defined problems that could be unfamiliar to teachers; (d) managing technology integration, which often accompanies constructivist learning; and (e) deciding between breadth and depth of content and type of assessment while maintaining alignment with standards. Additionally, Newman (2005) suggested that facilitators assume personae in PBL: learners, creators, directors, challengers, evaluators, negotiators, modelers, designers, facilitators, and supporters. Dole, Bloom, and Kowalske (2016) examined the impact of a week-long field experience of facilitating PBL and PjBL on teachers' pedagogy. They found that teachers shifted their classroom structure by letting go of control and giving students ownership and changed instructional methods to allow deep thinking. Similarly, Park and Ertmer (2007) investigated the impact of PBL on preservice teachers. Compared to pretest lesson plans, teachers adopted a student-centered approach in their posttest lesson plans through integrating group activities and choices; shifting curricular characteristics toward project-based approaches; and expanding learning goals beyond content to problem solving.

Scaffolding

Saye and Brush (2002) classified scaffolds into two primary categories: soft scaffolds and hard scaffolds. In PBL classrooms, the teacher in most cases is the sole source of soft scaffolding unless peer scaffolding is employed (e.g., Belland, 2014). Belland (2014, p. 512) found that soft scaffolding was most likely to provide feedback, indicate important problem elements, model expert processes, and question learners.

Hard scaffolds—either computer-based, digital, or paper-based supports—are created and provided based on the anticipated needs of learners (Belland, 2014; Saye & Brush, 2002). Hard scaffolds are built in order to provide conceptual, metacognitive, procedural, and strategic supports (Grant & Branch, 2005; Hill & Hannafin, 2001) as needed or just in case they are needed. Belland and colleagues (Belland, 2010; Belland, Glazewski, & Richardson, 2011), Bell and Linn (2000), and Liu et al. (2014) have researched computer-based scaffolds in PBL environments and found improved creation of arguments linking evidence and claims.

Left to students' discretion, hard scaffolds are sometimes discounted or ignored (Brush & Saye, 2001; Ge & Land, 2003; Greene & Land, 2000). Students may not perceive the value of scaffolds or their utility. In some cases, students may view the scaffold as additional work and choose an easier path (Grant, 2011). Brush and Saye (2001) and Ge and Land (2003) also noted that student may avoid hard scaffolds unless explicitly directed to use them.

Challenges with classroom assessments

In K–12 settings, PBL assessment studies mostly employ a pretest–posttest design with a focus on recall of facts and concepts, measured through standardized tests and achievement assessments (Wilder, 2015). In fact, K–12 teachers may revert to traditional types of assessment for PBL when pressured to prepare students for standardized testing. For example, Pedersen, Arslanyilmaz, and Williams (2009) reported that sixth-grade science teachers, experienced in using PBL, implemented assessment strategies inconsistent with a technology-based PBL program. They used multiple-choice assessments, added structure to students' assignments, and used grades as extrinsic motivators, deemphasizing the PBL process. Pedersen et al. recommended finding balance between the constructivist requirements of PBL, teachers' practices, and classroom requirements. Both Wilder (2015) and Pedersen et al. found that teachers evaluated skills such as problem solving, critical thinking, and quality of work, but these were often ungraded and not counted toward achievement.

It is important to note contrasting results on PBL assessment with some studies showing no significant differences between PBL and traditional settings. This contrast stems from heterogeneity in PBL implementations and measures of assessment, several of which rely on self-reporting (Belland, French, & Ertmer, 2009; Condliffe, Visher, Bangser, Drohojowska, & Saco, 2015).

Teachers' uses of PBL

Teachers' implementations of PBL and other complementary pedagogical approaches are dictated internally by their pedagogical beliefs and externally by available resources and support (Ashgar et al., 2012). Consequently, their implementations of PBL are varied. For example, in a review of literature, Jerzembek and Murphy (2013) stated that teachers showed an orientation toward the PBL practice, and they all discussed learning goals identification and group and independent student work. However, some excluded self- or peer evaluation, self-reflection, and students' generation of hypotheses, which are part of the Barrows/Hmelo-Silver model (Barrows, 2006; Hmelo-Silver, 2004).

A continuum of teaching styles affords PBL implementations. For example, Liu et al. (2014) found that some teachers were more "hands on" and others were more "hands off" (p. 70). In addition, some teachers followed lesson plans and used all of the learning materials included with *Alien Rescue*. Other teachers selected specific materials to use in their classes, and still other teachers created additional instructional materials to support their students. Teachers in Lehman and colleagues' (2006) evaluative study reported academic improvements and successes for their students, which are typical (e.g., Jerzembek & Murphy, 2013; Torp & Sage, 2002). The teachers also found professional satisfaction with their implementations, such as moving to a facilitator of learning. Tamim and Grant (2013) found that some teachers reinforced content previously taught with supplemental PjBL (reinforcers), some extended learning by complementing fundamentals taught earlier through PjBL (extenders), some initiated learning with it, embracing its process to the fullest extent (initiators), and others used PjBL fluidly to meet students' needs and fill learning gaps (navigators).

Research Methods Used in K–12 Contexts

Research methods used in K–12 contexts mirror other research done on PBL. Whether investigating categories of learning outcomes (Saunders-Stewart et al., 2012) or processes of PBL implementation (Hung, 2011), study methods vary between experimental, qualitative, or mixed. This section gives an overview on the type of research conducted under each of these methods.

Experimental Designs

Experimental and quasi-experimental designs with PBL and complementary pedagogies are difficult or intimidating to implement. Using recent literature reviews and meta-analyses (Belland et al., 2009; Holm, 2011; Jerzembek & Murphy, 2013; Leary, Walker, Shelton, & Fitt, 2013; Strobel & van Barneveld, 2009), only 26 studies implemented quantitative data collection methods for experimental, quasi-experimental, or mixed-method designs. These studies covered years from 1996 to 2009. However, more recent research has included experimental designs (e.g., Beatrice, Amadalo, & Musasia, 2015; Wirkala & Kuhn, 2011). Collectively, the studies included problem solving, SDL opportunities, and a variety of collaborations. With PjBL, Holm (2011) reports that students had greater learning gains in content knowledge assessments, and learning gains were more pronounced for middle- to low-ability students. Achievement was also higher in schools where whole-school initiatives or system-wide policies were aligned to PjBL (Ravitz, 2008, 2010).

Experimental studies continue to be troubled by poor reporting in research designs. The use of self-report measures as a primary or sole measure does little to move the field of PBL in K–12 education forward beyond student attitudes (Belland et al., 2009; Jerzembek & Murphy, 2013). In addition, reporting instrument validity and reliability is problematic. In many studies included (and excluded) in the literature reviews and meta-analyses, researchers adopted previous studies' instruments and either failed to report current validity and reliability results or omitted the previous authors' results (Belland et al., 2009; Jerzembek & Murphy, 2013).

Even in the most recent articles, authors continue to call for researchers to investigate the effectiveness of PBL and complementary pedagogies in K–12 (Rico & Ertmer, 2015). Interestingly, two trends are prevalent in experimental research for PBL in K–12. One movement in K–12 studies has been away from comparison studies with control groups and towards reporting the complexities implementations, particularly in the United States. This can be seen in the numbers of recent studies discussed below in the section on qualitative research. Second, there has recently been an increase in the numbers of international studies within K–12 contexts (e.g., Beatrice et al., 2015; Cheriani, Mahmud, Tahmir, Manda, & Dirawan, 2015; Widyatiningtyas, Kusumah, Sumarmo, & Sabandar, 2015).

Qualitative Designs

As research on PBL effectiveness encountered issues related to definition of terms, validity and reliability of measurement, and heterogeneity in design and implementation (Belland et al., 2009; Hung, 2011; Walker & Leary, 2009), a shift from quantitative to qualitative approaches emerged to investigate not only PBL outcomes but also its process. The main advantage of exploring the PBL process is looking at its multifaceted nature, which influences outcomes in a variety of ways (Hung, 2011). Strobel and van Barneveld (2009) conducted a meta-synthesis of meta-analyses to study "how the differences in the definitions and measurements of learning contribute to the inconclusiveness about the effectiveness of PBL" (p. 46). The qualitative nature of the meta-synthesis led them to categorize types of learning outcomes through which they were able to explain the discrepancies previously reported and compare differences in short-term knowledge retention versus long-term retention outcomes and performance.

In qualitative research focused on teachers, researchers are interested in describing classroom practices, depicting successful strategies, and challenges.

Moreover, researchers are interested in looking at how teachers' beliefs, motivation, and professional development influence these practices (Arce, Bodner, & Hutchinson, 2014; Cook & Weaver, 2015; Ertmer et al., 2009; Gourgey et al., 2010; Liu et al., 2012; Pecore, 2012). With students, researchers explore skills anticipated to be gained, such as problem solving, artifact creation, self-direction, metacognition, and collaborative behavior (Barron, 2003; Cicchino, 2015; Lee et al., 2015). For both purposes, researchers mainly use a case study approach and collect data through semi-structured interviews and observations (e.g., Arce et al., 2014; Ertmer et al., 2009; Gourgey et al., 2010; Lee et al., 2015; Pecore, 2012). These are sometimes combined with analysis of documents such as student notes, journals (e.g., Ertmer et al., 2009; Liu et al., 2012), artifacts (e.g., Barron, 2003; Grant, 2011), and video recording (e.g., Cook & Weaver, 2015).

Mixed-Methods Designs

Some studies also combine quantitative and qualitative methods in mixed-method designs. Quantitatively, data are mostly collected on student performance, their attitudes toward the intervention, and prior skills and knowledge. Qualitatively, data are collected on process components of PBL in addition to attitudes and perceptions. For example, Peters and Kitsantas (2010) looked at how their intervention that embedded self-regulatory training impacted the students' awareness of their metacognitive thinking, self-regulation, and gains in content knowledge. They collected data through tests and surveys to measure outcomes and they used interviews to look at the process. Duncan and Tseng (2011) explored design strategies in a high school genetics course. They analyzed written assessments for student understanding as well as their thinking process. In addition, they conducted interviews, collected artifacts, and analyzed videos of classroom instruction. By using mixed methods, researchers aim at gaining a holistic look at PBL and analyzing the intricacies of its implementation.

Conclusion and Recommendations

In this chapter, we presented an overview of the research conducted with PBL and other complementary pedagogies, including PjBL, inquiry, and anchored instruction, in K–12 education. The theoretical foundations of PBL were discussed and implementation outcomes for students and teachers examined. Finally, a section on the research methods associated with PBL in K–12 was presented. The uses of PBL in K–12 leave much work to be done.

Stronger depictions and descriptions of PBL implementations are needed. Because PBL can be so varied (Hung, 2011; Savery, 2006), the descriptions of how PBL, problem cases, tutoring, scaffolding, self-direction, and group interactions need much stronger explanations. Readers and researchers need better narratives in order to understand the PBL process (Hung, 2011). Clarity in the model of PBL, learning goals, and assessment measures are also required. Belland et al. (2009) have criticized the PBL research for a lack of validity and reliability when reporting assessment measures. Using Saunders-Stewart et al. (2012)

categories of learning outcomes may help to codify and advance research findings for specific outcomes. So, more specifics with regard to measures and processes would benefit researchers and practitioners. Researchers and practitioners would also be better served with varied study designs. These designs should not limit measuring changes in knowledge, skills, and performance quantitatively but extend to exploring how and why these changes occur under PBL qualitatively.

The use of scaffolds as temporary supports continues to be unclear. As Belland's (2010, 2013, 2014) work suggests, there are a number of different types of scaffolds that can be employed to support students. However, how and when to fade these supports is still largely unknown or left to the discretion of the classroom teacher. Moreover, in some cases, the scaffolds are used only one time during a problem case or project, so the fading is inconsequential.

In addition, the ease with which self-report measures can be implemented and analyzed contributes modestly to new knowledge with PBL. More robust experimental and quasi-experimental designs are needed to identify nuances of learning outcomes and implementations, which ones are generalizable and which ones are context-dependent. For example, PBL implementations typically require collaborations and/or small groups (i.e., tutorial groups). However, Wirkala and Kuhn (2011) found increased achievement with PBL even without collaboration. More research is needed to determine under what conditions these findings occur.

For assessment, instruments are needed not only to measure knowledge gains in PBL but also application, individual and group work, and nonacademic outcomes such as SDL, which can be challenging (Ertmer et al., 2009; Wilder, 2015). The literature shows an emphasis on pretest–posttest settings, with use of quizzes and multiple-choice tests (Pedersen et al., 2009; Wilder, 2015) with few robust cases showing other forms of evaluation such as rubrics, journal writing, group work evaluation, peer evaluation, and self-evaluation (Ertmer et al., 2009).

Also, much of the research with PBL in K–12 is siloed, or segmented based on discipline. For example, the research on inquiry (e.g., Banchi & Bell, 2008; Meyer et al., 2012) and project-based science (e.g., Krajcik & Blumenfeld, 2006; Krajcik & Shin, 2014; Marx et al., 1997) are separated from the research findings regarding PBL, PjBL, and anchored instruction. These siloes of research restrict advancements in the field.

Except in the cases of the recent whole-school implementations (e.g., Mosier et al., 2016), the implementations of PBL in K–12 tend to be isolated implementations and classroom teacher-dependent. There is currently no reported evidence for long-term or longitudinal findings for better student immersion and skill acquisition (Wilder, 2015). Even with whole-school implementations, research (e.g., Gourgey et al., 2010) has not provided strong confirming evidence (c.f. Krajcik & Blumenfeld, 2006; Krajcik & Shin, 2014). In a literature review, Holm (2011) reported that students had learning gains with PjBL. Similarly, Ravitz (2008, 2010) reported learning was higher with PjBL in whole-school implementations or system-wide policies for PjBL. More substantive and rigorous research studies are needed. Rationales for implementing PBL continue to rely too heavily on researcher interests and on positive student and teacher perceptions.

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Section III

Instructional Design of PBL

Introduction

Section III of the handbook provides a comprehensive analysis and application of instructional design principles and processes that guide the design and implementation of problem-based learning (PBL). Bridging research and practice, the chapters in this section provide an integrated and grounded view of the pedagogical processes, instructional strategies, techniques, and assessment strategies required for the successful design and implementation of PBL. The chapters are sequenced to provide a structured view of PBL design, covering problem and process design, designing for facilitation and scaffolding, effective group process, self-directed learning (SDL), assessment, and technology applications that support PBL unit design, facilitation, and participation.

Starting with Chapter 11 "Problem Design in PBL," Hung describes the criticality of problems in PBL by stating that problems are not just a trigger to start the learning process, rather, they are a significant component for effective student learning throughout the PBL process, and therefore it is imperative to ensure the effectiveness of the problems used in a PBL implementation. Hung discusses how the design and quality of PBL problems could have an impact on various aspects of student learning during the PBL process and provides a model for systematically designing effective PBL problems.

Next, in Chapter 12 "The Problem-Based Learning Process: An Overview of Different Models," Wijnia, Loyens, and Rikers discuss the types of process models that prescribe how learning in PBL should be structured. The authors describe how process models vary based on the type of knowledge students are expected to obtain and the types of problems and learning activities that are most suitable for achieving the learning objectives. A distinction is made between process models that emphasize procedural knowledge acquisition and process models that emphasize declarative knowledge acquisition. Examples of how these process models have been implemented in higher education contexts are presented.

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Edited by Mahnaz Moallem, Woei Hung, and Nada Dabbagh.

The third chapter in this section, Chapter 13 "Facilitating Problem-Based Learning," starts with a review of the epistemology underlying PBL and its facilitation, the goals of PBL facilitation, and characteristics of good facilitators. More specifically, Hmelo, Bridges, and McKeown describe nine strategies for facilitation and provide examples of implementation. The importance of professional development in supporting facilitation for a wide range of teachers' experience levels is also discussed. The authors also examine the role of new technologies in facilitating PBL and how such technologies can be used across the PBL cycle.

In Chapter 14 "Scaffolding in PBL Environments: Structuring and Problematizing Relevant Task Features," Ertmer and Glazewski provide a review of how scaffolding has been conceptualized and used in PBL, and emphasize that scaffolds should be designed and activated with intentionality based on a detailed understanding of the learners and context in which they are used. The authors discuss the primary functions of scaffolding in PBL and the major types of scaffolds used in PBL, noting the importance of anticipating both hard and soft scaffolding needs prior to PBL implementation. The evolution of scaffolding models from the use of human tutors to distributed and blended models that incorporate human and nonhuman artifacts or agents is also described.

In Chapter 15 "Designing for Effective Group Process in PBL Using a Learner-Centered Teaching Approach," Blumberg discusses how to design for effective group process in PBL using a learner-centered teaching approach. The author emphasizes that the PBL process uses iterative group methods by design, where students progressively integrate more knowledge to solve problems. The steps of the PBL iterative group process are presented and then mapped onto the learner-centered teaching paradigm. The chapter also describes the roles and responsibilities of instructors and students within the PBL group process to show how they are congruent with the learner-centered teaching approach.

Chapter 16 "The Role of Self-Directed Learning in PBL: Implications for Learners and Scaffolding Design," by Ge and Chua, describes the role of SDL in PBL. The chapter discusses the various demands placed on learners' SDL in PBL and explores strategies for designing effective scaffolds to cultivate learners' positive epistemic beliefs for PBL, motivate learners for SDL, and foster their cognition and metacognition. Guiding questions are provided for PBL instructors to help learners develop SDL skills, and the role of learning technologies in nurturing SDL learners is discussed.

In Chapter 17 "Types and Design of Assessment in PBL,", Albanese and Hinman discuss assessment in PBL and how it should encompass curricula and courses, the evaluators, the students, and peers. The authors caution that the goal of assessment in PBL should be inclusive of larger goals such as promoting teamwork and developing problem-solving skills, and not only focused on assessment of learning. The chapter provides examples of how to design formative assessment that can be incorporated to facilitate student learning, and summative assessment to determine whether students have achieved the competencies desired.

The final chapter in this section, Chapter 18, focuses on "Technology Applications to Support Teachers' Design and Facilitation of, and Students'

Participation in PBL." In this chapter, Belland describes the challenges that emerged in the design and facilitation of PBL units as PBL spread to contexts outside of medical education, and how technology-based tools and processes are central to student and teacher success in PBL. The chapter reviews theories of learning and motivation that inform PBL, and emphasizes the role of these theories in the design of tools and processes to support PBL in nonmedical contexts.

11

Problem Design in PBL

Woei Hung

Introduction

Barrows (1996) once explained that "the curricular linchpin in PBL … is the collection of problems in any given course or curriculum with each problem designed to stimulate student learning in areas relevant to the curriculum" (p. 8). Indeed, learning in PBL is driven, structured, and inspired by problems. In PBL, problems situate students in an environment where they develop and practice their problem-solving skills. Problems serve as a vehicle to afford the content knowledge to be studied. Problems contextualize abstract content knowledge to practical, meaningful working knowledge. Problems provide a real-time workspace for students to immediately practice applying the content knowledge. Also, problems challenge and therefore motivate students to learn. Problems are not just a trigger to start the learning at the beginning of the PBL process. Rather, they are a critical and significant component of the instruction in student learning throughout the PBL process. Therefore, it is imperative to ensure the quality of the problems used in a PBL implementation, as they are the critical essence in a student's learning process and achievement of the learning goal.

Many PBL researchers agree that the design of problems could certainly influence the effectiveness of PBL courses and curriculum (e.g., Duch, 2001). These negative impacts could range from causing students difficulty in identifying learning objectives (Sockalingam & Schmidt, 2011) to decreasing student interest (Hung, Mehl, & Holen, 2013b). Literature has shown that a number of issues could emerge and affect students' learning processes and outcomes when the problems do not properly support the intended learning goals or motivate them to learn.

First of all, insufficient content knowledge coverage is perhaps the foremost issue brought forward by ineffective PBL problem design. Albanese and Mitchell (1993) reported in their meta-analysis of PBL studies that "content is covered in PBL at a rate 82% as fast as in the conventional curriculum" (p. 76). This raises a

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concern that PBL curricula might cover about 20% less than does traditional curricula. They asserted that it would require a greater number of problems than had been used to cover the same amount of content as in a lecture-based curriculum. Moreover, there has also been an issue in terms of how much of the intended content knowledge and skills were sought out and studied by the students given that PBL is a self-directed learning process. This issue was investigated in a number of studies where student generated versus faculty intended learning objectives were compared. The average correspondence rate in these studies was only about 62% (e.g., Coulson & Osborne, 1984; Dolmans, Gijselaers, Schmidt, & van der Meer, 1993; O'Neill, 2000; van Gessel, Nendaz, Vermeulen, Junod, & Vu, 2003). Putting these two statistics together (62% of 82%), on average, PBL students were studying only about 51% of the curriculum content while the traditional students were instructed with 100% of lecture-based curriculum. This is an alarming sign that deserves special attention from PBL researchers and educators.

Second, PBL uses authentic real-life problems to contextualize content knowledge to help students make connections between abstract content knowledge and the situations in which they can be applied. Selecting effective context-appropriate problems may present less of a challenge for professional disciplines. However, selecting real life problems that effectively prepare students for the future could be difficult in K–12 education or general disciplines in higher education such as biology or chemistry because there is a wide range of possible professions in which the subject matter could be applied. Third, motivating students to learn could be another challenge in PBL problem design. Barrows (1986) suggested that promoting students' motivation to learn is one of the instructional goals of PBL. This assertion has been confirmed in numerous PBL studies (e.g., Albanese & Mitchell, 1993; Liu, Horton, Olmanson, & Toprac, 2011). However, one variable that needs to be taken into account is that the studies showing PBL's motivational effects were mostly conducted in the initial implementation stage. The novelty effect may play a role in student motivation and engagement in these initial implementations. A few studies that investigated long-term effects of PBL on students' motivation have suggested otherwise (e.g., Moust, van Berkel, & Schmidt, 2005; Romito & Eckert, 2011). Belland, Kim, and Hannafin (2013) also voiced their doubt in the validity of Barrow's (1986) assumption of motivational effects of PBL. The general trend of PBL studies in the area of motivation seems to suggest that PBL does intrinsically motivate students to engage more in the learning process initially. However, PBL's ability to maintain students' motivation may need to come under closer scrutiny.

Designing effective PBL problems that afford sufficient content knowledge, support appropriate levels of problem-solving skill development, and maintain a desired level of students' motivation to learn may not be as straightforward as it seems. Problem design is a critical step in a PBL implementation as the quality and the affordance of the problem could affect students' learning in various ways, such as ability to identify learning objectives, or motivation. PBL problems require undergoing an instructional design process that is a rigorous, systematic, and analytical decision-making orchestration. Therefore, in this chapter, I will discuss a systematic problem design model that could help PBL educators and instructional designers take into account critical considerations to ensure the effectiveness of PBL problems.

The 2nd Generation of the 3C3R PBL Problem Design Model

Different from problems used in lecture-based instruction, which mainly serve practice purposes, PBL problems are far more complex and consist of multiple components because they function in much greater capacities. Therefore, a conceptual framework for systematically designing effective PBL problems would be beneficial for PBL instructional designers and educators. Ten years ago, I proposed the 3C3R PBL problem design model (Hung, 2006), and later, a 9-step PBL problem design process (Hung, 2009) to provide PBL educators and instructional designers with a systematic problem design process to craft effective PBL problems. Since the model was first proposed, a number of additional components have been incorporated into the model as a result of continuing research efforts over the past several years. In the following sections, I will discuss the 2nd generation of the 3C3R model.

Three Classes of Components

The 3C3R PBL problem design model (Hung, 2006) was originally proposed as a conceptual framework to guide instructional designers and educators to design effective problems for PBL implementations in all disciplines and all levels of learners. The model focuses on aligning proper affordances of the problem with the learning objectives of the PBL module by considering the 3C3R cognitive components in a problem. In this 2nd generation of the model (see Figure 11.1), a new class of components—enhancing components that weigh in affective and social aspects of learning—have been incorporated to augment the comprehensiveness of the model.

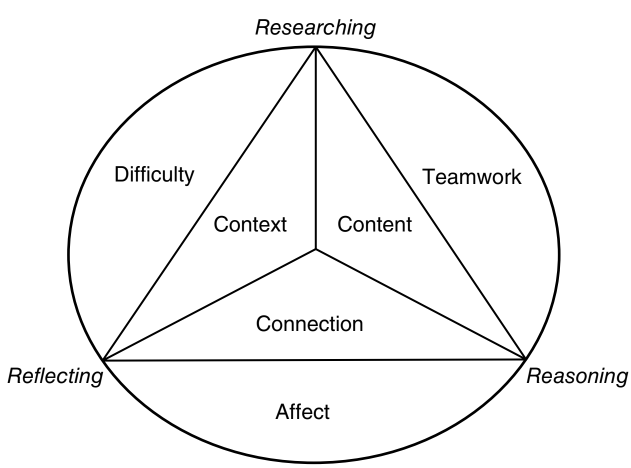

Figure 11.1 The 2nd Generation 3C3R PBL Problem Design Model.

The 2nd generation 3C3R model now consists of three classes of components: core, processing, and enhancing components. First, core components include content, context, and connection that deal with the design of the problem in supporting content/concept learning. These core components primarily address the issues of appropriateness and sufficiency of content knowledge, knowledge contextualization, and knowledge integration. Second, the processing components, which are researching, reasoning, and reflecting, concern the learners' learning processes, and problem-solving skills. These components function to guide students' learning toward the intended learning goal and objectives, adjusting the level of cognitive processing required for solving the problem to align with the cognitive ability of the learners, or alleviating students' initial unfamiliarity and/or discomfort with PBL when necessary. Lastly, enhancing components comprise affect, difficulty, and teamwork. Enhancing components consider the psychological, emotional, or social effects brought by these components in a problem that could have an influence on the students' level of motivation, engagement, self-directed learning, or collaborative/cooperative learning.

Core Components

The content, context, and connection core components of the 3C3R model address the problem design considerations in terms of affording proper content knowledge coverage, situating students' learning the content in appropriate context, and facilitating effective knowledge integration.

Content

Contrary to some people's impressions, content knowledge acquisition is one of the main learning goals of PBL. Most PBL pioneer researchers have emphasized the importance of knowledge acquisition in PBL (e.g., Barrows, 1996; Hmelo-Silver, 2004; Schmidt, 1983). As Breuker (2013) contended, "…domain knowledge … is the fuel for the reasoning engine" (p. 179). Hence, acquisition and retention of basic content knowledge is a necessary condition for problem solving or any application of knowledge. Knowledge acquisition in PBL is achieved through the processes of solving problems (Barrows, 1996). Rather than acquiring abstract content knowledge first from lectures and then practicing applying it to solve problems, PBL helps students simultaneously construct domain knowledge, apply the knowledge, and develop problem-solving skills. This is especially true for soft content knowledge. Content knowledge can be classified into two categories: soft content knowledge and hard content knowledge. The former refers to the profession-specific soft skills or implicit concepts, culture, or practice, such as ethics in patient care in medical education, communication skills in business education. On the other hand, hard content knowledge refers to domain-specific facts, concepts, principles, rules, as well as their applications. When designing PBL problems, a few elements of the content component should be taken into consideration.

Proper affordance of curricular standards

Some may have mistakenly equated PBL to free-form inquiry-based learning that provides minimum to no guidance for students (e.g., Kirschner, Sweller, &

Clark, 2006). Quite to the contrary, PBL curricula are designed to help students obtain specific instructional goals and learning objectives and follow a specific process (e.g., Barrows & Myers, 1993; Schmidt, 1983). Therefore, the first step in designing PBL problems is to set goals and objectives in accordance with the course or curricular standards (Azer, Peterson, Guerrero, & Edgren, 2012; Drummond-Young & Mohide, 2001). Only with clearly defined learning objectives, can we design PBL problems that properly afford them.

Setting goals and learning objectives is one thing. Whether or not students can identify them from the problem is another. Research has shown that identifying the intended learning objectives from the problems was one of the challenges that PBL students experienced (Hung et al., 2013b; Sockalingam & Schmidt, 2011). Thus, once a problem is identified to afford the intended learning objective, its problem statement needs to be carefully designed to present sufficient and appropriate information to guide the students to identify the intended learning objective, yet keep the problem challenging. Crafting problem statements to meet these criteria could be approached from two directions. One is the design of the researching and reasoning components of the problem, which I will discuss shortly. The other is the consideration of the scope of the problem.

Scope of problems

The second element of the content component is ensuring proper scope of PBL problems, both breadth and depth. First, designing the breadth of the problem can be accomplished by conducting task analyses on the learning objectives in terms of the knowledge, skills, and/or abilities (KSA) required to fulfill the learning objectives. The same analysis should also be conducted on the candidate problem to specify the KSA required to solve the problem. The results of these analyses could reveal the degree of correspondence between the two. Based on this information, the designers can adjust the breadth of the PBL problem as needed to better afford the students' learning both in the content area and the problem-solving skills required to achieve the learning objectives. Among the various task analysis methods, a learning hierarchy analysis (Gagné, 1962) would be useful for analyzing the instructional content and tasks because curricular standards are often general and context-independent. Other more specific task analysis methods, such as PARI (Precursor-Action-Results-Interpretation) (Hall, Gott, & Pokorny, 1995) or the Information Processing Method (Scandura, 1973) would be suitable for performing the analysis on the PBL problems since these analysis methods are to map out the cognitive reasoning processes in solving the problems.

However, as discussed, hierarchically well-organized content knowledge structure does not fit well in ill-structured real-life problems, which are the type of problems to be used in PBL (Barrows, 1994; Hung, Jonassen, & Liu, 2008). It is almost impossible to have a real-life problem that could perfectly afford the set of learning objectives in a given module. This may partially explain PBL's less sufficient content coverage issue that Albanese and Mitchell (1993) observed. One solution to this issue may be selecting a problem whose scope is (or adjusting its scope to be) slightly or moderately larger than the KSA specified by the learning objectives, and then design the researching and reasoning components in the problem to guide students toward the KSA learning objectives. Using moderately overafording problems (for details, please refer to Hung, 2009) in conjunction with various connection approaches (discussed in detail in the connection component section) could alleviate the issue as well as help students integrate content knowledge.

Context

The second core component in the 3C3R model is context. The notion that learning through solving real-world problems prepares student readiness for real-world settings (Barrows, 1986) is based on the conception of contextualized knowledge, or situated cognition (Brown, Collins, & Duguid, 1989; Lave & Wenger, 1991). Godden and Baddeley (1975) suggested that when content is learned in the same or similar context in which it will be applied, the knowledge and skills would be recalled and retained more easily because context furnishes the background of the problem and makes it a story. Contextual information provides multiplicity and redundancy of embedded cues for effective retrieval, according to Paivio's dual coding theory (Paivio, 1986). Context also provides a structure for the content knowledge to fit into where it will be used in the problem, which helps integrate individual pieces of knowledge into a meaningful working schema (Bartlett, 1968). Both soft and hard content knowledge need an appropriate context to be meaningful to the students.

To be an effective problem solver, the student needs sufficient hard content knowledge and specific situational/contextual knowledge that is implicit but crucial to making hard content knowledge and soft content knowledge usable. This type of knowledge helps index students' domain knowledge for when and where to use it in real-world contexts (Barrows, 1986). Lack of situational/contextual knowledge may account for students' difficulties in transferring knowledge to real-life situations, as Prawat (1989) argued.

The uniqueness of every given real-life context imposes different constraints and ways of thinking, and sometimes different cultural practices, which a problem solver will naturally take into account. For example, a civil engineer will take much more extreme measures in considering the effect of possible earthquakes when designing a building structure in California than when designing a building in Florida. The ability to detect and consider explicit as well as implicit constraints is one of the keys to effective problem solving. Therefore, the context component of PBL problems should help students construct their contextual knowledge along with the domain knowledge. In considering the context component of PBL problems, contextual validity and degree of contextualization are two important design elements.

Contextual validity

According to Hays and Gupta (2003), PBL problems should be evaluated in terms of whether the context in which the problems are situated is valid for its intended instructional goal. For example, a PBL problem within the context of a hospital emergency room in a city may be less contextually valid for training medical students who will be primarily working in hospitals in rural areas. Therefore, the contextual validity in PBL problems should be evaluated by examining their clinical/practical relevance to the learners' future professional settings (Dolmans & Snellen-Balendong, 1997). Also, this relevance needs to be addressed explicitly in the problem to guide the students' thinking and learning directions (e.g., primary concerns) and process (Yeung, Au-Yeung, Chiu, Mok, & Lai, 2003).

Degree of contextualization

Providing contextual information in the problem helps guide students to consider profession-specific constraints or primary concerns (Martin & Beach, 1992) and establish their situational knowledge. However, the amount of contextual information needs to be appropriate. Overcontextualized PBL problems may overwhelm the learners with unnecessary information or mislead their problem-solving reasoning, while undercontextualized problems may cause the students to fail to consider issues that are implicit but critical in that particular setting. Thus, the appropriate degree of contextualization in designing PBL problems will depend upon the learners' projected future settings. For instance, medical school students studying cells have a very specific and certain projected future context in which they will apply their knowledge, while the range of projected future contexts for high school students learning the same topic is broad and general. Therefore, the degree of specific contextual information in the problems should be calibrated to an appropriate level to properly guide the students' reasoning in the problem-solving process.

Connection

The third core component of the 3C3R model is connection. The conception of problem-organized knowledge structure is for students to construct their domain knowledge as working schemata. With these "packaged" schemata (a collection of cases or problems), students can effectively retrieve relevant knowledge when they are solving the same or similar problems in real-life settings (Gallagher, 1997). However, both Hung (2003) and Lieux (2001) have observed that very few college students proactively integrate the knowledge learned. Given that students are not intrinsically apt to integrate what they have learned, students' "packaged" knowledge could become "compartmental" knowledge according to the cognitive flexibility theory (see Spiro, Coulson, Feltovich, & Anderson, 1988). To solve ill-structured problems effectively, the problem solvers not only have to possess a rich repertoire of necessary knowledge (Battig, 1979), their knowledge base also must be a highly interlinked and cross-referenced network (Spiro et al., 1988). The highly interlinked network is an enabler for devising effective solutions to ill-structured problems (Kitchner, 1983). Several approaches can be used to incorporate a connection component in PBL problem design.

Prerequisite approach

Activating prior knowledge and elaboration are two of the critical tasks in PBL process (Schmidt, Rotgans, & Yew, 2011). The cognitive processing is to connect newly learned knowledge with the existing knowledge to form or expand students' schemata. Therefore, a common logical sequence for designing the connection component of PBL problems is from simple to complex, which was confirmed by PBL practitioners (e.g. Angeli, 2002). The prerequisite approach ensures that the problems at the more complex level build upon and call for concepts and information that appeared in the preceding problems. When the structural relationships among the concepts to be learned are sequential or hierarchical, this approach is an appropriate instructional design choice to help students logically connect the related concepts and information and structure their knowledge base.

Overlapping approach

Hierarchical relationships do not always exist among the concepts in a domain, such as subjects in humanities or politics. To help students establish an integrated conceptual framework, the concepts should be grouped into a set of problems. Yet, each concept should not appear exclusively in one problem. The concepts should appear in several problems so that the learners can study each concept in relation to other concepts. By understanding multiple sets of concepts involved in multiple problems, the learners link these subnetworks into a larger and more complete network.

Multifacets approach

Savery and Duffy (1996) suggested that guiding learners to test ideas in different contexts would broaden their conception about a topic. The multifacets approach helps students enrich their conceptual understanding and repertoire by helping them realize the dynamic nature of concepts. For example, the concepts in the domain of structural engineering could be used differently in situations of designing buildings to withstand earthquakes or hurricanes. The characteristics or nature of the variables or concepts could change from one context to another or over time. As Hoffman and Ritchie (1997) suggested, learning concepts in only one type of problem may hinder the students' ability to transfer and deal with complex, real-world problems. The overlapping approach helps students link related concepts within a particular domain or context, while the multifacets approach enables students to integrate multiple conceptual networks across different contexts.

The issue discussed earlier about real-life problems rarely perfectly affording a particular set of learning objectives could be remedied by these three connection component design approaches. Depending on the nature of the content knowledge (e.g., sequential, hierarchical, or semantical, or causal), the main idea of these three approaches is to craft problems that carry slightly more content knowledge than the learning objectives of the modules. This way, the extra content knowledge not only helps students interconnect the concepts among problems, but also resolves the difficulty in finding real-life problems that perfectly align with learning objectives.

In sum, the function of the three core components of the 3C3R model—content, context, and connection—is to establish the core foundation of a PBL problem that will sufficiently and precisely afford intended learning goals and objectives, contextualize domain knowledge, and guide students to form integrated conceptual frameworks.

Processing Components

The three processing components of the 3C3R model are researching, reasoning, and reflecting. The nature of these processing components is dynamic, as opposed to the static nature of the core components. These processing components are to calibrate the problem-solving process in that particular problem to (a) activate the core components, (b) facilitate students' development of problem skills in accordance with their cognitive readiness, (c) alleviate the issue of students' initial unfamiliarity and/or discomfort with PBL (Dabbagh, Jonassen, Yueh, & Samouilova, 2000; Hoffman & Ritchie, 1997), and (d) encourage students engagement in metacognitive activity. Problems are puzzles where certain pieces of information are missing or vague, therefore resulting in impasses in the reasoning and solution path in the problem space (Newell & Simon, 1972). These impasses are where learning happens, as Blumberg, Rosenthal, and Randall (2008) argued. There are two types of impasses: KSA gaps (the dots in the problem space) and reasoning–solution path gaps (the links between the dots). When encountering KSA gaps, students need to acquire the necessary KSA in order to uncover the missing dots. When encountering a reasoning–solution path gap, students will need to exercise their reasoning skills to connect the dots (newly acquired KSA or prior knowledge) to form a viable solution path to the goal. Thus, by carefully designing where the gaps are (i.e., by giving or omitting certain information) in the problem statement, the problem can be calibrated to guide students' content knowledge construction, as well as problem-solving and reasoning processes. Hence, the researching component functions to map out the content KSA gaps in the problem based on the learning objectives. On the other hand, the reasoning component designs the reasoning–solution gaps on the solution path for students to exercise applying the newly acquired knowledge from the researching process to solve the problem. Also, the reflecting component aims to create a natural environment for reflection activity.

Researching

Content knowledge gaps identification

The first stage of a problem-solving process is understanding the problem (Bransford & Stein, 1984) in order to construct the problem space. This problem space allows students to identify what is known and what they need to know (the unknowns) in order to connect the dots on the problem-solving path to the solution. The unknowns are the KSA gaps. Thus, when considering the researching component, the first step is to identify where the content KSA gaps should be in the problem space. This consideration should be aligned with the KSA specified by the learning objectives. On the other hand, due to the nature of ill-structured real-life problems, some KSA could be used for solving the problem but not be part of the learning objectives. Thus, when designing this component of the problem, these nonlearning objective-related KSA should also be identified. This analysis can help craft the problem to have appropriate KSA gaps in the problem that afford the content knowledge (i.e., the learning objectives), as well as to guide students away from the nonlearning objective KSA if necessary.

Goal specification

Setting problem space for ill-structured problems that are likely to be open to multiple interpretations and possess multiple solutions and solution paths (Jonassen, 1997) is difficult. One effective technique to guide students to take the learning objectives related path(s) is by giving a clear goal(s) of the problem. Scott's (2014) multilevel analysis on PBL design characteristics and student learning process showed that there was a significant correlation between learning goal orientation and self-directed learning. Conceivably, the design of the problem could shape the students' information-seeking behaviors (Dabbagh & Williams-Blijd, 2009; Goh, Chan, Lee, & O'Grady, 2015). Several studies have confirmed that a clear goal state of the problem significantly directs student learning (Barron et al., 1998; Hung et al., 2013b; Hung & Holen, 2011; Petrosino, 1998).

Context specification

This technique is not as direct as goal specification. However, it could help further guide not only students' specific domain KSA acquisition, but also their reasoning patterns and process. In most professions, the domain knowledge is highly context-specific. Some concepts or principles may be the common foundation for several fields or professions, yet their applications could be drastically different from one profession to another. This is because the context determines the problem solver's frame of reference, and therefore, determines information or knowledge needed to be researched and acquired (Flesher, 1993). Furthermore, context also influences a problem solver's primary concerns in a problem reasoning process. For example, Martin and Beach (1992) observed that engineers' primary concerns were economic issues, while personnel officers' primary concerns were practical matters. Thus, context specification could also be used to help students internalize their profession-specific primary concerns when solving their PBL problems.

Reasoning

As Blumberg et al. (2008) contended, "impasse resolution is seen as a catalyst for the acquisition of new knowledge and problem-solving strategies" (p. 1531). Researching and reasoning are two sides of the same coin. The two components represent the two types of cognitive processes that an individual is engaged in during a problem-solving process iteratively. Both cognitive processes achieve the same goal, which is uncovering the unknowns that are necessary for a viable solution path to the goal. The difference between researching and reasoning is the focus and the types of cognitive processes. Researching focuses on searching for relevant information and understanding it (the missing dots or nodes in the solution path), while reasoning aims at how to connect the dots to form the solution path to reach the goal. Therefore, the researching component is to design the missing dots or impasses on the solution paths, and the reasoning component is to design how these dots are connected to form the solution paths. In other words, the design of reasoning gaps focuses on how the intended KSA could be used for reasoning through the problem space. Depending upon the types of reasoning needed, the following are a few examples, rather than an exhaustive list, of the types of problem reasoning gaps designs.

Causal reasoning design

Causal reasoning is one of the most common cognitive processes inherent in problem solving (Brewer, Chinn, & Samarapungavan, 2000; Thagard, 2000). For example, besides the KSA gaps in a problem of a patient with a heart disease identified in the researching component, the causal reasoning gaps should also be identified and designed in the reasoning component where the students will need to explain what and how the symptoms are caused (i.e., the mechanism). By explaining the chain of cause–effect relationships, the students are applying the static KSA (from the content component) that they acquire from engaging in researching to explain the mechanism of the causal relationships and devise solutions to the problem (e.g., the diagnosis and prescription for the patient). Therefore, when causal reasoning is an intended learning objective for reasoning skills, the design of the reasoning component should focus on where the reasoning path(s) could be so that the students will be reasoning causally through the key nodes on the solution path(s), as well as the types of problems that would appropriately afford this reasoning pattern and process.

Logical reasoning design

Logical reasoning is also a common cognitive process used in problem solving (Jonassen, 2000). When logical reasoning is part of the learning objectives, the design of the reasoning component should ensure that the information provided (or omitted) will afford solution paths for this type of reasoning. In these solution paths, the students will not only have to research the intended KSA, but also engage in using them in reasoning through a number of IF–THEN scenarios in order to solve the problem. For example, giving information about the conditions where a patient's allergic reaction appears and does not appear as part of the description in a problem could create a logical reasoning cue for the students to engage in logical thinking to deduce the allergen.

Decision-making reasoning design

Decision making requires cognitive processes of listing critical attributes, setting criteria for evaluating options, comparing pros and cons against the evaluation criteria, and justifying the decision. Decision-making reasoning could appear in a simple problem such as deciding a menu for Thanksgiving dinner or a complex dilemma problem (see Jonassen, 2000) such as the resolution between environmental protection and energy demands over the utility of nuclear power. One way to guide a decision-making reasoning path in a problem could be imposing constraints in the criteria of the final solution. For example, a problem about mitigating a flood threat to a city could require the students to submit a proposal that also includes alternative solutions in addition to their proposed solution and the justifications for the decision. This creates the decision-making reasoning requirement (listing, comparing, and justifying) that the students will have to engage in to arrive at the final conclusion.

Reflecting

The third processing component is reflecting. Most PBL researchers (e.g., Hmelo, 1998; Schmidt, 1983) agreed that reflection is a crucial element in the PBL process that optimizes learning outcomes. Through engaging in the metacognitive activities such as knowledge abstraction and summary, or self-evaluation (Barrows & Myers, 1993), the students have the opportunity to systematically and conceptually organize and integrate their knowledge, as well as refine their problem-solving skills. In the 3C3R model, reflecting is a metacognitive component in PBL problems. This component optimizes the PBL processes by ensuring the maximum effects of other components in the PBL problems. The reflecting component is also one feature in the 3C3R model that helps the learners not only integrate what they have learned, but also go beyond the intended scope of the PBL problem and develop self-directed learning skills. Normally, reflection is accomplished with guidance given by tutors (Gallagher, 1997). Incorporating a reflection component into PBL problems can promote learner independence and metacognitive skills and, ideally, cultivate their disposition to reflect on their own learning. This way, learners can elevate their learning outcomes and reach the goal of developing self-directed learning skills.

In his transformative learning theory, Mezirow (1990, 1997) articulated three types of reflection. They are content reflection, process reflection, and critical reflection. Content reflection involves examining one's understanding and conceptualizing the content knowledge. Process reflection focuses on self-evaluation of problem solving and the learning process. Critical reflection, on the other hand, is the problem solver questioning the preassumptions, common beliefs, or conventions of problems on which he or she worked. The knowledge abstraction and summary cognitive activities suggested by Barrows and Myers (1993) support the content reflection and process reflection. Content and process reflections can help students build a solid conceptual knowledge base, as well as problem solving and a self-directed learning skill set. Yet, critical reflection is in fact the metacognitive process that advances students toward being experts in the field. An individual can only transform knowledge rather than just receive knowledge when he or she is able to critically examine and reflect on the knowledge from its fundamental level.

Thus, when designing the reflecting component in PBL problems, formative and summative reflective processes could be considered to support content, process, and critical reflections. A formative reflective process should occur throughout the PBL course along with the processes of researching and reasoning. The learners should evaluate and reflect on their problem solving and learning processes, and adjust their strategies accordingly during the course of learning. The formative reflective process should focus on content and process reflection: whether (a) the breadth of knowledge is what the PBL problem is designed to cover; (b) the depth of their study on the topic is adequate; (c) their research methods are effective and efficient; (d) their reasoning processes are logical and effective; and (e) their problem-solving strategies are effective. Interactive journal writing has been reported as an effective tool for promoting synthesis of processes during student learning (Andrusyszyn & Davie, 1997). Thus, interactive journal writing can be used to help the learner engage in such processes as well as to receive feedback from the instructor to guide self-assessment throughout the course. For example, a task built into a PBL problem, such as "you need to keep a journal and report to you supervisor on a weekly basis," or "a chart of your analysis results needs to be submitted to the client by the end of the first week" can embed formative reflection as part of the problem-solving process. When there is a final product to be produced in a PBL module, formative evaluation of the prototype of the product could be a very effective formative reflection tool.

Another type of reflecting component is a summative reflective process. Very often learners equate the end of learning with the end of the semester or having found a solution to a problem. Thus, the reflecting component should also encourage learners to continue learning about the topic, and cultivate in learners the habits of experts. Thus, summative reflection may need to focus more on critical reflection. For this type of reflective process the reflecting component in PBL problems could include (a) a content/process reflection element (e.g., incorporating a requirement such as "you need to provide a diagram describing your solution" in the PBL problem), (b) follow-up problems or questions (e.g., "what if the funding got cut 25% in the middle of the project, what would you change in your proposal?"), or (c) a critical reflection problem (as a final problem—a problem that challenges the common assumptions of the previous problems).

Enhancing Components

The new set of components in the 2nd generation of the 3C3R model, which are enhancing components, include affective factors, problem difficulty, and teamwork functions. They help enhance the PBL problems to promote students' motivation and engagement, self-directed learning, and cooperative/collaborative skills. The 3C3R components focus on the objective content acquisition and cognitive processing of a problem-solving process, while the enhancing components consider the subjective psychological and social interactions of a problem-solving experience.

Affect

As mentioned in the introduction of this chapter, the assertion that PBL intrinsically motivates students to learn (Barrows, 1986) has been challenged to some degree (e.g., El-Wazir, Hosny, & Farouk, 2011; Moust et al., 2005; Romito & Eckert, 2011). Motivation in the context of PBL is a complex psychological construct that could be affected by a number of factors, such as tutors/instructors (Glew, 2003), personality conflicts among students (Steinert, 2004), or design of PBL problems (Hung, 2006, 2009). According to Deci, Vallerand, Pelletier, and Ryan (1991), one component of motivation is basic psychological needs. Deci and Ryan's (1991) self-determination theory (SDT) argues that the basic psychological needs for competence, relatedness, and autonomy are key factors to promoting students' motivation in learning. Among these three psychological needs, relatedness is perhaps the most instructionally amenable as the other two have been addressed in the PBL process and method, such as problem-driven instruction and self-directed learning.

Relatedness refers to the social needs of humans to connect with others. It is a human tendency that we develop a sense of connection with someone, some groups, or something that shares commonality or similarity with our own life experience. This sense of connection is a likely source for an individual to determine whether an action is needed in a situation that involves someone or something triggering the connection, and in turn, motivating him or her to take action. One thing is clear that the sources for these types of psychological or emotional connections are mostly from life experience. Unlike textbook problems, PBL problems are real-life problems. However, real-life problems alone do not necessarily motivate students to solve the problem. Rather, real-life problems that trigger psychological needs of relatedness could increase the chance for students to develop such connection and ownership to the problem, and in turn, motivate them to take action to solve it. Hung and colleagues (Hung, Ak, & Holen, 2013a; Hung et al., 2013b; Hung & Holen, 2011) identified a number of affective elements that could influence students' sense of connection, motivation, and engagement during a PBL process.

Subjects presence

Subjects presence refers to the degree of presence of person(s) who were involved in or related to the problem during the PBL module implementation. This affective element differentiates the "real and live" problem from the "real but on paper" or "fictional character" problems for the students. Hung et al. (2013b) reported that when the students were able to communicate with the actual person who was involved in the problem, they were more engaged, asked more questions, and stayed more focused. Also, the students in the studies conducted by Hung and his colleagues (Hung et al., 2013a) rated subject presence as the second highest factor that would motivate them to learn in the PBL process.

Location proximity and temporal proximity

These two affective elements have similar psychological effects on the students' sense of realism and the development of relatedness. Location proximity refers to the distance between the students' physical location and the location where the problem occurs, while temporal proximity denotes the remoteness in time in relation to present time. A real-life problem that happened remotely in time or physical space could be perceived by the students as real but remote. These temporally or physically remote real-life problems may generate less psychological or emotional relatedness with the students, and hence decrease their engagement or willingness to take ownership of the problem. Therefore, the temporal and local proximity of the problems could play a role in the students' psychological connection to the problem, which could lead to varying degrees of engagement and commitment to solving the problem.

Career and personal interests

According to Keller's ARCS model (1987) and Deci and Ryan's SDT (1991), relevance and the psychological needs for competence are two critical factors that affect motivation. Thus, students' motivation is likely promoted with problems that meet their career or personal interests. For professional disciplines, finding authentic problems presents fewer challenges for the instructional designers. However, one guideline regarding choosing problems to meet students' career interests is balancing problems among subdisciplines. The set of problems should represent the profile of the discipline (e.g., big game, waterfowl, fish, etc.

in a wildlife management curriculum), rather than concentrate on one area (e.g., the instructor's expertise or research area). As for subject matters that are not profession-specific (e.g., a college biology course or topic of density in a high school physics class), the selection of problems in regard to career interests could follow a guideline of using problems from the professions in which the subject domain knowledge could be applied. In terms of selecting problems that meet personal interests, it would be much more challenging as it is difficult to find problems that universally interest the entire class or cohort. Social interests (refers to current trends or interests at a societal level) may be used to identify suitable problems for this purpose.

Difficulty

Problem difficulty is a component that could affect students' problem solving both cognitively and psychologically. Problem difficulty level is positively correlated with the demands of cognitive processing, which could consist of a variety of cognitive processes (e.g., researching and reasoning) and cognitive capacity, such as cognitive load (Sweller, 1988). Therefore, it affects the chance that an individual can successfully solve the problem (Wood, 1985). This probability of succeeding in completing the task could be perceived by the students as an indicator for judging the return of their cognitive investment. Hence, problem difficulty could start out as a cognitive factor in influencing students' problem solving and possibly induce a self-evaluation. The result of this self-evaluation could have a psychological influence on the students' motivation and willingness to put full effort into the problem-solving process if the difficulty level is exceedingly beyond or below the appropriate problem difficulty zone. This conjuncture was partially supported by Jacobs, Dolmans, Wolfhagen, and Scherpbier's (2003) study that surveyed 244 medical students about their perceptions of problem difficulty in relation to their willingness to engage with problems. Thus, if problem difficulty can be managed as much as possible during the design process, potential frustration and detrimental effects on students' learning experiences could be greatly reduced. Until then, students can confidently engage in self-directed learning while at the same time being challenged because the cognitive demands of solving the problem with students' cognitive ability have been well aligned. According to Jonassen and Hung (2015), complexity and structuredness are two main dimensions in analyzing the difficulty level of a PBL problem. The complexity dimension deals with the complication and involvedness nature of the problem, while structuredness addresses the degree of the unknowns in the problem.

Parameters of problem complexity

According to Jonassen and Hung (2015), the dimension of complexity comprises four parameters: breadth of knowledge required to solve the problem, attainment level of domain knowledge, intricacy of problem-solution procedures, and relational complexity. First, breadth of knowledge refers to the amount of domain knowledge needed in order to solve the problem. According to Kotovsky, Hays, and Simon (1985), the difficulty of problems varies positively with the size of the problem space. Therefore, the greater the amount of general and domain knowledge required for solving a problem, the greater the size of the problem space, and therefore, the more complex the problem. This knowledge includes factual information, concepts, principles, and procedures needed to solve the problem (Sugrue, 1995). Second, attainment level of domain knowledge addresses the difficulty level of comprehending or applying the concept. Abstractness of the concepts (Bassok, 2003), difficulty in grasping (Kotovsky et al., 1985), and the level of advancement of the concepts required are the three factors that could affect the level of problem difficulty under this parameter. Third, the parameter of intricacy of problem-solution procedures is the effort required to execute the procedures. Ways to measure this parameter may include the length of its solution path, the extent of complication of the tasks and procedures in these steps, or the time needed to execute them (Quesada, Kintsch, & Gomez, 2005) to solve a problem. Lastly, the parameter of relational complexity refers to the number of relations needed to be processed in parallel during a problem-solving process (Halford, Wilson, & Phillips, 1998). The more complex the relations in a problem, the more processing load is required during problem solving, and as a result, the higher the cognitive load and more complex the problem is.

Parameters of problem structuredness

Wood (1983) defined the structuredness of a problem as the degree to which the ideas in the problem are known or knowable to the problem solver. Jonassen and Hung (2015) dissected this dimension into five parameters: intransparency, heterogeneity of interpretations, interdisciplinarity, dynamicity, and legitimacy of competing alternatives. The intransparency parameter describes the scope of the unknown portion of the problem space. Most complex problem-solving researchers agree that this parameter is an essential feature of ill-structured problems (Frensch & Funke, 1995). The higher the degree of intransparency, the more ill-structured the problem is. Second, the parameter heterogeneity of interpretations refers to the number of possible interpretations and perspectives for understanding or solving the problem, as well as evaluating the solutions. The more open the problem is to interpretations, the more ill-structured the problem is. The third parameter is interdisciplinarity. The degree of interdisciplinarity affects the level of problem structuredness in two ways. When a problem requires interdisciplinary knowledge or considerations to solve it, one critical element to successfully solve the problem is making sure that all facets (disciplines) have been taken into account. Also, because of the interdependency of the various disciplines, changing a subdecision in one area will subsequently affect others. As a result, the task of balancing all aspects of the problem makes solving this type of problem very challenging. Fourth, dynamicity is one of the defining properties of ill-structured problems (Frensch & Funke, 1995). It describes the instability of the variables and states in the problem throughout the problem-solving process, which is also referred to as continuity by Bassok (2003). Dynamicity variables are often emergent in nature, and therefore make the problem extremely unpredictable and therefore ill-structured. Lastly, the parameter of legitimacy of competing alternatives refers to the extent to which the number of conceivable options for executing operators within the problem space.

With an understanding of the difficulty profile of a problem, the students' preference for moderately ill-structured problems while seeking challenges from the complexity of the problems found in Jacobs et al.'s (2003) study is quite logical. Thus, an analysis of the complex and structuredness profile of the problem could help the instructional designer determine an appropriate balance among the parameters in the problem difficulty profile. This way, the problem is challenging enough to motivate students and maintain interest, yet support students' confidence in the problem-solving process (Scott, 2014). To design the difficulty level of a PBL problem, the techniques discussed in the processing section could be considered. The researching component calibration techniques, especially the guideline of goal specification, can be used to guide the design of the structuredness dimension of the problem. Also, the reasoning component design principles can be used to adjust the complexity dimension of the problem.

Teamwork

Collaborative learning is another major characteristic of PBL (Schmidt, 1983). The educational conception of this feature is rooted in social constructivism and aims to accomplish two instructional goals. First of all, small-group learning provides the students with a learning environment where learning is no longer just an individual cognitive process but also a socially collective construction process (Curseu & Rus, 2005; Hung, 2013). Thus, PBL students are co-constructors of the knowledge under study. Furthermore, in small-group settings, students are knowledge constructors as well as knowledge contributors. According to social constructivism (Vygotsky, 1978), through the social interaction, students bring in multiple perspectives and diverse prior knowledge and life experience to the collective knowledge construction process. Also, by means of social negotiation, the diverse or conflicting knowledge and perspectives brought by the group members are reconciled for them to construct a practical working knowledge in that social context.

In small-group learning in PBL, oftentimes students collaboratively understand and define the problem, identify learning objectives, divide the researching for necessary information evenly, then individually research and study the portion they are assigned, and then reconvene as a group to share and learn from other group members. This jigsaw learning format is effective for the students to develop their interpersonal skills and collaborative skills. It also helps reduce the individual students' cognitive load with the division of labor to process the amount of information and reasoning for solving a PBL problem. However, the jigsaw learning format may not be adequate for helping students to develop teamwork skills, which involve more structural interrelationships (Johnson & Johnson, 1987). Thus, when teamwork or cooperative skills are the target learning objectives in a PBL module, a few guidelines could be considered.

Explicit roles, functions, or responsibility

When possible, select a problem that inherently has explicit and diverse roles with clear functions or responsibilities required in the problem-solving process to increase the team diversity (Scott, 2014). For example, for college engineering students, designing a simple circuit for an LED lamp may support collaborative learning, where each student could assume any role in the design process since the knowledge it requires is relatively simple and generic. On the other hand, designing an electrical car using solar power may provide a better learning environment for teamwork cooperative learning. This is because the tasks in the latter problem are much more complex and require each team member to possess or acquire specific knowledge as well as effective coordination, communication, and leadership within the team. The clearly defined roles will give the students a sense of specific functions and responsibilities that they assume and carry. Without a clear role definition (i.e., job description), students may not have an opportunity to develop their work efficiency and ethics because there are no specific functions or responsibilities for them to fulfill or no clear subgoal to accomplish.

Interdependency and systemic support

As mentioned, interdependency is a key for effective teamwork (Johnson, Johnson, & Holubec, 1998). Having clearly defined roles is one of the conditions for interdependency to make a positive impact on the team-based problem solving. A complex problem that a team member's tasks depend on or are influenced by the timely completion and the quality of other team members' work will help students understand the nature of interdependency and, in turn, develop their cooperative skills and work ethic. Thus, when designing the teamwork component, the functional interconnected relationships among the roles in the problem will need to be explicitly addressed. This way, the team members would be able to configure themselves into a cognitive system to collectively perform a variety of cognitive functions to accomplish a specific problem solving goal and practice intersupportive or cooperative skills.

The enhancing components may not be as critical as the 3C3R components in ensuring students' knowledge acquisition and application and problem-solving skills development. Nevertheless, they are important in enhancing the quality of the students' engagement and mindfulness during the PBL process, which is a critical element in contributing to effective learning outcomes. Metaphorically speaking, these enhancing components are like salt: it may not increase the nutrition of the food but it enhances the flavor of the food so that people will be attracted to and willingly consume it. Without a healthy level of motivation, the level of engagement may be reduced and, consequently, the level of learning outcomes may be degraded.

Conclusion

The 3C3R PBL problem design model was originally conceived to enhance students' learning outcomes in PBL by optimizing its essence, which is the problems. After a decade of further research in the area of PBL problem design, the 2nd generation 3C3R model incorporates an additional set of components to enhance students' motivation, engagement, and learning experience. Affording the same purpose as the 1st generation of the 3C3R model, the 2nd generation 3C3R model extends its framework beyond cognitive aspects to psychological, emotional, and social aspects of a PBL learning process. With the considerations of the cognitive aspects of 3C core components that ensure the proper affordance of intended content knowledge and learning objectives and the 3R processing components that guide the students to engage in specific types of problem-solving reasoning process, the enhancing components provide the instructional designers and PBL educators with a subset of the conceptual framework to help enhance students' learning processes and experiences. The quality of the problems is vital in a PBL implementation. A theoretically sound conceptual framework and systematic design process are necessary for producing high-quality, effective, and engaging PBL problems. The 2nd generation 3C3R model is conceptualized to achieve this very purpose.

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12

The Problem-Based Learning Process: An Overview of Different Models

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Introduction

Problem-based learning (PBL) was first introduced in the late 1960s in an attempt to reform medical education at McMaster University, Hamilton, Ontario. It was hoped that by introducing students immediately from the start of the program to patients and their problems, learning would be perceived as more meaningful and subsequently students' motivation would be stimulated (Spaulding, 1969). Since then PBL has been implemented in various curricula, such as engineering, law, psychology, business education, and K–12 education (Barrows, 1996; Loyens, Kirschner, & Paas, 2012; Schmidt, Van der Molen, Te Winkel, & Wijnen, 2009).

However, as Norman and Schmidt (2000, p. 725) point out "the little acronym covers a multitude of sins" as PBL is practiced very differently across institutions all over the world (Maudsley, 1999). In particular, different opinions exist on the PBL process or "problem-solving process" that should be implemented. The PBL process is defined as the type and order of learning and discussion activities that are emphasized and implemented to tackle the problem (Holmberg-Marttila, Hakkarainen, Virjo, & Nikkari, 2005). The PBL process is embedded in the curriculum of an educational program. The implementation of PBL can vary from a single course to an integrated approach in which the entire curriculum is problem-based (Savin-Baden, 2003). Although the PBL process can be influenced by one's interpretation of PBL (Schmidt, 2012), process models are focused on the design and implementation of learning activities and should not be confused with pedagogical models. In this chapter, we aim to give an overview of the most common process models that have been developed and the factors that influence their design; however, please note that it is not possible to give a complete overview of all process models that have been applied worldwide (Maudsley, 1999).

We first discuss the core characteristics of PBL and the different types of problems that are commonly used in PBL. Second, we describe contrasting

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interpretations of PBL and how this has affected the types of PBL process models that have been applied in higher education, including the types of problems used. Subsequently, we address how the PBL process might be applied to younger learners and different educational levels (Rotgans, O'Grady, & Alwis, 2011; Torp & Sage, 1998). Finally, we discuss conditions that need to be considered in the instructional design and implementation of the PBL process.

Problems and Core Characteristics

Researchers generally agree that PBL has five core characteristics (Barrows, 1996; Hmelo-Silver, 2004; Schmidt et al., 2009). These characteristics include: (a) the use of problems as the start of the learning process, (b) collaborative learning in small groups, (c) student-centered learning, (d) the guiding role of tutors, and (e) ample time for self-study. In PBL the learning cycle starts with an ill-structured problem, such as a case, a story, a visual prompt, or a phenomenon that needs explaining (Barrows, 1996). Ill-structured problems are problems that do not have clearly specified goals and can have multiple solutions or solution paths (Jonassen, 1997).

After being presented with the problem, the PBL cycle includes at least the following phases: (a) an initial discussion phase in which the problem is defined and hypotheses are generated, (b) an information gathering and self-study phase, and (c) a debriefing or reporting phase. During the PBL process, students work on the problem in small groups of 5–12 students, especially in the initial discussion and reporting phases (Barrows, 1985; Segers, Van den Bossche, & Teunissen, 2003). During the initial discussion, students define the problem and try to come up with tentative theories or hypotheses explaining the problem. Because students' prior knowledge is insufficient to explain the problem fully, learning issues are formulated for further self-study. Learning issues are questions that help guide the self-study activities of students. During self-study, students gather new information by studying resources (e.g., books, articles, internet sites) or by consulting experts (Poikela & Poikela, 2006; Schmidt et al., 2009). These resources can be student selected, instructor suggested, or a combination of both. After a period of self-study activities, students meet again in their group to discuss their findings and apply their new knowledge to the problem.

Different Types of Problems

Although in PBL the learning cycle starts with the presentation of an ill-structured problem, the term "problem" can be somewhat misleading, as it points people to thinking that there is something to be solved (Plowright & Watkins, 2004), whereas a PBL problem can best be seen as a trigger that instigates the learning process. Problems in PBL often do not have one canonical solution but need to be explained instead of solved. In this section, we discuss two types of problems that are commonly used in PBL: strategy problems and explanation problems (for other problem examples, see Jonassen & Hung, 2008 and Schmidt & Moust, 2002).

Strategy problems (or diagnosis-solution problems; Jonassen & Hung, 2008) can be used for the acquisition of procedural knowledge, such as learning to apply the reasoning or decision-making process experts use (Dolmans & Snellen-Balendong, 2000; Schmidt & Moust, 2002). A strategy problem contains, for example, a description of the complaints of a patient combined with data about the patient's history and findings from physical examinations. The aim of the problem is to simulate professional practice and determine the appropriate course of action in the situation described in the problem, such as getting to a diagnosis (Dolmans & Snellen-Balendong, 2000) or determining the underlying biomedical mechanism that can explain the patient's illness or complaint (Barrows, 1985).

In contrast, *explanation problems* can be used to acquire declarative knowledge. Explanation problems contain a neutral description of a set of phenomena or events that need to be explained (Dolmans & Snellen-Balendong, 2000; Schmidt & Moust, 2002). An example is the "Little Monsters" problem (Schmidt, Loyens, Van Gog, & Paas, 2007, p. 92): "Coming home from work, tired and in need of a hot bath, Anita, an account manager, discovers two spiders in her tub. She shrinks back, screams, and runs away. Her heart pounds, a cold sweat is coming over her. A neighbor saves her from her difficult situation by killing the little animals using a newspaper." The aim of these problems is learning the underlying structures or mechanisms of these events.

The choice for a specific type of problem depends on the interpretation of PBL and its underlying aim (Schmidt, 2012; Schmidt et al., 2009). The most important distinction can be made between "PBL as simulation of professional practice," which originated from Howard S. Barrows' (1985) work and "PBL as mental model construction," which was promoted by Henk G. Schmidt (1983). In "PBL as simulation of professional practice," the acquisition of procedural skills is emphasized; therefore, strategy problems are more commonly used in this version of PBL. In contrast, in "PBL as mental model construction," explanation problems are more commonly used due to its emphasis on the acquisition of declarative knowledge.

The PBL Process in Higher Education

PBL as Simulation of Professional Practice

The "PBL as a simulation of professional practice" view has its origins in medical education and was popularized by Barrows (Neville & Norman, 2007; Schmidt, 2012). Barrows (1985) stated that the overall aim of PBL is to prepare medical students for their clinical years and later clinical work. Although other goals, such as knowledge acquisition, are important as well, in the PBL process the role of *inquiry* is emphasized (e.g., Barrows, 1985; Barrows & Tamblyn, 1980; Hmelo, 1998). Therefore, the process of working on problems needs to approximate the real world as closely as possible by replicating the type of reasoning that would be used in professional practice (Barrows & Myers, 1993; Koschmann, Myers, Feltovich, & Barrows, 1994). This is often referred to as the clinical or hypothetico-deductive reasoning process (Barrows & Feltovich, 1987; Barrows & Myers, 1993). Specifically, data are gathered, hypotheses are generated and tested, and conclusions are drawn in an interactive, recursive manner.

To be able to approximate the reasoning process of experts, the problem needs to address real-world concerns (Barrows & Myers, 1993). In the context of medical education this is ideally a simulation of encounters with actual patients such as strategy problems (Dolmans & Snellen-Balendong, 2000; Koschmann et al., 1994). The problem should allow for free inquiry (Barrows, 1985; Koschmann et al., 1994). Therefore, when selecting or designing an appropriate strategy problem, it must be ensured that students can get answers for all questions through physical examinations and laboratory tests that they might request from actual patients. This can, for example, include the use of trained actors/standardized patients or paper-based simulations. An example of a paper-based stimulation is the problem-based learning module (PBLM), which contains the patient's initial complaint, but also the results of questions, examinations, and tests that can be consulted during the PBL process (Distlehorst & Barrows, 1982).

Clinical reasoning in PBL by Barrows and colleagues

The PBL inquiry process was first described by Neufeld and Barrows (1974) as *biomedical problem-solving* for all medical students enrolled at McMaster University and consisted of a sequence of learning activities that had to be performed by individual students or student groups (see Table 12.1). However, the process was further refined and described in later works by Barrows and colleagues at the Southern Illinois University School of Medicine (Barrows, 1985; Barrows & Myers, 1993; Koschmann et al., 1994; Koschmann, Kelson, Feltovich, & Barrows, 1996). Students work in small groups on the patient case or problem (Barrows, 1985). After encountering the problem, the PBL process consists of five stages: (a) problem formulation, (b) self-directed study, (c) problem reexamination, (d) abstraction, and (e) reflection (Koschmann et al., 1994). The first three stages revolve around the problem. These stages form a continuing or recursive process. That is, reexamination of the problem can result in further learning issues that need to be discussed and studied. The process is facilitated by a tutor.

During Stage 1, *problem formulation*, students are encouraged to handle the problem exactly as experts would evaluate the problem or patient (Barrows, 1985, see Table 12.1). Students make notes on a blackboard or similar device that is divided into four categories: Facts, Ideas or Hypotheses, Learning issues, and Actions (i.e., plans for resolving or improving the problem situation; Koschmann et al., 1994). The process starts by identifying the cues or *facts* that seem important in the problem (Barrows, 1985). Based on this first inventory, students come to a mental image or an initial concept of the problem, such as "What is the problem we are facing here?" Subsequently, students generate as many *ideas* and *hypotheses* as possible about the underlying mechanisms responsible for the patient's complaints by use of their prior knowledge and common sense. Students are allowed to use a medical dictionary or a few appropriate preselected textbooks if it enables them to continue the reasoning process. Tutors stimulate problem synthesis by letting students summarize the significant facts that have been learned up to that point.

Table 12.1 PBL as Simulation of Professional Practice

	Biomedical problem-solving	PBL process by Barrows and colleagues	Newcastle approach	Clinical Seven Step approach
Author(s)	Neufeld and Barrows (1974)	Barrows (1985); Koschmann et al. (1994)	Neame (1989)	Dolmans and Snellen-Balendong (2000)
Institution of origin	McMaster University, Canada	Southern Illinois University, United States	University of Newcastle, Australia	Maastricht University, The Netherlands
Process description	Sequence of learning activities: 1) Listing questions that arise from the problem 2) Translating questions into learning issues 3) Identification and study of educational resources 4) Synthesizing information into an explanation 5) Evaluation (i.e., individual and group performance, problem and resources)	**Stage 1: Problem formulation** Iterative process of 1) Extracting cues/facts from the problem 2) Hypothesis generation 3) Deciding on an inquiry strategy 4) Discussing and practicing clinical skills for tests or examinations requested at step 3 5) Data analysis 6) Problem synthesis 7) Deciding on an action plan 8) Identifying learning issues **Stage 2: Self-directed study** 1) Resource identification 2) Self-directed study **Stage 3: Problem reexamination** 1) Critiquing/discussing resources 2) Problem reassessment by applying new knowledge Stage 3 can result in new learning issues and self-directed study **Stage 4: Abstraction** 1) Summary and integration of learning **Stage 5: Reflection** 1) Evaluation	Model for diagnostic decisions: 1) Cue recognition 2) Initial formulation 3) Hypothesis generation 4) Hypothesis organization (possible mechanisms) 5) Inquiry strategy with recursive cycles with: a) Need to know: patient personal or clinical data b) Need to learn 6) Problem reformulation 7) Final formulation 8) Diagnostic Decision	1) Identify central issue and inventory of prior knowledge 2) Determine the type of data that need to be obtained 3) Relate these data to step 1 4) Try to discover the mechanism that explains the findings 5) Generate hypotheses 6) Consider the certainty of the diagnosis 7) Draw up a management plan

The sequence of learning activities start *after* the problem is presented.

After ideas and hypotheses are generated, students need to come up with an inquiry strategy. They need to determine what actions need to be taken to decide which ideas might be right (e.g., questioning the patient, physical examinations, or laboratory tests). After consensus is reached about the questions or examinations that need to be undertaken, the problem should allow for students to receive the results of these tests or examinations to stimulate further discussion. For example, a PBLM contains results of the patient's tests or examinations that can be consulted (Distlehorst & Barrows, 1982). These additional results are analyzed and as the inquiry process moves forward, facts accumulate and hypotheses can change (Barrows, 1985). Students' ongoing image of the problem should always be compared against their working hypotheses or the new data obtained.

Throughout the process of defining and analyzing the problem, students identify learning needs for which *learning issues* for further study are formulated (Koschmann et al., 1994). Stage 1 ends when students come to a *decision* concerning the underlying mechanism they believe is involved in the current problem and possible treatment approaches (Barrows, 1985). The learning issues that have been recorded then need to be reviewed and studied.

In Stage 2, the *self-directed, self-study phase*, students select and study appropriate learning resources (Barrows, 1985; Koschmann et al., 1994). Students can choose to study individually or in small student groups (Neufeld & Barrows, 1974). Learning resources can include various printed resources, but might also include other resources, such as videos, X-rays, scans, or consultations with specialists (Barrows, 1985). During self-study, students are encouraged to take notes and make diagrams that they can take with them for the next group meeting.

In Stage 3, *problem reexamination* or *applying knowledge*, students return to their groups from their self-study period (Koschmann et al., 1994, 1996). They first comment on the resources they have used. Although students might have the tendency to tell other students what they have learned, it should be avoided that students give each other mini-lectures (Barrows, 1985). Instead, students need to be encouraged to apply their new knowledge to the patient problem, as they are now assumed to be *experts* who have the appropriate knowledge to resolve the problem. They do this by again engaging in the clinical reasoning process (i.e., hypothesize, inquire, analyze, and synthesize). By doing so, students can evaluate their performance during Stage 1 by revising hypotheses, applying new knowledge and resynthesizing the facts, identifying new learning issues if necessary, and redesigning decisions (Barrows & Myers, 1993). However, this stage should not take as long as Stage 1 (Barrows, 1985).

After the discussion of the problem, two additional stages occur: abstraction and reflection (Koschmann et al., 1994). In Stage 4, *abstraction*, student groups are asked to articulate the knowledge they have learned and how this adds to their prior knowledge (Barrows, 1985; Koschmann et al., 1994). If possible, the problem should be contrasted to other problems the group has seen, to be able to make generalizations and connections, and to explore similarities and differences. In the final *reflection* stage, groups need to evaluate the performance of students and the group as a whole (i.e., reasoning skills, knowledge about the problem, self-study skills, and contributions to the group process). If poor performance or problems in the process are identified, discussion should occur on how these issues can be corrected.

The PBL process described above has some implications for the way the curriculum is structured. For example, the time needed for each problem depends on students' prior knowledge and the number of learning issues involved. Student groups should therefore be allowed to negotiate the time needed to answer their learning issues (Barrows, 1985). Subsequently, the type of PBL process described by Barrows (1985) requires that courses are not too rigidly scheduled or structured. That way, students can repeat some steps before concluding the learning process for a particular problem. Furthermore, although initially the PBL process is conducted in small groups of five to seven students, when students gain more experience (e.g., third-year students), they eventually need to abandon the group process and start working on problems individually. However, group meetings can then be valuable to discuss individual approaches.

Other inquiry process models

The medical curriculum at the University of Newcastle, Australia (Neame, 1989) is another example of PBL in which the inquiry process is emphasized (see also Schmidt, 2012). In contrast to the process model by Barrows (1985), which prescribes that courses should not be tightly scheduled, learning is centered around 3-hr group meetings twice a week (Neame, 1989). Tutors guide the students in their learning process and make sure that the steps are worked through in a logical and orderly fashion. Similar to the PBL process described by Barrows (1985), the process for coming to a diagnostic decision starts with the presentation of a patient problem from which students need to extract important cues (Neame, 1989). Students then develop an initial problem formulation and generate possible hypotheses. Later on in the discussion, students examine if the hypotheses can be organized into categories, such as organizing them by type of mechanism that might explain the patient's problems. A strategic inquiry is formulated in which students specify the type of information that is required to identify the cause that might explain the patient's problems. On demand, the tutor can provide this information and the students can decide to reformulate their conceptualization of the problem, reduce the number of hypotheses that have been generated, and repeat the strategic inquiry cycle. Simultaneously, learning deficits and goals for further learning are identified. Studying of important resources can be done individually or in groups depending on the students' preferences. During fixed resource sessions, staff can be consulted to discuss learning difficulties that are encountered. However, students set the agenda and control the direction of these sessions.

In summary, although the acquisition of content knowledge remains important (e.g., Barrows, 1985), the key element in these process models is that the problems and the reasoning process applied in group meetings approximate reality (Barrows & Myers, 1993; Koschmann et al., 1994) so that students can learn and apply the (inquiry-based) reasoning process of experts. These models have been very influential for PBL in general, and have also been applied in other settings, such as secondary education (Barrows & Myers, 1993). Nevertheless, it can be questioned whether PBL can actually help students acquire better reasoning skills. Research examining the development of clinical reasoning skills revealed that novice students and expert professionals used a similar method of reasoning (e.g., Neufeld, Norman, Barrows, & Feightner, 1981; see also Norman, 2005). The main difference between novice students and expert clinicians is that the latter possess superior formal and informal knowledge, which can be used when presented with a problem (Norman, 2005). Therefore, Schmidt (2012) emphasizes the importance of focusing on declarative knowledge acquisition instead of procedural knowledge acquisition.

PBL as Mental Model Construction

A second strand of PBL focuses on the construction of mental models (Schmidt, 2012). At Maastricht University, all study programs (e.g., law, health sciences, economics, psychology) are problem-based (Schmidt & Moust, 2000). Because patient problems could no longer be used in all courses, the problem was redefined as a description of phenomena that need to be *explained* (Schmidt, 2012). According to this view, the central aim of PBL is to help students build flexible mental models of the world (Schmidt et al., 2009). In these process models, the role of the initial analysis of the (explanation) problem is emphasized. During this initial discussion, prior knowledge is activated and elaborated upon (Schmidt, 1983). Prior knowledge activation is considered to be the driving force for learning in PBL (Schmidt, Rotgans, & Yew, 2011), because it is believed that discrepancies between prior and new knowledge are more easily resolved. Moreover, active elaboration of ideas has been found to facilitate long-term memory (Van Blankenstein, Dolmans, Van der Vleuten, & Schmidt, 2011). Table 12.2 gives examples of PBL process models focusing on mental model construction.

Seven Step approach

The *Seven Step approach* or the *Seven Jump* was designed at Maastricht University, The Netherlands (Schmidt, 1983; Schmidt & Moust, 2000) and is the best-known model for the "PBL as mental model construction" view. The Seven Step approach enables students to tackle problems during two group meetings a week, guided by a tutor. During the first group meeting, students are presented with the problem. After reading the problem, students perform the first five steps: (Step 1) clarification of unknown concepts, (Step 2) formulation of a problem definition, (Step 3) brainstorming on the problem, (Step 4) problem analysis, and (Step 5) formulation of learning issues for further self-directed study. The first step assures that every student has the same interpretation of the problem and is able to understand the text. In the "problem definition" step, the group reaches consensus about the phenomena that need to be explained. In the brainstorming step, students articulate as many potential ideas, explanations, or hypotheses for the problem one by one without interruption by other students. In the problem analysis step, these ideas are further elaborated upon and critically evaluated. Because students' prior knowledge is insufficient to explain the problem fully, learning issues are formulated for further self-study.

After the first meeting, students use these learning issues to select and study relevant literature resources (Step 6). Because selecting literature is a difficult

Table 12.2 PBL as Mental Model Construction

	Seven Jump method/Seven Step approach	Optima 7-Jump (e-learning)	Malmö model	Eight Step approach
Author(s)	Schmidt (1983); Schmidt and Moust (2000)	Rienties et al. (2012)	Rohlin et al. (1998)	O'Neill et al. (2002)
Institution of origin	Maastricht University, The Netherlands	Maastricht University, The Netherlands	Lund University, Sweden	University of Manchester, United Kingdom
Process description	**First meeting:** 1) Clarification of unknown concepts 2) Defining the problem 3) Brainstorming possible explanations. No criticism or discussion. 4) Problem analysis: group and arrange explanations 5) Formulate learning issues **Self-study period:** 6) Self-study **Subsequent meeting:** 7) Share findings	**Initial discussion of task:** 1) Identify difficult terms 2) Identify the main problem(s) and brainstorm to formulate learning issues 3) Start to solve learning issues (e.g., by referring to personal experience or by use of course-prescribed or additional literature) **Postdiscussion of task:** 4) Elaborate on the findings of Step 3 5) Reach agreement on answers through discussion 6) Check if all learning issues are answered 7) Summary main points of discussion (guided by a tutor)	**First meeting:** 1) Define problems 2) Generate hypotheses 3) Formulate learning issues **Self-study period:** 4) Collect additional information outside the group **Next meeting:** 5) Synthesize newly acquired knowledge 6) Test hypotheses	**First meeting:** 1) Clarify unfamiliar terms 2) Define the problem(s) 3) Brainstorming possible explanations 4) Arrange explanations into a tentative solution 5) Define learning issues and requisite clinical experience **Self-study period:** 6) Self-study privately and gain clinical experience **Subsequent meeting:** 7) Share results of private study 8) Discuss clinical experience in light of that understanding

The sequence of learning activities start *after* the problem is presented.

task if learners have little domain knowledge, novice students are often provided with a restricted set of resources (e.g., book chapters, articles) to choose from (Schmidt et al., 2007). Finally, after 2–3 days of self-directed study, students share their findings in the next meeting (Step 7). Students synthesize their findings in light of the original problem and the goal is to make sure that students then have acquired a better and deeper understanding of the underlying mechanisms of the problem.

As mentioned, the Seven Step approach can best be applied in the context of explanation problems (Dolmans & Snellen-Balendong, 2000). To be able to use strategy problems in the curriculum as well, an alternative process model was developed: the clinical seven step approach. The goal of the model is obtaining a diagnosis and deciding on a management plan, therefore it was placed in Table 12.1, which discussed "PBL as simulation of professional practice" process models.

Variations on the Seven Step approach

The Seven Step approach is also applied at many other institutions (O'Neill, Morris, & Baxter, 2000; Woltering, Herrler, Spitzer, & Spreckelsen, 2009) and has inspired the development of other process models (Dahlgren & Öberg, 2001; Foldevi, Sommansson, & Trell, 1994). Table 12.2 includes some examples of how researchers have altered or extended the Seven Step approach.

In Optima 7-Jump, the process is adapted to cope with e-learning (see Rienties et al., 2012). In e-PBL the division between steps is less obvious to learners. Brainstorming, problem analysis, and formulation of learning issues occur simultaneously because learners interact with the materials and their peers several times a week. The revised PBL process intended to reduce fragmentation of the process.

In other models, the Seven Steps have been either reduced or extended. For example, in the Malmö model, Steps 3 and 4 were combined into one step (Rohlin, Petersson, & Svensäter, 1998). However, O'Neill, Willis, and Jones (2002) included an eighth step "discussion of clinical experience," so that PBL could be used in the clinical years of the educational program as well (instead of only using it in the preclinical years). Although this model still emphasizes declarative knowledge acquisition, in Step 8, students could use their clinical experience in addition to books, lectures, and articles, so that they can elaborate on their knowledge by using the information gained inside (i.e., group discussion) and outside (i.e., exposure to clinical experience) the group.

Other Interpretations and Models

PBL as "learning how to learn"

An important goal of PBL is to help students acquire self-directed learning (SDL) skills (Barrows, 1986; Hmelo-Silver, 2004; Silén & Uhlin, 2008). SDL refers to the ability of students to be in control of their own learning process rather than being directed by their teachers (Loyens, Magda, & Rikers, 2008). These skills are believed to become increasingly important in our fast-changing society, as some of the knowledge learned in school will eventually become outdated. It is therefore not surprising that some curricula emphasize the role of PBL for acquiring self-directed or "learning how to learn" skills. The importance of "learning how to learn" is for example underscored by researchers from Linköping University in Sweden (Dahlgren, 2000; Silén & Uhlin, 2008) and in the Harvard New Pathways curriculum (Tosteson, 1994).[1] In order for students to become self-directed, they should be given the opportunity to take control of their own learning (Candy, 1991). In PBL, students receive some autonomy to take responsibility for their own learning process by formulating their own learning issues and selecting their own literature resources, which might help students to become self-directed learners. However, Silén and Uhlin (2008) stress that only giving students the opportunity to search and make choices about what to read is not enough, tutors need to challenge and support students with these tasks.

Self-evaluation is an important skill of SDL (Candy, 1991). The Linköping model or cyclical model of PBL resembles the Seven Step approach described earlier. Problems can take the form of a short descriptive text or an image or comic that triggers students' thoughts (Dahlgren & Öberg, 2001; Jansson, Söderström, Andersson, & Nording, 2015) as is the case in the Seven Step approach. However, the Linköping model includes a step in which the performance of the group and the individual students is evaluated.

The emphasis of SDL skills becomes clearer in the adaptations of the Linköping model that have been developed and applied at other institutions. Examples are the Tampere model (Holmberg-Marttila et al., 2005) and the model by Poikela and Poikela (2006). In these models learning is viewed as a continuous process consisting of eight phases (see Table 12.3). Although activation of prior knowledge is still considered important, these models place more emphasis on continuous evaluation. Each group meeting needs to close with a period of evaluation and feedback. Not only the quality of learning of individual students and the group are evaluated, but the self-study phase and selected resources as well. Students' information searching skills need to be developed (Poikela & Poikela, 2006). It takes practice and guidance before students' information literacy skills or "competence with information" is developed (Dodd, Eskola, & Silén, 2011). Tutors should therefore have discussions in their groups about what the most important resources are and where they can be found. Librarians can also help students to develop these skills (Dodd et al., 2011; Poikela & Poikela, 2006).

Segers et al. (2003) also suggested that PBL students need guidance during the self-study period. Research in PBL settings that used the Seven Jump process model demonstrated that the productivity of group meetings during the reporting phase is not always optimal (De Grave, Dolmans, & Van der Vleuten, 2002) and that self-directed self-study is a difficult and cognitively demanding task (Wijnia, Loyens, Van Gog, Derous, & Schmidt, 2014). Segers et al. (2003)

1 The Harvard New Pathways curriculum will not be further described as it has been reformed to emphasize case-based collaborative learning (Krupat, Richards, Sullivan, Fleenor, & Schwartzstein, 2016).

Table 12.3 PBL Models Focusing on "Learning how to Learn"

	Linköping model	Tampere model	Model by Poikela & Poikela
Author(s)	Dahlgren and Öberg (2001); Jansson et al. (2015)[a]	Holmberg-Marttila et al. (2005)	Poikela and Poikela (2006)
Institution of origin	Linköping University, Sweden	University of Tampere, Finland	University of Lapland, Finland
Process description	**First meeting:** 1) Overview: Problem is read, minor ambiguities or uncertainties are addressed 2) Brainstorming: Free association. No criticism or discussion 3) Systematization: Ideas are screened and structured 4) Problem description: The main problem is defined and learning objectives are formulated 5) Evaluation: Student's individual and group work are evaluated **Self-study period:** 6) Knowledge gathering: Individual/group work focused on learning objectives **Next meeting:** 7) Reporting: Findings are reported, described, and explained	**First meeting:** 1) Introduction: Selecting chair and scribe, reading the problem, clarifying unknown terms and concepts 2) Brainstorming: Free association 3) Review and organization of the existing information: Arranging notes into a logical and hierarchical explanation 4) Identification of learning objectives 5) Checking of shared understanding of learning objectives: The chair checks if everyone commits to and understands the learning objectives. Possible resources are discussed **Self-study period:** 6) Self-study: Searching information to answer learning objectives **Next meeting:** 7) Review of the information gathered: Discuss learning objectives one by one, focusing on issues that were unclear during self-study or new insights gained 8) Application of new knowledge to the problem: New discussion of the problem based on new knowledge In all phases continuous evaluation and assessment is emphasized	**First meeting:** 1) Problem setting 2) Brainstorming: free association 3) Systematization: structuring 4) Selecting most important categories in problem 5) Learning task: formulation **Self-study period:** 6) Knowledge acquisition **Next meeting:** 7) Knowledge integration: construction 8) Clarification: comparing with original problem In all phases, continuous evaluation and assessment is emphasized

[a] Original authors of the model were Hård af Segerstad, Helgesson, Ringborg, and Svedin. The model was translated by Jansson et al. (2015).

therefore proposed five learning activities that could be performed during the self-study phase to extend the Seven Jump method. Specifically, students were asked to: (a) identify the main points and concepts in the information resources, (b) make a schematic overview of the main points and concepts, (c) come up with new, concrete examples of problems that are relevant for the theories under study, (d) identify aspects that remained unclear during self-study, and (e) invent critical questions that could be used to evaluate students' own understanding and the understanding of their peers. Students were asked to perform these activities in pairs or groups of three during self-study and the reporting phase focused on the discussion of these learning activities. Students who performed the five activities in addition to the Seven Jump procedure gave the course a higher appreciation and indicated they experienced the group meetings as more productive and the tutor as more stimulating than a control group. However, there were no differences in test performance between the two groups and it is unclear whether SDL skills improved because of this intervention.

PBL as "learning by doing"

Another well-known PBL model is the Aalborg model at Aalborg University, Denmark (Kjersdam & Enemark, 1994; Kolmos, Fink, & Korgh, 2004). Half of the curriculum consists of course modules (e.g., lectures) and the other half consists of project modules (Kolmos, Holgaard, & Dahl, 2013). The Aalborg model applied in the project modules is classified as "learning by doing" (Kjersdam & Enemark, 1994). It is assumed that students learn best when applying theory and research to authentic problems (Askehave, Prehn, Pedersen, & Pedersen, 2015). Specifically, learning is organized around problems and *will be carried out* in projects (Kolmos, De Graaff, & Du, 2009). Students work together in project teams of two to three or six to seven students (Kolmos et al., 2004). A problem could be a contradiction, need, or anomaly, and places the learning in context (Kolmos et al., 2009). The project refers to the means by which the students address the problem and culminates in a tangible final product that will be graded (Barge, 2010). The process consists of three steps. In Step 1, *problem analysis*, the problem is presented, described, and assessed (Kjersdam & Enemark, 1994; Kolmos et al., 2004). During, Step 2, *problem solving*, possible ways of solving the problem are evaluated by use of scientific theories. In this step, lectures, literature, group studies, tutorials, field work, and experiments can be used to investigate (parts) of the problem. In the final step, *report*, the project group reviews the project, draws conclusions, and completes the project documentation.

Summary

Since PBL was first introduced in the 1960s, different process models have been developed that describe the sequence of learning activities that take place when students are trying to solve or explain the problem. As we tried to illustrate, the main aim of the learning process influences the PBL process and the types of problems that are used. Therefore, it is not possible to identify one ideal process model of PBL. The aforementioned models were all developed in higher education.

However, PBL has also gained popularity in other educational settings, such as K–12 education. The next section will discuss how the PBL process can be adapted for other educational contexts.

PBL Process Models in Other Educational Contexts

One-Day, One-Problem Approach

The One-Day, One-Problem approach is implemented at Republic Polytechnic (RP), Singapore and, as the name implies, enables students to tackle problems in 1 day (Rotgans et al., 2011; Yew & Schmidt, 2012). A polytechnic is a postsecondary institution that offers 3-year programs that aim to equip students with the necessary skills for their future profession (Rotgans et al., 2011). RP offers pre-employment training in life sciences, health sciences, engineering, and information technology. When students enter the polytechnic, they are typically 17 years old and have generally no prior experience with PBL. The One-Day, One-Problem approach was developed because it was assumed that these students, in general, were less mature and would experience more difficulty in acting as autonomous learners when compared to medical students (Rotgans et al., 2011). In particular, it was assumed that when polytechnic students had to work on one or two problems a week, as is often the case in higher education, this would result in problems such as absenteeism or procrastination. Therefore, it was decided to compress the PBL cycle into 1 day and to incorporate more tutor guidance than is provided in most other PBL models. Each day, then, covers a different subject.

Classes at RP consist of 25 students and a facilitator (Yew & Schmidt, 2012). Students are grouped into teams of five students. The day consists of five phases in which group meetings and self-study periods are alternated. The first phase is the problem analysis and takes approximately 1 hr. In this phase the tutor presents the problem and each student team activates their prior knowledge and identifies learning issues. In Phase 2, the first self-directed study period (2 hr) takes place. Individual students conduct research by reading online resources or teams work on worksheets and other resources that are provided. During this phase, students can teach one another within their team. In the third phase (1.5 hr), there is another group meeting with the tutor. Each team meets with the tutor for approximately 20 min to share their progress and understanding of the problem. The remaining time can be spent on further self-study or discussion. During the second self-study period (Phase 4, 2 hr), teams try to formulate a response to the learning issues and the problem. In the final phase, the reporting phase (2 hr), each team presents their findings and response to the problem. These presentations are usually in the form of PowerPoint slides. Students from other teams and the tutor can ask questions and the presenting team needs to defend and elaborate on these questions. During the final phase, the tutor can also clarify key issues if necessary. With respect to the different interpretations of PBL, the One-Day, One-Problem approach fits best within the "PBL as mental model construction" view as it is primarily focused on declarative knowledge acquisition (Schmidt, 2012).

PBL in K–12 Education

PBL is not limited to postsecondary or higher education, but is also applied in K–12 education (Ertmer & Simons, 2006; Torp & Sage, 1998, 2002). There are many different real-world problems that can be used with younger learners. A problem could for example, describe that an earth-like planet has been found but that its biosphere has been destroyed. Learners could then try to find out what caused the destruction and whether plants from earth could help restore the biosphere (see Torp & Sage, 1998). Table 12.4 presents two models that have been applied in K–12 education in the United States.

The PBL process proposed by Barrows and Myers (1993) for secondary school is very similar to the process model for medical students (Barrows, 1985; Koschmann et al., 1994). Again, it is argued, that the problems and the hypothetico-deductive reasoning process need to approximate the real world as closely as possible

Table 12.4 PBL Models That Can Be Applied in K–12 Education

	Barrows & Myers' model for secondary education	**K-12 model by the Center for Problem-Based Learning**
Author(s)	Barrows and Myers (1993)	Torp and Sage (1998, 2002)
Institution of origin	Southern Illinois University and Lanphier High School	Illinois Mathematics and Science Academy's Center for Problem-Based Learning
Process description	**Starting a new problem:** 1) Set the problem 2) Internalize the problem 3) Describe the product or performance required 4) Assign tasks (e.g., scribe) 5) Reasoning through the problem (hypotheses, facts, learning issues, and action plan) 6) Commitment to a possible outcome 7) Learning issues 8) Resource identification 9) Schedule follow-up **Self-study period:** 10) Self-directed learning **Problem follow-up:** 11) Critique used resources 12) Reassess the problem (hypotheses, facts, learning issues, and action plan) **Performance presentation after conclusion of the problem:** 13) Knowledge abstraction and summary 14) Self-evaluation (and comments from the group)	Teaching and learning events: 1) Prepare the learner (optional) 2) Meet the problem 3) Iterative cycle of activities: • Identify what we know, what we need to know, and ideas • Define the problem statement • Gather and share information 4) Generate possible solutions 5) Determine the best fitting solution 6) Present the solution (assessment) 7) Debrief the problem Instructions and assessment should be embedded within the teaching and learning events

(Barrows & Myers, 1993). A new element in the model is the "performance presentation" activity. During this learning activity, learners have to report on their conclusions. This report can come in many forms, such as oral, written, or audiovisual presentations, artworks, illustrations, graphs, portfolios, or mathematical analyses. The audience for these reports can consist of a wide range of people, such as peers, parents, or external experts (e.g., community or national leaders).

The model described by the Center for Problem-Based Learning (Torp & Sage, 1998, 2002) targets a wider range of learners. They argue that PBL can be valuable for all learners in K–12 education. For all learners, it is important to be able to apply what they have learned. To achieve this, they need to learn to think with the knowledge they have. They therefore have to be actively engaged in sustained thinking with issues and topics through the use of realistic problems. It is further argued that PBL can be used as a tool to help learners learn how to learn. However, in order to achieve this, teachers need to model and coach the appropriate cognitive and metacognitive behaviors. Table 12.4 presents an instructional template for the types of learning and teaching events that need to take place in this K–12 PBL process model. Torp and Sage (1998, 2002) argue it is important to note that these events are not to be seen as fixed or strictly sequenced; learners can revisit parts of the process, such as defining the problem and gathering new information.

As can be seen in Table 12.4, learners first need to be prepared for the learning activities, especially when they have never encountered PBL before (Ertmer & Simons, 2006; Simons & Klein, 2007; Torp & Sage, 1998, 2002). Therefore, the K–12 model by the Center for Problem-Based Learning includes "preparation" as a first step. For example, teachers could model the "KWL strategy": What do I *know*? What do I *want to know*? What have I *learned*? (Torp & Sage, 1998, 2002). Alternatively, teachers can let learners first engage in critical thinking or simulation-type experiences on a smaller scale, before introducing a more complex PBL experience. In the subsequent "meet the problem" step, learners are supported to develop a personal stake or interest in the problem, for example through role playing or by presenting a real-life problem from someone they know (e.g., the plants in the principal's garden that have difficulty growing).

Just as in the "PBL as mental model construction" models, prior knowledge activation is emphasized. Subsequently, learners need to activate their prior knowledge and identify what they still need to know using the KWL strategy. This will eventually lead to identification of a problem statement or learning issue for which information needs to be gathered. During this information-gathering phase, learners can work in groups of three to five learners on a particular "need to know" topic they have selected. Additional groups can be formed with one person of each topic group, so that information among groups can be shared. The information-gathering phase typically takes the most time. Teachers can decide when this phase is completed if the groups are no longer able to find new information or when a deadline is reached. For learners, it is often difficult to locate and identify the most important sources of information and therefore they need to be coached in this process. When the information-gathering phase has concluded, learners need to identify the best fitting solution of all possible solutions and prepare a presentation. Similar to the model proposed by Barrows and

Myers (1993), outside experts can be invited to assess learners' performance (Torp & Sage, 1998). Afterward, it is important to debrief the problem so that learners can reflect on what they have learned.

Conditions for an Effective PBL Process

First Meeting and Responsibilities

The PBL models developed for K–12 education include a learner preparation phase (Torp & Sage, 1998). However, preparation is important for all students who are new to PBL (Dahlgren & Dahlgren, 2002; Ertmer & Simons, 2006). To minimize cognitive load it is best to train students in their collaboration skills and the PBL process if they do not have prior experience with PBL (Loyens et al., 2012). Moreover, the level of tutors' guidance in group meetings or the self-directed study phase always needs to be adapted to the expertise and experience level of students (Schmidt et al., 2007).

Irrespective of the interpretation of PBL, it is additionally important to establish a safe and open climate in the group sessions (Barrows, 1985; Segers et al., 2003). Students need to feel free to express their ideas and generate hypotheses or explanations (Barrows, 1985). Therefore, when the group first meets, all students and the tutor should introduce themselves to the group (e.g., talk about their interests, aspirations, or experiences). Furthermore, students often have to fulfill certain roles during a PBL course, such as reading the problem, taking notes or minutes, and chairing the meeting. All students need to be encouraged to try out these roles and share responsibility for the group process (Barrows, 1985).

Cultural Influences

Although PBL can be applied in all cultural settings, cultural differences are another important factor that can influence the PBL process. For example, Frambach, Driessen, Beh, and Van der Vleuten (2014) found that if students' prior educational experiences were traditional or highly teacher-centered, such as in Middle Eastern countries or Hong Kong, they experienced more obstacles when participating in discussions. Moreover, the level of implementation of PBL influenced the discussion process: when PBL was combined with a partly lecture-based approach (in Hong Kong) students were less inclined to ask critical questions and often repeated factual knowledge obtained in these lectures during discussion. Furthermore, when implementing PBL, problem descriptions need to be adapted to the cultural context and possible resource restrictions need to be taken into account (Hallinger & Lu, 2012).

Conclusion

In this chapter, we gave an overview of the different process models that prescribe how the learning activities in PBL should be structured. Different views on PBL can be distinguished that influence the types of learning activities that are emphasized and the types of problems that are used. Barrows (1985) emphasized that the PBL process needs to approximate the reasoning of experts as closely as possible. The problems therefore need to be authentic and based on real situations. Schmidt (1983), however, emphasized the role of prior knowledge activation, and places more emphasis on the initial discussion of relatively short explanation problems. In other models, the role of learning how to learn (Dahlgren, 2000), or learning by doing (Kjersdam & Enemark, 1994) were emphasized, and affected the level of guidance that was offered or the way in which the solution to the problem was investigated or presented. Not only do the interpretations of PBL affect the process, but also learners' experience with PBL, age, and cultural factors are important to consider in the instructional design of the PBL process (Hallinger & Lu, 2012; Torp & Sage, 1998).

Please note that the overview provided in the current chapter is not exhaustive. Every institution that implements PBL likely makes some adjustments to the PBL process based on the domain under study or their own preferences and values (Lucero, Jackson, & Galey, 1985). It is not possible to identify one "ideal" model of PBL. When implementing PBL and choosing a process model, teachers need to ask themselves what type of knowledge they want their students to learn and what types of problems and learning activities are most suitable to obtain these objectives.

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13

Facilitating Problem-Based Learning

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> *…I want to find out … what is the depth of their understanding and I want them to recognize what they understand. But sometimes … I think in this instance to bring an issue up for the group to really work with and understand how it fits everything together. So I think I did this more as an attempt to … nail down an important point for them to recognize that they had developed themselves … I didn't know [if they knew that] so that's why I asked the question.…*
>
> (Hmelo-Silver & Barrows, 2015, p. 80)

We begin with a quote from Howard Barrows, a master facilitator, reflecting on his performance and on his role in facilitation. He viewed his role as helping the students recognize their understanding, putting ideas together, and, when necessary, asking questions. In this brief excerpt, several key aspects of facilitating problem-based learning (PBL) come to the foreground. Facilitation is one of the central and complex aspects of PBL. Although it may often mistakenly be perceived as passive, especially when compared with didactic approaches, effective facilitation is central to the success of a PBL group's social processes and learning. In this chapter, we review the epistemology underlying PBL facilitation; the goals of PBL facilitation, which include promoting deep engagement, supporting shared regulation, and self-directed learning (SDL); and promoting productive group dynamics. Next, we review research on factors related to effective facilitation, including facilitator characteristics such as subject-matter expertise, social and cognitive congruence, and being a peer versus an instructor. We also review specific strategies that facilitators use and educational technologies that can be used to support facilitation.

Facilitation strategies are designed to help scaffold social knowledge construction, support group regulation, and maintain group dynamics. Often these take the form of open-ended questions and revoicing student ideas. As PBL moves into a technology- and information-rich era, special considerations are needed for facilitating PBL in technology-mediated environments. Blended learning

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approaches have seen rapid shifts in the physical environment of many PBL classrooms. When combined with online access and new virtual spaces, these approaches are reconfiguring the dynamics of synchronous face-to-face facilitation and online facilitator engagement during SDL. Asynchronous PBL utilizing online meeting platforms and virtual environments are providing new opportunities for extending skilled facilitation. Finally, this chapter will also consider issues related to professional development of facilitators in terms of both the preparation and mentoring of new facilitators, and ongoing professional development needs of experienced facilitators.

Epistemology of PBL Facilitation

In his seminal work on the knowledge base for teaching, Shulman (1987) opposed technical approaches and envisaged “teaching as comprehension and reasoning, as transformation and reflection” devising an epistemological stance toward educating as “sound reasoning” (p. 13). As PBL educators, we not only engage in sound reasoning through designing PBL curricula and facilitating PBL tutorials, but by the very act of engaging in these processes, we, too, declare a fundamental philosophical stance toward knowledge and learning. Similar to Shulman’s concerns in the 1980s, debates surrounding knowledge and curriculum in the 2000s criticize the longstanding epistemic frameworks of foundationalism, instrumentalism, and pragmatism for their “excessive focus on an essentialist view of knowledge and its divisions and a neglect of the transitivity inherent in the development of knowledge within the disciplines” (Scott, 2014, p. 26). For PBL, this fundamental premise that disciplinary knowledge is inherently transitive, fluid, and dynamic permeates curriculum design. It is central to a facilitator’s practice and to the ultimate goal of developing the dispositions of lifelong learners (Boud & Feletti, 1997). PBL curriculum designers, therefore, adopt Whitehill, Bridges, and Chan’s (2013) position that:

> For those engaged in PBL, there is a general consensus that there is no stable “truth” to be uncovered but that truth and knowledge are evolving, contested and under constant re-construction…. Whilst guiding students through key disciplinary content, PBL educators also seek to provide students with ways of knowing not only in developing the skills to access knowledge but also in analyzing and synthesizing this knowledge so as to “manage” it. Rethinking our position on epistemology is, therefore, the first step in understanding PBL as a philosophy. (p. 3)

As a philosophy, curriculum design, and approach to classroom learning, PBL, therefore, provides scaffolds for learners to explore and understand the logic and fundamental precepts of their discipline (Lu, Bridges, & Hmelo-Silver, 2014). PBL facilitators model higher-order thinking and reasoning so as to foster an inquiry-oriented approach to learning (Savery, 2006). It is key for the PBL facilitator, therefore, to understand the cognitive and social principles of PBL as a situated approach to learning (Lave & Wenger, 1991) driven by both the contextual authenticity of the problems and issues at hand and the social dimension of mentored learning with peers in groups (Bridges, Chan, & Hmelo-Silver, 2016). In taking a situated approach, "learners are given real-world tasks and the scaffolding they need to carry out such tasks" (Collins & Kapur, 2014, p. 117). As one of these scaffolds, the PBL facilitator supports an apprenticeship in thinking by acting as a mentor for students' reasoning processes. As the social and cognitive dimensions of learning become enmeshed in new understandings of the learning sciences (Nathan & Sawyer, 2014), the foundational epistemic principles of learning in PBL remain not only current, but, perhaps, even more cogent given new understandings of the relationship between knowledge and the curriculum. These epistemic principles are embodied in the facilitators' goals and strategies.

Goals of Facilitation

The facilitator role is critical to making PBL function well. By making key aspects of expertise visible, and situating learning in meaningful tasks, PBL exemplifies the cognitive apprenticeship model (Collins & Kapur, 2014). In PBL, the facilitator models expert strategies for learning and reasoning, rather than providing content. Facilitators scaffold student learning through modeling and coaching, primarily through the use of questioning strategies (Hmelo-Silver & Barrows, 2006, 2008). As students become more experienced in PBL, facilitators can progressively fade their scaffolding, with the hope being that the collaborative learning groups will take on much of the facilitation task. The facilitator helps move the students through the PBL tutorial cycle (Hmelo-Silver, 2004) by maintaining the agenda and monitoring group dynamics and shared regulation. This monitoring assures that all students are involved, and that the facilitator's discourse moves encourage them both to externalize their own thinking and to comment on each other's thinking (Hmelo-Silver & Barrows, 2008; Koschmann, Myers, Feltovich, & Barrows, 1994).

The PBL facilitator (a) guides the development of higher-order thinking skills by encouraging students to justify their reasoning, and (b) externalizes self-reflection by directing appropriate questions to individuals. The facilitator plays an important role in modeling the problem-solving and SDL skills needed for self-assessing one's reasoning and understanding. Although facilitators fade some of their scaffolding as the group gains experience with the PBL method, they continue to monitor the group, making moment-to-moment decisions about how best to facilitate the PBL process. The facilitator directly supports several of the goals of PBL. First, the facilitator models the problem-solving and SDL processes. This might occur as the facilitator encourages medical students to generate and evaluate hypotheses, modeling a hypothetico-deductive reasoning process. In an engineering design problem, the facilitator might organize strategies around an engineering design cycle (Kolodner et al., 2003; Puntambekar, 2015). Second, the facilitator helps students learn to collaborate effectively. An underlying assumption is that when facilitators support the collaborative learning process, students are better able to construct flexible knowledge. The facilitator helps students collaborate by eliciting multiple perspectives (e.g., "Does everyone agree?"), creating opportunities for all group members to articulate their ideas, and helping support equitable participation in general (Ertmer & Glazewski, 2015). Third, the facilitator helps the group identify the limits of their understanding by pushing students to explain their thinking and define terms that might be used without understanding. When students are not able to explain further, the facilitator suggests that those might become learning issues for the group to research during SDL and then share, evaluate, and synthesize at ensuing tutorials. As well, the facilitator prompts reflections on the learning resources that are used, providing further support for one of the SDL goals.

Promoting Deep Engagement

An important role for the facilitator is to help promote deep engagement with the ideas and disciplinary forms of reasoning. In medicine, that is the hypothetico-deductive form of reasoning but it might be argumentation in other science contexts (e.g., Engle & Conant, 2002; Forman & Ford, 2014) or more case-based reasoning in design domains such as engineering (e.g., Kolodner et al., 2003; Puntambekar, 2015). By asking the right questions at the right time, the facilitator can encourage students to engage deeply with disciplinary practices and content (Hmelo-Silver & Barrows, 2008).

The adoption of a classroom culture that promotes disciplinary reasoning and the practice of appropriate thinking strategies such as presenting evidence can help students remain productively engaged in the problem. If students are continually pushed to make connections between claims and evidence and how they help reach learning goals, students will become more reflective (Ertmer & Glazewski, 2015). Reminding the students of the underlying or major question driving their work can also help students stay on track, as one challenge of group work is reminding themselves what their major goals are. Keeping students on track can also encourage students to remain engaged with the activity. Hmelo and Guzdial (1996) suggested that when facilitators push students to articulate what they've learned and what they need to know, either by asking directly or by supplying the student with structured checklists, diaries, or other types of record keeping, the students will develop metacognitive strategies that allow scaffolded support to be removed later. As Ertmer and Glazewski (2015) pointed out, some students are able to go through the motions of completing tasks in their PBL team without actually developing a deep understanding of the concepts they are presented with. By frequently checking in with students, questioning the reasoning of the group and of the individual, and pushing students' metacognitive abilities, facilitators can promote deep engagement with the content.

Supporting Shared Regulation and SDL

One of the challenges for facilitators is to support shared regulation and effective SDL processes within the group. In particular, helping the students recognize what they know, what they don't know, and what they need to learn, helps students develop metacognitive skills, set learning goals, and prepare for the information searching they will need to do as they later research their learning issues. Some of the questioning that facilitators engage in needs to help students identify learning issues and reflect on the effectiveness of their collaboration and learning strategies. In addition, the facilitator needs to help students think about vetting the resources that they use in learning and the balance between facilitator guidance and student self-reliance in that regard (Dolmans, 2016). The facilitator supports this by encouraging students to discuss the resources they identified in their SDL phase and evaluate them as a group, promoting shared responsibility for SDL (Chng, Yew, & Schmidt, 2015). Facilitators may also need to initially provide guidance for critically identifying reliable resources and perhaps initially constraining the resources students use to a manageable and high-quality set that they might later open up more broadly (Derry, Hmelo-Silver, Nagarajan, Chernobilsky, & Beitzel, 2006; Dolmans, 2016).

Promoting Productive Group Dynamics

An important part of the facilitator role, especially for less experienced groups is to help support productive group dynamics. This involves monitoring the group, helping to ensure that all group members are involved and that the important ideas don't get lost—especially when they come from lower-status members of a group. It can involve finding the balance between being completely nondirective and providing guidance with regards to the group dynamics and shared regulation (Järvelä & Hadwin, 2013; McCaughan, 2015; Savin-Baden, 2003). Savin-Baden (2003) argued that because of the need to be cohesive, the PBL group might better be considered a team. That cohesiveness might not arise without some of the support that the facilitator provides, in particular, encouraging the group to take an "interactional stance". An interactional stance refers to the notion that all group members should participate equally in the discussion as they are mutually engaged in building on each other's ideas, disagreeing when appropriate (in respectful and principled ways), sharing in regulating the group process, and attending to the contributions of other learners (Hmelo-Silver, 2004; Hmelo-Silver & Barrows, 2008; Imafuku, Kataoka, Mayahara, Suzuki, & Saiki, 2014). Nonetheless, one issue for facilitators in fostering productive group dynamics is that of group size. There is an inherent logic that, in a small-group setting, the facilitator is better able to gauge the level of understanding of individual learners than in mass lecture contexts and the original developers of PBL proposed that a PBL group "cannot function well beyond eight members" (Barrows, 1988, p. 43). In an empirical study, Lohman and Finkelstein (2000) examined the effect of group size in PBL on selected outcome measures by comparing three group sizes: small (three students), medium (six students), and large (nine students). The study recommended the use of medium size groups in face-to-face facilitated PBL due to increased levels of self-directedness and more favorable reactions toward the learning experience.

Characteristics of Effective Facilitators

Subject-Matter Expertise

Facilitators need to have expertise in facilitation strategies and at least a threshold level of content understanding to guide learners, that is, to better understand when to push students on content and the strategies to accomplish this, as well as when to hold back and allow students to regulate themselves and their group. Dolmans, Janssen-Noordman, and Wolfhagen's (2006) study of 573 PBL tutorial groups found that students could discern differing levels of facilitator expertise and perceived tutors to be least effective when they do not stimulate active learning processes. These tutors tended also to adopt a teacher-centric approach to facilitation. Analysis of students' responses to the item *tips for tutors* were grouped into four categories of areas for tutor improvement: (a) adequate evaluation; (b) being overly directive; (c) being too passive; and (d) content expertise. So it is clear that for students, content expertise was an important concern. In an analysis of a PBL tutorial, Hmelo-Silver and Barrows (2006, 2008) found that content expertise was a factor in determining when to guide groups to consider particular learning issues or hypotheses as compared to making a decision to let an issue leave the table. A review by Schmidt and Moust (2000) suggested that facilitator content expertise was a factor in student achievement. A more recent review by Leary, Walker, Shelton, and Fitt (2013) is more equivocal on the relationship between facilitator content knowledge and student achievement, though facilitator training appears to relate to student achievement. Nonetheless, content knowledge may exert an indirect effect as the facilitators use their content knowledge to determine what facilitation moves to make and when to make them. A key message from these results is that the effects of subject-matter expertise are mixed but also that this expertise is used in a more nuanced way than in direct instruction, in terms of helping the facilitator know when to use particular facilitation moves, when to push the students to explain because of relevance to the problem at hand, and when to let things go.

Cognitive and Social Congruence

Other characteristics of effective tutors are cognitive and social congruence (Cornwall, 1979; Schmidt & Moust, 1995; Yew & Yong, 2014). Cognitive congruence refers to the ability to explain ideas in a way that the student can understand because the facilitator shares a similar knowledge or professional base, and is able to understand the student's point of reference. Further, this includes the ability to communicate clearly and scaffold learning (Yew & Yong, 2014). Social congruence refers to interpersonal qualities of the facilitator including their personality, being able to relate to students, motivate students, creating a productive learning environment, and being professional (Yew & Yong, 2014). Given the student-centered approach of PBL, it makes sense that social congruence has been found to significantly influence students' learning processes and outcomes in PBL classrooms (Chng, Yew, & Schmidt, 2011).

Peer Facilitators

Peers can serve as facilitators in some PBL environments as they have the social congruence necessary in supporting facilitation and likely possess cognitive congruence, although they may lack the content expertise of faculty tutors. Especially in undergraduate, graduate, or professional education, peer tutors can assist in facilitating discussion and keeping discourse on track in one group, as a dedicated tutor, or several groups, as a floating tutor (Allen & White III, 2001). A meta-analysis of facilitator effectiveness suggested that peer tutors can be very effective, even when compared with faculty tutors (Walker & Leary, 2009). In a study of peer facilitators in an educational psychology course for preservice teachers, Hmelo-Silver, Katic, Nagarajan, and Chernobilsky (2007) found that these students effectively served as "soft leaders" who guided their groups gently, with humor and humility, but also helped maintain the group agenda and push their group-mates to explain their thinking. This research also showed that this facilitation function was sometimes distributed across multiple students. According to Duch (2001), there are several ways in which a peer or near-peer tutor can extend productivity. First, peers can serve as role models for group members who are inexperienced with PBL environments, and can help to encourage those who do not participate as much as others. Second, as many peer tutors have taken and excelled in the course for which they are tutoring, they can check for conceptual understanding. Third, peer tutors can make decisions about when to push students through understanding difficult content, and can act as gatekeepers for resources to lead students toward deeper understanding. This would require a greater understanding of PBL facilitation by the peer tutor, and would likely require some assistance by the teacher in the form of training. Hmelo-Silver (2000) provided just-in-time support with a set of prompt cards that provided strategies that could be used with different goals as well as example prompts, as shown in Figure 13.1. Lastly, the peer tutors can provide information about group progress to the teacher, and can give insight into what is working well and what is not.

4) PROBLEM SYNTHESIS

This should occur periodically throughout the session. The group needs to determine where they are at a given point in the process in order to figure out what to do next.

Ask a group member to summarize what they know up to this point without looking at the board.

EXAMPLES:

- Let's see what we know up to this point—group member 1?
- What do we know about the expert teacher problem—group member 1, see if you can tell us what we know without looking at the board.

Goal: To help the group assess their present understanding, and to see if this understanding is shared by all group members.

Figure 13.1 PBL Facilitator Prompt Card.

Facilitation Strategies

Facilitation is a subtle skill. It involves knowing when an appropriate question is called for, when the students are going off-track, and when the PBL process is stalled. Additionally, it requires knowing when to let students grapple with an idea versus when to suggest that the idea become a learning issue or to subtly guide them toward additional information or resources. These skills and strategies are applied both in-the-moment of a single tutorial and across the events of a full PBL cycle and require attending to accumulated consolidation across time. In a study of an expert PBL facilitator, Hmelo-Silver and Barrows (2006, 2008) found that he accomplished his role largely through metacognitive questioning and questioning that focused students' attention and elicited causal explanations. The facilitator used a variety of strategies to support his goal of getting medical students to construct causal models of a patient's illness. He asked students to explain their reasoning to the point where they realized that the limitations of their knowledge necessitated creating a learning issue. Another strategy was to ask students how hypotheses related to the patient's signs and symptoms in order to encourage the students to elaborate causal mechanisms. Finally, the facilitator also modeled reflection on his own performance. That research demonstrated that an expert facilitator has a flexible repertoire of strategies that can be tailored to different stages of the PBL process. Many of these strategies are designed to involve learners with disciplinary content.

As discussed earlier, strategies serve particular purposes as shown in Table 13.1. These include constructing explanations, promoting effective reasoning processes, helping learners become aware of the gaps in the knowledge and engaging learners in SDL. In addition to these educational goals, the facilitator also has performance goals, trying to ensure that all students are actively engaged in the learning process while also keeping the learning process on track, making their thinking visible, and scaffolding the groups in becoming increasingly self-regulated and reliant on themselves and others to address their learning needs.

Studying facilitation in a medical student group, Hmelo-Silver and Barrows (2006) identified several distinct strategies that facilitators used in a medical PBL setting, a subset of what is in Table 13.1. Some of these strategies may be widely useful, for example open-ended questioning (e.g., asking students to justify their reasoning) and revoicing. Revoicing involves repeating what students have said, perhaps rephrasing it to help the learners tune their language or refine their use of a concept. This can help in clarifying ideas as well as recognizing the contributions of the students who have contributed a particular idea. This is a strategy that is seen in many inquiry-oriented or dialogic approaches to learning (Resnick, Michaels, & O'Connor, 2010). Hmelo-Silver and Barrows (2006) provided examples of these strategies in action.

To generalize the work on facilitation, Zhang, Lundeberg, and Eberhardt (2011) used PBL for a summer professional development workshop, studying 6 groups with a total of 35 teachers. They found that experienced facilitators used a range of facilitation strategies "including questioning, revoicing, making connections, clarifying, reframing, summarizing, role playing, meta-talk, and modeling"

Table 13.1 Example Facilitation Strategies (from Hmelo-Silver & Barrows, 2006)

Strategy	Description	Purpose
1) Use of open-ended and metacognitive questioning	Wide range of questions that asked students to justify their thinking or that would ask students to engage in monitoring, evaluation, or reflection	General strategy to encourage explanations and recognition of knowledge limitations
2) Pushing for explanation	Use of what, why, and how questions; drawing flow chart	Construct causal models Help realize limits of their knowledge
3) Revoicing	Repeating what students have said, perhaps with slight rephrasing into more normative or disciplinary	Clarify ideas Legitimate ideas of low-status students Mark ideas as important and subtly influence direction of discussion
4) Summarizing	At slow points in discussion or when discussion is less focused, ask a student to summarize the group's current thinking	Ensure joint representation of problem Involve less vocal students Help students synthesize data Move group along in process Reveals facts that students think are important
5) Generate/evaluate hypotheses	Brainstorm ideas quickly and then focus inquiry based on evidence	Help students focus their inquiry Examine fit between hypotheses and accumulating evidence
6) Check consensus that whiteboard reflects discussion	Asking students if whiteboard reflects their discussion	Ensure all ideas get recorded and important ideas are not lost
7) Cleaning up the board	Have students focus on what is relevant and cross off ideas that might no longer be up for consideration	Evaluate ideas Maintain focus Keep process moving
8) Creating learning issues	When students can't define or explain, asking if that should be learning issue	Knowledge gaps as opportunities to learn
9) Encourage construction of visual representation	Suggesting students draw diagram, flow chart, concept map, etc.	Construct integrated knowledge structure that ties mechanisms to observable effects

(p. 342). They also found that the PBL facilitators provided encouragement, used humor to create a relaxing climate, and in general provided the kind of positive feedback needed to establish a learning community. Often these facilitation techniques are enacted through open-ended questioning.

Questioning

In order to move beyond the routine IRE (initiate, response, evaluate) structure of classroom discourse that is typically found in teacher-centered pedagogy, strategies that lead toward progressive transformative discourse need to be used (Hmelo-Silver & Barrows, 2008). The facilitator's use of questioning as a way to guide student learning is a powerful tool. Questioning can open or close a line of discourse, focus attention on certain content, activate prior knowledge, and assist in goal setting among other benefits (Burbules, 1993; see Hmelo-Silver & Barrows, 2008 for a description of questioning strategies). In essence, questioning is an important tool for facilitation and serves many purposes. Hmelo-Silver and Barrows (2008) found that the facilitator asked many types of questions. One type of simple question was a verification question such as "Are headaches associated with high blood pressure?" Such questions can serve to bring the group's attention to a particular kind of idea. More complex questions asked for definitions, examples, or causal relationships or mechanisms; for example, asking, "What do you guys know about compression leading to numbness and tingling?" A final kind of question tended to be task-oriented or meta-level questions that focused on group dynamics, monitoring, and SDL. For example, to check that the group was all on the same page, Barrows asked, "Megan, do you know what they are talking about?" Other questions in this category might include asking students what they wanted to do next or if an idea needed to be a learning issue.

Facilitation in Larger Classes

An important issue in moving beyond the traditional model of PBL that requires one facilitator to a group is one of scale. The role of the facilitator is extremely important in modeling thinking skills and providing metacognitive scaffolding. The medical school environment is privileged in being able to provide a facilitator for each small group. It is less clear how this might translate into other environments. Hmelo-Silver (2000) has successfully managed to facilitate multiple groups, using a *wandering* facilitation model. In this model, the facilitator rotates from group to group, adjusting the time spent with each of the groups in the classroom according to their needs. By looking at large poster sheets created by each group and hung on the classroom walls, she was able to dynamically assess the progress of each of the groups and adjust her facilitation efforts accordingly. In addition, students rotated through the facilitator role with the help of prompt cards that gave examples of different techniques that could be used at different stages of the PBL process (see Figure 13.1). This is a lower level of scaffolding than is possible in a one-facilitator-per-group model so some adaptations of PBL are needed to accomplish some of the facilitation functions. For example, reflection rarely happens in groups without a facilitator and so alternative mechanisms, such as structured journals, are needed to ensure reflection (Hmelo-Silver, 2000). This *wandering facilitation* strategy was used with undergraduate students, who are a more varied group than medical students but are still more mature than elementary and secondary students. Further research is needed to explore strategies that can be used to facilitate PBL with less mature learners in a typical classroom of 25 or more students.

In another approach to managing a large class, Nicholl and Lou (2012) created a questioning guide that was used as a scaffold. Large classes (in the Nicoll and Lou example, 100 students) can be split into small teams of five or six. The instructor can answer questions and would hold large class discussions when multiple groups asked a similar question. In this way, students were asked to self-facilitate their groups as much as possible by following the guide provided by the instructor. The group members set ground rules, gave each other feedback at the end of each class and case, were able to assign jobs and learning issues to each member, and used the questioning guide that was designed to encourage accountability, critical thinking, and productive discussion. Feedback was collected from students for a period of 5 years, during which 92% of students reported that the facilitatorless format was beneficial and helped them develop their own facilitation skills. Thus, there are ways of using questioning in larger classes when the instructor cannot provide close guidance.

Facilitator Professional Development

We have argued in this chapter that facilitation is central to the PBL process and have noted that facilitator expertise and skills are viewed by students as key to success in terms of academic and social outcomes. Note that this section is focusing on faculty as facilitators rather than peers. The professional development of facilitators, therefore, is an additional aspect worthy of some consideration. This should be considered in terms of induction for skill development of new facilitators as well as in the provision of master classes for experienced facilitators to refine their craft. Quality assurance is also a critical link to both initial and ongoing facilitator development. In meeting these challenges in a case of large-scale implementation (over 100 PBL groups with 80 facilitators), Young and Papinczak (2013) identified strategies that were both organizational and specific to their professional development program:

- "Continual and needs-based professional development
- A return to Barrow's original vision of PBL facilitation
- Applying educational innovations from higher education
- Tutors using student feedback to improve practice." (pp. 826–827)

An induction program for new PBL facilitators needs to address the skills, strategies, and techniques of facilitation, and the underlying philosophical premises of the approach. For novices with a personal educational background and teaching experience rooted in didactic approaches, there may be both a conceptual and practical struggle to transition from role of teacher as "sage on the stage" to facilitator as "guide on the side." This change in role needs to be clearly linked to the fundamentally different view of content and knowledge in a PBL curriculum. This learning can be addressed through constructivist approaches but should remain central to professional development programs at all levels.

Faculty development program providers also now see a changing population in their programs. Some novice facilitators have themselves been educated through PBL programs and have an intimate understanding of facilitation and group processes. Interestingly, however, although facilitators may have experienced PBL as students, they may also lack an underlying conceptual understanding of the rationale for PBL or its design. Although experienced with the approach in the classroom, they are often surprised by the depth of curriculum planning and detail required in problem/case design and associated facilitator briefing and debriefing processes. This debriefing process is another important aspect of facilitator reflection that helps them learn to improve their facilitation skills and strategies. For fully integrated curriculum designs, novice facilitators should also be aware of the system-level matrix mapping of PBL learning issues and PBL problems/cases and their associated assessments across the years of a curriculum (Bridges, Yiu, & Botelho, 2016).

When focusing on PBL facilitator skill development, Salinitri, Wilhelm, and Crabtree's (2015) survey of programs indicated common approaches to include live or video-based observation of experienced facilitation with real students, various permutations of simulated facilitation through role play, and hybrid approaches combining information sessions and active engagement with the process. Their recommendation of constructivist designs utilizing technologies is both supportive of the PBL philosophy and draws on technologies to support the next-generation PBL. Other experiences with PBL faculty development indicate that engagement with dialogic processes is critical for facilitator development, particularly when also supporting curriculum reform processes in transitioning to a PBL curriculum design (Murray & Savin-Baden, 2000). Engaging facilitators in sustained dialogue begins in induction programs and includes the following central elements:

- active, practice-based approaches to facilitator skill development;
- reflective debriefings;
- sustained mentoring; and,
- programmatic peer review for quality assurance.

Like other forms of professional development for teachers, PBL facilitator training is a complex process that needs to be systematically designed and implemented. Another level of complexity is added when technology is added to the PBL mix.

Facilitating Technology-Supported PBL

Educational technologies can address longstanding issues regarding scaffolding student learning. Recent reviews of the use of technologies in PBL in health science education (Jin & Bridges, 2014) and more generally (Verstegen et al., 2016) indicate developments in this new iteration of PBL. Of the 28 included research studies between 1996 and 2014 in Jin and Bridges' (2014) systematic review, three types of educational technologies were found to have been adapted or specifically developed to support students in the PBL process of inquiry: (a) learning software and digital learning objects (n = 20); (b) large screen visualizations such as interactive whiteboards (IWBs) and plasma screens (n = 5); and (c) learning management systems (LMS) (n = 3). The findings indicated emerging new forms of PBL in a "digital ecosystem" (p. 10). Five positive effects for student learning in technology-enhanced PBL were identified from these studies:

- providing rich, authentic problems and/or case contexts for learning;
- supporting student development of medical expertise through the accessing and structuring of expert knowledge and skills;
- making disciplinary thinking and strategies explicit;
- providing a platform to elicit articulation, collaboration, and reflection; and,
- reducing perceived cognitive load.

Technical support, infrastructure, and resources were found to be critical to successful uptake and implementation of PBL and these organizational issues are common across the wider educational technologies literature. Verstegen and colleagues' (2016) review across a wider range of educational contexts also indicated the centrality of technologies in supporting contextual and collaborative learning in PBL and noted the emergence of intelligent tutoring systems.

There are broadly two approaches to engaging with educational technologies that impact directly on facilitation. Facilitators may draw upon an array of educational technologies *infused within* the traditional, small-group, face-to-face process of inquiry into the PBL cycle (Bridges, Botelho, Green, & Chau, 2012). Alternatively, educational technologies may be drawn upon to *replace* traditional face-to-face PBL to adapt to distributed learning contexts such as supporting students on field placements (Ng, Bridges, Law, & Whitehill, 2013) or fostering internationalization initiatives (Hmelo-Silver et al., 2016). At the larger, curriculum level, educational technologies can scaffold PBL designs and processes. For example, devising PBL-oriented LMS and curriculum maps can support curriculum coherence (McLean & Murrell, 2002; Tedman, Alexander, & Loudon, 2007) and integration (Bridges, Yio, & Botelho, 2016) with potential for learning analytics to be generated for quality enhancement.

Using Technology to Directly Support Facilitation

The increasing use of technology in PBL classrooms allows for great flexibility on the part of the teacher and the student. Teachers can more quickly and closely monitor student progress, and students are afforded opportunities to strengthen metacognitive processes and ask for more guidance when necessary. Learning management systems can also be instrumental in a PBL classroom, especially in asynchronous learning environments. Asynchronous PBL is often conducted in a threaded discussion format, which encourages replies to an idea; however, such threads often make it difficult for a facilitator to track the development of the discussion (Orrill, 2002). Students tend to make fewer posts, though they may be more reflective (Hmelo-Silver, Nagarajan, & Derry, 2006; Lan, Tsai, Yang, & Hung, 2012). These threaded discussions present challenges for PBL facilitators, because they have less opportunity to provide immediate feedback in the context (Hmelo-Silver & Derry, 2007). Other challenges include limited quality and quantity of student participation (Guzdial, 1997; Hewitt, 2005), and off-track discussions (Dennen, 2005; Ellis, 2001). As in face-to-face PBL facilitation, these online discussions can be stimulated with tutor encouragement, revoicing, providing participation guidelines, and summarizing the discussion (Beaudin, 1999). Other effective approaches include responding to a majority of student posts, directing comments to specific individuals, and significant instructor participation (Tagg & Dickenson, 1995). However, all of these strategies are labor intensive, and depend upon a tutor's ability to understand what is happening in the PBL groups. The benefit of online systems is in the amount of data that they can make available for facilitators, but it can also be overwhelming (Hogaboam et al., 2016).

One way to make the data tractable is through the use of learning analytics and dashboards. Dashboards provide a way for teachers to quickly assess the progress their students are making, see student questions or feedback, and monitor the pace of the lesson. Dashboards are often customizable and enable the user to see only what they need to without being encumbered by too much information. But the design and use of dashboards can pose challenges to meet the needs of facilitators. In a study of asynchronous PBL, Hogaboam et al. (2016) found that facilitators focused on student *output* rather than on their *activity* as evidence of engagement and did not find the data visualizations easily interpretable. The latter finding was attributed to the data being displayed out of context. Research on using dashboards and learning analytics in PBL is still nascent and requires research on how facilitators use the data as well as professional development to help them interpret the visualizations.

Educational Technologies Infused Within and Across the Face-to-Face PBL Cycle

At the level of PBL as an instructional approach where facilitators work with students in small group inquiry, technologies can draw upon a range of affordances and modalities, which can be infused across the whole PBL cycle of inquiry. Given that PBL is situated within a social view of learning, technological tools have the potential to support the social dimension of learning for team-building and collective reasoning processes (Lu, Lajoie, & Wiseman, 2010), particularly when students are in the SDL phase of the PBL cycle (Bridges, 2015). Wikis and forums can also be useful for promoting and enhancing student interactions out of class as well as providing timely feedback (Spector et al., 2016).

Table 13.2 describes examples of additional strategies for facilitating with technologies (see also Verstegen et al., 2016). One expanded role in the PBL group is that of student scribe as technology manager, particularly if group notes are digital and linked to the large screen display for collaborative text construction (shared documents, concept maps, wikis, etc.) or archiving group notations on learning objects and sourced images such as X-rays or design documents. Large-screen hardware linked to the PBL student scribe's laptop can range from passive displays to interactive screens such as IWBs. Early research in this area has found IWBs to encourage more adaptive approaches to problem solving (Lu & Lajoie, 2008). A more recent adaption of technologies in PBL is the use of Bluetooth sharing tools such as Clickshare™ so that multiple group members' laptop screens

Table 13.2 Strategies for Facilitating Face-to-Face PBL with Technologies

Technology	Strategy
Large-screen visualizations	Ensure control of screen displays is in the hands of students (scribe and group) (Bridges et al., 2014) Manage online searching (text and multimedia) via the scribe for: ● real-time sharing to support group critique of sources (Jin, Bridges, Botelho, & Chan, 2015) ● supporting students' structuring and framework building as real-time collaborative note making (such as with Google docs™) as part of the problem-based learning synthesis process (Lu et al., 2010) Invite a second "scribe" to take on "interactant role" with interactive screens to: ● manipulate 3D inquiry objects (Yang, Zhang, & Bridges, 2012) annotate images and share with the group (Bridges et al., 2014) ● make disciplinary thinking explicit using tools such as concept mapping software (Mok, Whitehill, & Dodd, 2014; Bridges, Corbet, and Chan, 2015)
In-class videos	Provide whole-group, synchronous viewing to support collective engagement and knowledge co-construction (Bridges, Corbet, and Chan, 2015) To activate prior and current knowledge during initial viewing in the first stage of the problem-based learning cycle, use the sequential disclosure approach to pause videos so students can identify facts and start hypothesizing For application and synthesis in the final stages of the problem-based learning cycle, replay the video for recapping and see if the group feels they have addressed the problems and issues at hand
Out-of-class videos	Ensure all students view prior to class meeting by sharing initial observations with group in class
Moderating wikis, forums, and other synchronous activities	Model good forum practices in class by having each group member log into and post to a wiki or forum issue in real time using a central display. This familiarizes students with the technology and allows in-class feedback and reflections on the quality of postings Make expectations for participation clear (e.g., frequency of posting, quality of responses, expectations for timeliness)

can be displayed via the central, large screen for group discussion. These adoptions of a variety of educational software within face-to-face facilitation using large-screen visualizations can support cognitive apprenticeship and induction into disciplinary reasoning processes.

PBL materials developers are also adopting multimodal resources to motivate and capture the interest of digitally adept students. New digital resources in medical education include the use of videos, 3D representations, virtual reality simulations, and, most recently, anatomy holograms. A major advantage of the inclusion of videos to replace or enhance PBL scenarios or cases is the ability to enhance authenticity. One issue arising is the level of complexity provided by a video filmed in an authentic versus a simulated, role-played environment or paper-based scenario. Research has found that, while videos may change the amount of talk across different PBL phases, the quality of the discussion is at deeper levels with more time spent on problem identification (Chan, Lu, Ip, & Yip, 2012). Thus, they can support facilitation and promote the goals of facilitation, namely deep engagement and promoting productive group dynamics.

Educational Technologies to Replace Face-to-Face PBL

As PBL has evolved from its origins in medical education (Barrows, 2000), a new wave of curriculum designers and developers have sought to address issues of flexibility and scalability for improved student learning. One challenge for professional programs with community-based elements such as internships and study abroad opportunities has been how to maintain PBL group inquiry processes in distributed learning environments. Until recently, technologies have not been able to address the key concern of facilitating highly interactive exchanges in dynamic group environments, especially if using asynchronous models (Mattheos, Schittek, Attstrom, & Lyon, 2001). Ng et al. (2013) concluded that:

> online communication tools now support learning environments that afford increasingly reliable and stable one-to-one, one-to-many, and many-to-many text, audio and audio–visual interactions in real time and that by including multimedia search engines and databases, hypertext and various synchronous collaborative activities, this framework constitutes a powerful suite of tools for using online PBL to leverage modern technologies in the curriculum. (p. 4)

Their pilot adoption of synchronous web meeting platforms was one novel approach to maintaining group interactions and supporting students' while off-campus. Ng and colleagues' (2013) 4-week experience using Adobe Connect™ as an online PBL tutorial platform found high student uptake while not losing any academic gains when compared to assignment results from face-to-face PBL. In comparison to face-to-face PBL, the facilitator perceived no differences in coordinating group discussion, although new activities included student sharing of files and student collaborations on a shared notes file, and even found "the flow of discussion seemed to run more smoothly, and the amount of intervention required by the tutor was reduced" (p. 8). Similarly, Lajoie et al. (2014) used video as a context for synchronous PBL on medical communications with a synchronous web conferencing platform to connect medical students across continents. As a proof-of-concept short-term study, the facilitators had to both support the PBL discussion, and deal with helping the students adapt to the technology, including time delays because of bandwidth limits in one of the sites.

As raised in the discussion of face-to-face facilitation earlier, feasibility of staffing and administering small PBL groups has been insurmountable for some programs. Innovative online solutions seek to address the issue of scalability through simultaneous management by one online tutor of multiple groups engaged in inquiry processes. For example, in the STELLAR project, Derry et al. (2006) used a mix of face-to-face and asynchronous interaction to help distribute some of the facilitation onto the learning environment and to allow a facilitator to interact with multiple groups. This system also allowed the course instructor to mentor less-experienced teaching assistants and provide advice as needed, which would be difficult in a face-to-face setting (Hmelo-Silver et al., 2006). An alternative to using web meeting platforms has been to conduct PBL in immersive virtual reality environments such as SecondLife™ (Savin-Baden et al., 2011; Savin-Baden, Poulton, Beaumont, & Conradi, 2016). Health sciences facilitators identified that, despite requiring an initial phase of adjustment to the potential distractions of an immersive, avatar-based environment, there were positive effects on student decision making although of a different order to traditional views of PBL knowledge construction.

Conclusion

Facilitation is an integral aspect of PBL environments, and requires time, training, and commitment to learn on the part of the teacher. Although facilitation skills are subtle, there is growing empirical evidence that characteristics like social and cognitive congruence as well as content expertise play a pivotal role in promoting the deep engagement that leads to student learning. Here, we reviewed research on factors related to successfully facilitating PBL lessons, certain strategies that promote learning, educational technologies that support facilitation, and approaches to the professional development of facilitators.

Facilitator strategies aid scaffolding collaborative knowledge construction, supporting shared regulation, and maintaining group dynamics. The use of questioning as a strategy is especially relevant and is a possible avenue for continued research. Although there have been several types of questions identified as well as the roles that they may play in the classroom, there has been a lack of research into which types of questioning are most useful in certain situations like moving a group through a difficult concept or asking students to link evidence with inferences.

Professional development for teachers, such as workshops for both new and veteran facilitators, is necessary to learn and practice skills. This is even more the case when using technology to support PBL. Mentoring of newer teachers by teachers more experienced with PBL is an indispensable method of training as well.

As PBL classrooms are more immersed in technology, special considerations are needed for facilitation and managing blended learning environments that incorporate online access and virtual spaces. Technology can be used as a tool to assist the facilitator in monitoring student progress, watching for questions, and providing access to resources. Specific types of technologies like dashboards, LMS, and IWBs (smartboards) have been especially useful as stimuli and scaffolds in PBL environments.

We conclude with the importance of reflection in facilitation. A good facilitator will demonstrate how they can be constructive in improving their own performance for students, but they will also engage in being a reflective practitioner through discussions with colleagues and curriculum designers so as to continually improve their own practice as well as the wider implementation of PBL at their institution.

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14

Scaffolding in PBL Environments: Structuring and Problematizing Relevant Task Features

Peggy A. Ertmer and Krista D. Glazewski

> *Scaffolding … enables a child or novice to solve a problem, carry out a task or achieve a goal that would be beyond his unassisted efforts. This scaffolding consists essentially of the adult "controlling" those elements of the task that are initially beyond the learner's capacity, thus permitting him to concentrate upon and complete only those elements that are within his range of competence. The task thus proceeds to a successful conclusion … [which] may result, eventually, in development of task competence by the learner at a pace that would far outstrip his unassisted efforts.*
>
> (Wood, Bruner, & Ross, 1976, p. 90)

Scaffolding is one of the key features of a problem-based learning (PBL) environment (Ertmer & Glazewski, 2015; Hmelo-Silver, Duncan, & Chinn, 2007). As observed by Barrows and Tamblyn (1980), instructors and/or tutors are expected to provide learners with consistent and dynamic support throughout the problem-solving process. Although Barrows did not use the scaffolding metaphor in his early descriptions of PBL, the small-group tutorial sessions he recommended were designed to support students' efforts to become independent learners. That is, Barrows recognized, and others have since confirmed (Hmelo-Silver et al., 2007; Wu & Pedersen, 2011), the critical role scaffolding plays when transferring the responsibility for learning over to students in a problem-centered environment. Furthermore, given the diverse contexts in which PBL now occurs (Hung, Jonassen, & Liu, 2008; Yadav, Subedi, & Lundeberg, 2011), scaffolding considerations have become even more critical—without their incorporation into the environment, PBL is unlikely to be an effective learning model.

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Origins of Scaffolding

Scaffolding, as originally conceived, is rooted in the structure of support. Wood et al. (1976) originally employed the scaffolding metaphor to capture the range of assistive efforts observed when one tutor guided young children toward completion of a complex block-building task. To formalize the tutor's responsibilities, the researchers specified that he/she should intervene gradually, beginning with verbal directions prior to demonstrating or helping. The researchers then captured the scaffolding patterns that emerged across participants, which included fostering learner interest, simplifying the task to make it more manageable, maintaining forward direction, marking critical features, controlling frustration, and demonstrating or modeling (Wood et al., 1976). In addition, the researchers emphasized ideas that subsequently became closely associated with Vygotsky (1978), including the idea that scaffolding should be accomplished within a learner's range of competence, which requires limiting or eliminating elements that are beyond his or her capacity.

Although Wood et al. (1976) did not explicitly discuss the concept of fading, this notion is closely associated with the idea that learners are expected to become independent in the specific domain or problem space. Belland (2011) referred to this as "transfer of responsibility," noting the need to prioritize this transfer as an integrated element of the scaffolding process. One example, presented through the *Wise Practice Video Database* (Callahan, 2016), depicts an interaction between a high school social studies teacher and his student, who is struggling to determine a newspaper's bias through an analysis of an original source article in the context of problem-based historical inquiry. In the interaction, the teacher supported the student's ability to make inferences from the newspaper's depiction of events by asking her a range of questions:

> [Is the newspaper] sympathetic to one side or the other, or is it a straight story that doesn't make any judgments of right or wrong?.... Are we supposed to feel one way or another from reading this?
>
> ...OK, so that's the third piece of evidence you've told me that says, "I see that the family was told by the FBI to do this. Here's how the family felt about the FBI." So ... the common thing I see you saying here is that you see what the family sees, you hear what the family hears, you feel what the family feels.

During the exchange the student moved from expressing prevailing uncertainty to identifying the perspectives that were *not* presented as a way of determining bias in the story. In a follow-up interview, the teacher explained:

> I could tell very early on that she's actually read the article. She's done the work. She's just having a problem putting all the pieces together. I'm not giving her any new information because I want her to work through it herself.
>
> ...And it's frustrating for her because she can't complete the task I've set for her, and it's frustrating for me because she doesn't see what she has.

> But this skill of finding bias and the reason for writing the document, looking at the position of the document, is hopefully a skill that she'll take with her in her everyday life for the newspapers she reads and the television shows she watches … to look at the bias and the point of view … that's the skill that I want her to learn. That's the underlying real value of this conversation. So for me to give it to her as opposed to her learning that skill on her own—that would defeat the purpose.

This example illustrates how the teacher implemented his goal of transferring responsibility for learning to his student. As emphasized at the end, simply telling his student the answer would defeat the purpose of the exercise. Thus, as a component of scaffolding, fading allows instructors to complete the instructional cycle by returning to the original goal of the lesson.

Why Scaffolding in PBL?

Scaffolding plays a crucial role in the PBL process, no matter the context in which it occurs. That is, the PBL model, as originally conceived by Barrows (1986), involved consistent and regular support in the context of one expert tutor per team of medical students. As Barrows described, the role of the tutor was to (a) move students' learning forward through discussions, (b) keep students' learning processes on track, and (c) facilitate and manage productive group work. As such, Barrows considered the tutor's scaffolding role to be the "backbone of problem-based learning" (p. 93).

As PBL began to diffuse to other contexts, educators moved from the one-tutor-per-small-group model to one-facilitator-per-many-groups. Woods (1991) described the many complexities involved in shifting a chemical engineering program to PBL in ways that were feasible for one faculty member to manage with a course enrollment of 20–45 students. He accomplished this by placing primary responsibility for facilitation on the teams. Woods began with an intensive workshop to transition students to self-directed PBL, which comprised a predictable learning routine: group-negotiated learning goals, student-to-group microteaching sessions, and a chairperson for each meeting to keep the team moving forward. Team meetings occurred during class time when the faculty member was available for consultation. Woods reported that over a 10-year period, he and his colleagues refined the approach and began to observe learning gains that met or exceeded exam performance of students in non-PBL sections of the same course. Results from this work informed how to organize the one facilitator-per-many-groups approach and also provided specific ideas for how to scaffold students' efforts: through both targeted skill-building approaches as well as just-in-time support. It is important to remember, however, that this approach places more demands on both the instructor (who must continually rotate among groups), and students (who work, primarily, as independent, self-directed teams).

Diffusion of PBL into K–12 contexts was initially formalized and promoted through gifted education. Curriculum specialists from the Illinois Mathematics and Science Academy (IMSA) partnered with Barrows and documented one of the first formal visions of PBL in public education (Barrows & Kelson, 1993; Barrows, 1996). In response to widely observed educational problems (e.g., passive student learning, inert knowledge, lack of relevance), the authors called for transformation of the K–12 curriculum through PBL. The IMSA began to disseminate PBL through summer teacher workshops, allowing PBL to gain a firm foothold in gifted education prior to being adopted more widely (Gallagher, Stepien, & Rosenthal, 1992; Stepien, Gallagher, & Workman, 1993).

One pattern that has prevailed over 60 years of formalized PBL is its use with advanced learners prior to including a wider range of learners. For example, medical students tend to be advanced, high-achieving learners. Woods (1991) described how the push to adopt PBL within the undergraduate chemistry program typically began with senior-level students. It was not until students requested earlier exposure that the program expanded. Similarly, at the K–12 level, PBL was first introduced into gifted programs before making inroads with more diverse learners. However, PBL was never limited to advanced learners; that is, teachers were quick to find value in PBL and almost immediately adapted it for use in a diverse range of settings. In fact, Gallagher and Gallagher (2013) documented the capacity of PBL to reveal unseen academic potential among low-income, high-minority, and underserved students. Now that PBL has a firm position in more diverse contexts, scaffolding represents an even more critical component as instructors seek to support a wider range of learners.

Scaffolding Functions in Problem-Centered Learning

Although scaffolds serve a variety of functions in problem-centered learning environments, most educators would agree that the ultimate goal of scaffolding is the transfer of responsibility from teacher to student, as noted earlier (Belland, 2011; Smit, van Eerde, & Bakker, 2013). For example, Saye and Brush (2007) documented their scaffold designs over four iterations of *Decision Point!*—a multimedia unit that immersed high school learners in problem-based historical inquiry. The authors concluded that scaffolding structures that fostered student independence included strategies for approaching the problem, organizing information and arguments, engaging empathy, and/or challenging epistemological assumptions. Because their research involved observations over four iterations, the researchers were able to consider issues of fading. However, they cautioned that building internal capacity is a gradual process and not likely to result in student independence after one or two exposures. Indeed, this is one of the primary reasons for using a problem-centered approach—to facilitate a shift toward greater self-direction while simultaneously increasing students' knowledge, complex reasoning, and problem-solving skills (Goel et al., 2013; Strobel & van Barneveld, 2009; Walker & Leary, 2009).

Given the complexity of problems addressed in a PBL context, scaffolding students' learning comprises a key component of the teacher's role (Ertmer & Simons, 2006; Hmelo-Silver & Barrows, 2006). In general, scaffolding (whether via human or nonhuman means) is used to accomplish two major goals: (a) to guide students through the complexity of the task so they can productively engage with the problem, and (b) to help students focus on those aspects of the tasks that are most relevant—a function referred to as "problematizing" (Reiser, 2004). According to Reiser, scaffolds allow instructors to provide an optimal level of challenge by maintaining a balance between active engagement and "nonproductive floundering" (p. 287). We discuss each goal in more detail.

Structuring/Minimizing Task Complexity

According to Smit et al. (2013), scaffolding involves setting up the instructional situation so that students can enter in and engage with a complex task without becoming overly confused or frustrated. Wood et al. (1976) referred to this as "reducing the degrees of freedom" by simplifying the task (p. 98), while Wu and Pedersen (2011) described it as "reducing the scope for failure in a task" (p. 2353). In general, the goal is to reduce cognitive load so students can engage in practices that would otherwise be out of reach (Davis & Miyake, 2004). Further, by successfully engaging in these tasks, students' performances on future tasks are also expected to improve (Reiser, 2004).

This aspect of scaffolding addresses what Vygotsky (1978) referred to as the zone of proximal development (ZPD); that is, the gap between what learners can accomplish on their own and what can be accomplished with assistance. There are many ways to bridge this gap including structuring or subdividing complex tasks, preselecting relevant data, narrowing options, offloading more routine parts of the task, and explicitly guiding students through the task by modeling or making thinking visible. Furthermore, there are various ways in which these functions can be performed—either by the *teacher* via just-in-time support (i.e., soft scaffolding; Saye & Brush, 2002), or by preselected, predesigned *instructional materials, or artifacts* (i.e., hard scaffolding; Brush & Saye, 2002). According to Stone (cited in Davis & Miyake, 2004), scaffolds can comprise multiple types: sources, tools, and other individuals.

Hard scaffolds

In general, teachers rely on instructional materials, either paper- or technology-based, to reduce task complexity (Brush & Saye, 2002). For example, Puntambekar and Kolodner (2005) used paper-based design diaries to support middle school students as they engaged in a complex design challenge related to managing erosion on a coastal barrier island. Each page of the diary contained prompts that helped students address each step in the design process (e.g., problem understanding, information gathering, choosing between alternative solutions). According to the authors, diary pages served many functions including externalizing the activities involved in designing, making clear the range of activities students should complete, and providing suggestions for next steps. In effect, these prompts served to divide the design process into manageable chunks while also providing explicit guidance for completing each step.

As an example of a computer-based tool used to reduce task complexity, Choi, Land, and Turgeon (2015) built a "Collaboration and Negotiation Tool" to help novice online learners ask meaningful questions of their peers. To scaffold students' efforts, the researchers narrowed the types of questions students could ask to three specific types (clarification or elaboration questions, counterarguments, and context- or perspective-oriented questions), thus reducing cognitive load. Each question type was further separated into possible scenarios that suggested relevant uses of that type. For example, students could choose one of the following reasons for asking a clarification question: (a) your explanation is not clear, (b) your explanation is not complete, and (c) you did not answer the question correctly. The tool then provided tips and examples for each situation, which guided learners' subsequent construction of effective questions. According to the authors, although students who used the tool asked more questions than those who did not, there were no differences in learning outcomes. The authors speculated that more adaptive and dynamic forms of scaffolding, such as instructor and peer modeling, might be needed to *complement* the static question prompts. This supports the suggestion, described earlier, to use various types of scaffolds in tandem.

As an additional example of a hard scaffold used to reduce task complexity, *ExplanationConstructor* was developed as a computer-based science journal to promote meaningful, contextualized, knowledge-integrated arguments within an inquiry-based context (Sandoval & Reiser, 2004). Recognizing that knowledge is represented through explanation, but that students needed help reasoning through explanations that require causal judgments, the tool included prompts to guide arguments (thus, structuring the task). Subsequently, students selected a specific argument from a predefined set of explanations (thus, narrowing the options). One primary outcome was that students demonstrated high capacities for developing strong arguments based on claims supported by evidence, although the authors cautioned against assuming conceptual understanding based on these outcomes (Sandoval & Millwood, 2011).

Soft scaffolds

One of the most common soft scaffolds teachers use to reduce task complexity comprises providing explicit guidance through the task (Brush & Saye, 2002), typically through modeling or making thinking visible. Making thinking visible was originally conceptualized by Collins, Brown, and Holum (1991), who recommended that teachers' thinking be made visible so that "…students can observe, enact, and practice [tacit processes] with help from the teacher and from other students" (p. 3). According to Hmelo-Silver and Barrows (2006), the PBL setting represents a cognitive apprenticeship that initiates students into the thinking practices of the discipline. Edelson (2001) noted that novice learners initially tend to examine more complex problems superficially and are unable to apply domain knowledge to contend with the depth and complexity of an issue. Studies suggest that while inquiry-based learning experiences have the potential to enhance students' scientific inquiry skills, there are limits to the sophistication of students' conceptualizations of scientific problems and their abilities to apply appropriate scientific knowledge to a problem (Bell, Blair, Crawford, & Lederman, 2003).

To address this issue, experienced teachers often use classroom dialogue as a scaffold to "help their students develop better understandings of concepts and content" (Akerson, 2005, p. 248). Newstetter (2006) delineated many of the questions teachers might use to model the kind of internal monitoring students are learning to develop: "…That sounds like the beginning of a hypothesis. Can you make it into one?… How does your research apply to the problem?… Do you feel like you have exhausted all possibilities for research on this topic? Where else could you look?" (p. 222). By modeling appropriate ways to think about disciplinary issues and by making students' thinking visible through prompting, the PBL facilitator can foster the important habit of questioning one's own, as well as other's, thinking. Through repeated practice, students' arguments become more sophisticated (Engle & Conant, 2002; Hmelo-Silver & Barrows, 2006).

Because one of the primary goals of PBL is to develop students' self-directed learning skills (Hmelo-Silver, 2004), the soft scaffolds that teachers provide, especially in the form of making thinking visible, are critical to the attainment of this goal. For example, teachers might begin the problem-solving process by modeling how to think about the problem, using language of the discipline. In addition, teachers might model how to actually complete the task, prompting students to compare their own processes with the approach modeled by the teacher, an expert, or other students (Pedersen & Liu, 2002–2003). Engle and Conant (2002, p. 437) present a specific example of how a fifth-grade teacher used modeling to help students understand how to make evidence-based arguments to convince other students that the opinion they held was superior:

> So maybe I decided malaria [was worse], and Ms. A [the current student teacher] decided DDT [*was*]. Ms. A might say "I think DDT because of THIS," and then I would raise my hand [*is raising her hand*] because I have something to say to that. I'd either wanna BACK her up and say "yeah and also THIS" [*gestures a point*], or I'd want to say "oh NO, I don't think that, because I think malaria is worse, because of THESE reasons" [*gestures multiple reasons*]. (November 22, 1995)

Soft scaffolds can also take the form of just-in-time instruction. Lu, Lajoie, and Wiseman (2010) described four forms of dynamic, soft scaffolds used by the instructors in their study: providing information requested, providing new information, asking verification or clarification questions, and eliciting elaboration of student reasoning. As another example, McNeill and Pimentel (2010) described how a middle school science teacher encouraged students to expand their justifications for arguments and to link their ideas to other students' ideas. Through her dynamic use of open-ended questioning strategies, the teacher engaged her students in "reflective discourse"—explicitly prompting them to make their meanings clear, consider multiple perspectives, and reflect on their own thinking as well as that of their classmates.

Problematizing Relevant Task Features

The second major goal for the use of instructional scaffolds is to explicitly draw students' attention to those parts of the problem they might otherwise overlook. This is typically accomplished by making "some aspects of students' work more problematic" (Reiser, 2004, p. 287), either by introducing some form of cognitive dissonance or by generating students' deep interest in a controversial, or unresolved, issue. In contrast to the types of scaffolds previously discussed, which are specifically designed to *reduce* complexity, problematizing scaffolds are designed to force students to grapple with complex ideas or processes; in other words, they trigger a direct confrontation with the task complexity. This, then, may "actually add difficulty in the short term, but in a way that is productive for learning" (Reiser, 2004, p. 287). Reiser describes problematizing as the flip side of structuring, and notes that these two functions can be either complementary or in tension within different contexts or designs.

Soft scaffolds

As with scaffolds that reduce complexity, problematizing scaffolds can be provided by either teachers (i.e., soft scaffolds) or instructional materials (hard scaffolds). In terms of soft scaffolds, teachers can induce problematizing by drawing attention to some aspect of the problem that requires more consideration (e.g., asking students to connect their thinking to disciplinary issues or to specifically address discrepancies among different peers' ideas). In general, the goal is to increase students' participation in resolving substantive problems and thereby decreasing their tendencies to engage in superficial analyses or nonreflective work. As such, when "students are proceeding along without being mindful of the rich connections of their decisions to the domain content" (Reiser, 2004, p. 288), teachers are encouraged to problematize the problem-solving process by purposefully "rocking the boat."

Problematizing scaffolds can force students to slow down and/or avoid premature closure of discussions that uncover controversial or opposing viewpoints, especially if students appear ready to dismiss the potential disagreement. For example, Engle and Conant (2002) described how a fifth-grade teacher legitimatized an argument that emerged among a group of students over the species classification of killer whales, by emphasizing that there were two sides to the argument and that both sides had legitimate points. The teacher, through her actions and discourse, "explicitly indicated that the question was worthy of disciplinary engagement, both in being legitimately unresolved and in already having some evidence behind it" (p. 440). And although only one student initially held the minority viewpoint, the teacher made it clear that both sides would have time to present their arguments (with evidence) and that the group could decide the outcome/solution afterwards.

Hard scaffolds

Hard scaffolds, in the form of either low- or high-tech support, can also be used to problematize the task students are challenged to complete. Reiser (2004) described three ways in which this might occur: (a) eliciting articulation, (b) eliciting decisions, and (c) surfacing gaps and disagreements. Scaffolds that are designed to *elicit articulation*, such as those incorporated into the mathematics model-eliciting environment (Hjalmarson & Diefes-Dux, 2008), require students to be explicit about their reasoning as they build deeper understandings of concepts (in this example, algorithms and number sense). For example, a teacher incorporated questions into her unit for students to answer at every milestone:

"How confident are you about your answer?" This had the effect of helping students make their thinking visible, as well as prompting them to become more intentional in their responses.

In a similar fashion, computer-based scaffolds can *elicit decisions* by forcing students to choose from a limited set of options or to make decisions they might have overlooked, such as those prompted within the WISE environment (Web-based Inquiry Science Environments; Linn, Clark, & Slotta, 2003). For example, as students learn to develop evidence-based arguments, the WISE software forces a classification decision in which students must explicate the relationship between a specific piece of evidence and a particular position being advanced. By purposefully prompting students to document the results of their decision-making processes, WISE problematizes students' engagement in scientific inquiry in a way that is productive for future learning.

Finally, hard scaffolds can be used to *surface disagreements* related to disciplinary goals. As an example of a relatively low-tech hard scaffold, a high school biology teacher introduced a PBL unit using the question, "Should there be a meat tax?" Recognizing that students might be inclined to agree on the answer to this question, the teacher assigned groups of students to different stakeholder positions (e.g., farmer, doctor, parent, economist). Scaffolds were provided in the form of newspaper or journal articles that accurately represented the assigned viewpoints (Brush et al., 2014). This had the effect of surfacing legitimate arguments on both sides of the question.

Evolution of Scaffolding Models: From Tutor to Blended Approaches

According to Smit et al. (2013), responsiveness is at the heart of the scaffolding process. However, on-the-spot decisions regarding how to best facilitate students' learning are a "demanding undertaking for teachers in whole-class settings" (p. 823). Given this, many researchers advocate the use of both hard and soft scaffolds within an instructional setting. For example, Puntambekar and Kolodner (2005) found that when hard scaffolds (in the form of design diaries) were not integrated within teachers' daily classroom activities, they were not effective. In other words, teachers needed to augment the diaries with adaptive questioning and modeling to help students connect design actions and activities (e.g., planning, building, and testing) with entries in their design diaries. Similarly, Wu and Pedersen (2011) observed that without teachers providing scaffolds during students' use of a computer-based scaffold, students were less likely to internalize the information provided, ignore the advice given, or disregard reflective prompts in favor of simply completing the given task.

The advancement in technological tools, such as those used by Puntambekar and Kolodner (2005) and Wu and Pedersen (2011), have enabled a one-to-unlimited enactment of PBL via a more robust integration of scaffolding resources provided by teachers, peers, and technology. Pea (2004) proposed "…'mixed initiative' designs of scaffolding processes in which people and machines join together in helping someone learn something in the sense that certain scaffolding activities can be the responsibility of the teacher… and other scaffolding activities provided by the software" (p. 444). In other words, tools and resources might be adapted to cultivate a learning moment or meet a spontaneous need. Although Saye and Brush (2002) refer to this integration as a blending of hard and soft scaffolds, others have characterized blended approaches differently. We describe two additional conceptualizations.

Distributed Scaffolding Models

Puntambekar and Kolodner (2005) advanced the idea of distributed scaffolding, arguing that "…support needs to be distributed across the different tools and agents in a classroom and redundancy needs to be built in" (p. 212). As noted earlier, their research incorporated many forms of scaffolding such as prompted design diaries, guided pin-up sessions, intermittent milestones with peer and teacher questioning/feedback, and whole-class discussions. One important outcome of this research was the researchers' recognition of the central role of *redundancy* in scaffolding. More specifically, Puntambekar and Kolodner found that students who had ignored supports early in the design process (e.g., in their design diary prompts) had a chance to pick them up later in preparation for another milestone (e.g., the pin-up session). Thus, the authors' findings refined how we understand blended approaches, but also demonstrated affordances of a distributed system, such as the benefit of embedding redundancy of supports.

Synergistic Models

Tabak (2004) coined the term "synergistic scaffolds" to refer to numerous artifacts, agents, and support structures that are "…co-constituted to support the same need" (p. 330). She illustrated this with an example from a high school biology class that engaged students in a problem of evolution through a population study of the Galápagos Island finches. Some of the particular challenges included marshaling background knowledge, enacting specific practices of biology, making determinations about relevance, and forming judgments supported by evidence. The researcher noted that it was not simply a learner–resource interaction that led to deeper learning, but rather, sequences of interactions and multiple exposures across time and activities. In other words, it was important for facilitators to prioritize multiple forms of scaffolds to meet a defined need.

Blended Approaches

The range and diversity of the blended scaffolding models help illustrate the complexity and range of needs that scaffolding addresses. However, when considering the possibilities of blended models, we argue it is important to foreground scaffolding *functions* over scaffolding *forms*. Pea (2004) elaborated on this idea:

> …Scaffolds are not found in software but are functions of processes that relate people to performances in activity systems over time. The goals of scaffolding research going forward should be to study how scaffolding

> processes—whether achieved in part by the use of software features, human assistance, or other material supports—are best conceived in ways that illuminate the nature of learning as it is spontaneously structured outside formal education and as it can most richly inform instructional design and educational practices. (p. 446)

In other words, it would be shortsighted to target a specific technology, tool, or resource as the priority scaffold in PBL. Ultimately, we must prioritize the needs of the learner; scaffolding decisions should comprise a range of considerations, which we discuss in the remainder of the chapter.

Scaffolding Design Considerations

Scaffolding design considerations comprise anticipating where students are likely to struggle during a planned PBL unit and then intentionally "designing" scaffolds to address students' needs, whether by simplifying the task or focusing them on relevant task features. While the creation of hard scaffolds, to meet *anticipated* needs, represents one important responsibility of PBL instructors, additional efforts are needed that enable them to be intentional in their responses to students' *emerging* needs. In this section, we discuss how teachers can purposefully plan for and enact both hard and soft scaffolds during a PBL unit.

Defining the Problem Space

Scaffolding design considerations begin with defining the *problem space* that the PBL unit is intended to address (Ertmer & Koehler, 2014, 2015). Before teachers can determine where students are likely to struggle in a unit or where they may simplify or ignore relevant task complexities, they must first determine what content and/or skills students are expected to learn from the unit—that is, the *afforded* problem space. According to Hmelo-Silver (2013), the problem space refers to "the specific ideas and concepts that are part of the goals of the problem at hand" (p. 24). By understanding what content and/or processes students should address in the unit, teachers can determine what they want/need the scaffolds (either preplanned or dynamic) to do.

Defining the problem space for a new PBL unit follows a process similar to what teachers do when they develop any new lesson. Typically, lessons are designed to address an overarching goal (e.g., Understand the food chain) as well as specific discipline-based standards (e.g., Determine ecological/energy significance of eating foods at different levels of the trophic pyramid). The same is true for PBL units, although PBL units often afford opportunities for students to engage in multiple related topics simultaneously. Although some of these related topics will emerge organically, due to students' specific interests and questions, teachers should pre-identify the primary problem space being targeted, as well as anticipate the related conceptual space that might emerge (Hmelo-Silver, 2013).

In addition to outlining targeted content, defining the problem space also includes specifying those twenty-first-century skills (National Research Council, 2012), such as collaboration and communication, which will be practiced and evaluated during the unit. Indeed, scaffolds might be particularly useful while students are learning to be self-directed, work in groups, or think critically about information retrieved during initial research efforts. van den Hurk, Wolfhagen, Dolmans, and van der Vleuten (1999) noted that during early experiences with PBL, students need more assistance during the exploration (i.e., finding and using available resources) and integration (i.e., merging ideas across disciplines) stages of the process. Scaffolds provide an important means for supporting these processes that are inherent to a PBL approach.

Anticipating the Need for and Generating Hard Scaffolds

We argue that hard scaffolding, which anticipates student needs, is enacted to serve the scaffolding functions previously emphasized: structuring or minimizing task complexity, and problematizing relevant features. More specifically, hard scaffolding is often explicitly designed to enable learners' entry into the problem, enlist and maintain their interest, or embed expertise in the form of content or strategic guidance to support learner success.

Enabling entry and enlisting interest

One prevailing research finding is that PBL fosters personally relevant experiences for learners (Ertmer & Glazewski, 2018; Hmelo-Silver, 2004; Strobel & van Barneveld, 2009); as such, educators generally assume that relevance will translate into increased student interest. However, sole reliance on problem relevance to trigger interest may not be sufficient to engage all learners in a classroom. Thus, we recommend intentional and designed experiences to enable entry and enlist learner interest, particularly at the introductory stage of the problem. More specifically, enabling entry comprises scaffolds that make the problem comprehensible and tangible for learners, while enlisting learner interest includes scaffolding techniques to stimulate and engage learner curiosity. In many instances, scaffolding strategies can be used to accomplish both goals simultaneously.

One common example reflects teachers' and designers' uses of *novelty*, which might be achieved by sharing a local story that can be connected to a persistent national issue. For example, in a PBL workshop for teachers, faculty introduced the problem, "Is my food safe?" though a local event of a foodborne outbreak (Glazewski, Shuster, Brush, & Ellis, 2014), which was then connected to national patterns of outbreaks. Novelty can also be introduced by leveraging new technologies. For example, across the various iterations of *Alien Rescue*, an immersive, multimedia PBL experience for middle school students, the designers enlisted student interest through various novel effects (Liu, Williams, & Pedersen, 2002). Early versions recorded a montage of news stories at a local studio to grab students' attention, while the most recent iteration leverages 3D and virtual reality technologies to immerse students in the problem (Liu et al., 2014). While these designed experiences serve a variety of purposes, we argue that they scaffold a significant process in enlisting learner interest at the outset. However, it is important to remember that novelty may not sustain learners' interest over time (Yaman, Nerdel, & Bayrhuber, 2008) nor is it the only way to enlist interest.

Another way to enable entry and enlist interest is through *staging* activities (Baumgartner & Reiser, 1998; Edelson, Gordin, & Pea, 1999), which also serve the additional purpose of building learner knowledge and competence. For example, in a problem such as, "Is my food safe?" the science teacher might set up a demonstration to challenge students' initial assumptions that all food bacteria is bad. This demonstration could include examples from food production that present instances of bad bacteria (i.e., cross contamination from unsafe practices) and good bacteria (i.e., yogurt and cheese production), thus setting up a challenge to preconceived ideas as well as establishing a deeper understanding of bacteria.

In *Learning by Design*, Kolodner and colleagues (2014) use the term "messing about" to characterize the activities that stage entry and interest. Because the problems are organized around design projects, learners begin with materials and a structured activity meant to prompt questioning, observation, and hypothesis generation. For example, in one project the students were challenged to design and build a propelled vehicle. During the initial messing-about activity, students were given a propeller, a rubber band, and a specific question regarding what might affect the cars' performances. As students explored, they were asked to generate questions. The messing-about activity served as the source for a follow-up whiteboard activity in which questions, observations, and hypotheses were collectively recorded and the teacher guided students in establishing priorities and determining next steps.

Providing strategic guidance and embedding expertise

Scaffolding strategies that support the goals of providing guidance and embedding expertise can take many forms, but often involve annotation or supplementary materials that students may access. One study investigated the role of embedded strategic guidance and specific content hints in an earth science multimedia PBL unit (Simons & Klein, 2007). In the quasi-experimental study, classes of students from the same teacher were added to a scaffolding condition (none, optional, or required). Findings indicated that students in the scaffolding-optional and -required conditions performed significantly better than the no-scaffolding condition on project performance, but results were confounded by the fact that the teacher seemed to want to "make up for" the lack of student resources in the no-scaffolding condition. Brush and Saye (2008) investigated outcomes of high school social studies students who engaged with a problem that asked them to consider strategies that would yield a more just society. The researchers embedded numerous strategic and content scaffolds within the unit to support knowledge building, argumentation, and debate. More specifically, as one way to induce students' understanding of multiple perspectives of an historical event, the facilitators problematized stakeholders' perspectives by asking students to assume an assigned perspective and then apply a critical lens to the perspective presented by a historical textbook summary. Documented outcomes included observations of high student achievement and engagement, as well as historical empathy and a deeper grasp of the nuance of historical events. Taken together, these studies underscore the need for blended scaffolding to foster complex understandings.

Anticipating the Need for and Using Soft Scaffolds

Soft scaffolds, by definition, are typically invoked in response to on-the-spot evaluations of students' needs, typically requiring teachers to either reduce task complexity or problematize relevant features. As such, instructors must be aware of, and prepared to use, common forms of adaptive support (Smit et al., 2013). To determine whether a soft scaffold is needed, the instructor uses her understanding of the targeted problem space to compare what is being addressed during students' research, or discussed in student groups, to the targeted problem space. If the comparison indicates limited coverage or misconceptions in understanding, then the teacher watches for opportunities to reinforce, probe, or question students in order to bring attention to those aspects that have been misinterpreted or skirted. In this section, we discuss four types of adaptive support: revoicing, redirecting, surfacing, and extending, and how they might be "designed" and used during a PBL unit. Although soft scaffolds are likely to take more forms than just these four, we focus on these as a few of the more common.

Revoicing

Revoicing comprises restating what students have said, while simultaneously providing additional clarification or elaboration (O'Connor & Michaels, 1993). Hmelo-Silver and Barrows (2006) described how Barrows used this strategy during PBL discussions to (a) clarify ideas, (b) legitimize the ideas of low-status students, (c) mark ideas as important, and (d) subtly influence the discussion direction. McNeill and Pimentel (2010) provided an example of how a teacher used a series of strategies during a student discussion: she began with revoicing, followed by an additional question for the student to consider, and subsequently pointed out a connection to another student's comment. After the first student commented that the "sun was too old" to explode, the teacher stated, "The sun is too old? [Do] you think that has to do with global climate change?" The student replied, "It's like dying out." Then, the teacher asked the student to consider connections to another student's comment: "But Sam is saying that in places it's actually not warm it's colder.… In some places it's too warm [and] in other places it's too cold" (p. 218).

Redirecting

Instructors will often find that students get sidetracked when working in open-ended learning environments and thus fail to focus on the most important aspects of the task (Kolodner et al., 2003). To address this tendency, instructors can redirect students using a variety of prompts. As Kolodner et al. (2003) noted, "Learning in a context of problem solving can be quite overwhelming; there is much going on and many different things might be learned or overlooked" (p. 507). To help middle school students stay on track, Kolodner and her colleagues introduced the idea of interweaving small- and whole-group activities, which allowed students to see how others were thinking about the design challenge and also provided opportunities for the teacher to highlight the relevant science concepts, especially to those who might be off-track. In addition, teachers used the classroom whiteboard to capture students' initial and changing conceptions, thus enabling them to track emerging understandings.

As another example of redirecting, Ertmer and Koehler (2015) illustrated how a facilitator used this strategy during an open-ended case-based discussion. In the discussion, which was focused on different stakeholder needs regarding product liability training in a manufacturing environment, a student criticized the legal department (represented by Richard), blaming it for some of the existing problems:

> *Student:* One major problem is Richard appears unwilling to move, believing Legal has created a viable product.... With Richard unwilling to approve anything, Craig [the instructional designer] has no real options, at least none that will produce new results. Convincing Richard to work toward an alternative solution is key to making any real progress.

In response, the instructor acknowledged, but disagreed with the student's comment, and then used the opportunity to redirect the student's attention to a more fruitful line of thought, one that focused more on solutions as opposed to critiquing stakeholders:

> *Facilitator*: I don't think Richard is completely unwilling to move (remember he said that Craig could "jazz up the course").... So what might common ground look like? Can we start to formulate a specific strategy for this course that Craig could take to Richard for approval? (p. 83)

Surfacing

Surfacing can help an instructor problematize, or bring to the foreground, aspects of the topic that students may not acknowledge or even recognize. As such, surfacing draws students' attention to an issue or perspective they didn't initially consider. In our earlier example of detecting bias in a primary source document, the teacher noted that he wasn't giving the student any information that she didn't already have, he was simply drawing her attention to what was in front of her (e.g., "That's the third piece of evidence you've told me that says..."). As illustrated by this example, surfacing can build on what students have already mentioned, helping them gain greater understanding of the relevance of gathered information.

As another example of how surfacing might be used in a problem-centered classroom, as part of the case-based discussion described earlier (Ertmer & Koehler, 2015), one of the students suggested that, perhaps, the training manager (Louise) had hired an outside consultant so that if things did not go well, the consultant would take the fall. The instructor, then, used this comment to surface a perspective that the students had not yet considered:

> If we think about this from Louise's point of view—there was no hidden agenda—she just wanted this training off her desk.... I'm pretty sure we shouldn't be reading all these ulterior motives into this. It just gets us off track!

By introducing this new perspective, the instructor was also able to emphasize a more general strategy for effective case-based discussions; that is, for students to be aware of the legitimacy of different stakeholders' perspectives.

Extending

During open-ended discussions, instructors need to be "prepared to be dynamic" (Cennamo, 2015, personal conversation, November 6, 2015), which translates into finding, and taking advantage of, opportunities to build on students' contributions to the small- or whole-group discussion. As a form of just-in-time instruction, extending strategies can be used to clarify and elaborate on, as well as provide examples for, concepts that are introduced or discussed by the students. For example, after a student in a case-based discussion noted that it was important for an instructional designer to "document his decisions," the instructor responded by first revoicing the student's comment and then extending the comment as a way to direct other students' attention to the relative importance of the student's recommendation: "Documenting the decision is critical. In fact, that should be something we ALWAYS do when working with clients."

One strategy that can be used to extend students' understanding is the reflective toss (Schoenfeld, 1998). According to Hmelo-Silver and Barrows (2006), the reflective toss comprises the teacher acknowledging a student statement but then throwing the responsibility for elaboration back to the student. Many times, revoicing is followed by an additional question (as noted in the example above: "The sun is too old. Do you think that has anything to do with global climate change?") in order to help students clarify and monitor their thinking. In this example, the second question comprises the use of the reflective toss, which, as illustrated here, almost always takes the form of a specific question that probes a student's initial response.

In the following example from Barab, Sadler, Heiselt, Hickey, and Zuiker (2010), the teacher builds on her students' comments to extend their understanding of what makes a stream healthy. Note that the teacher says very little—she primarily asks questions to push the discussion forward. Because the teacher is aware of the concepts that need to be covered, she can skillfully ask questions that enable students to provide the relevant information themselves:

Teacher: How can we tell if the stream is healthy or not healthy? Talk to your neighbor real quick. Okay, how can you tell if the river is healthy or not healthy? What are the scientific factors that will help the scientists?
Girl 1: Temperature.
Teacher: The temperature, yes.
Girl 2: The pH.
Teacher: So, temperature, pH, and we know that pH is—
Boy 1: How acidic the water is.
Teacher: Okay, what else?
Girl 3: The dissolved oxygen is the amount of oxygen gas in the water.
Teacher: Why is that important?
Girl 3: To see how much the fish can breathe.
Teacher: Okay. Who else wants to add to that?
Boy 2: Well, if there's not much oxygen in the water then maybe the fish have some sort of trouble breathing. Maybe something causes the lack of air.

BOY 3:	Fish don't need oxygen.
GIRL 4:	They need the oxygen inside the water.
BOY 3:	Yeah,' cause they breathe through their gills.
GIRL 4:	The bubbles in the water.
TEACHER:	So by comparing the dissolved oxygen amounts in sites A, B, and C, we'll be able to see if it's similar or if it's different. What else do we have? (p. 395)

In a PBL setting, a facilitator's questions will typically build on students' thinking, yet the responsibility for sense-making lies with the students (Hmelo-Silver & Barrows, 2006). Because of this, the instructor must be keenly aware of how to use students' comments and questions to guide them through the intended problem space. Given this, the instructor's comments cannot be scripted in advance, but rather, must be offered dynamically in response to the ongoing group discussion. Still, a teacher can be prepared to use soft scaffolding by applying a variety of self-cueing methods (e.g., classroom whiteboard, notes, reminders, classroom rituals) to prompt her to revoice, redirect, surface, and/or extend students' ideas. Together, these types of intentional reminders can be used to habituate the use of soft scaffolds so they occur dynamically and organically in the PBL context, thus enabling instructors to resist their natural tendencies to provide answers and give direction (Kolodner et al., 2003).

Conclusion

Despite different interpretations of the scaffolding metaphor and varying emphases on what or how to scaffold student learning in a problem-centered context (Lajoie, 2005; Yadav et al., 2011), it is generally agreed that scaffolds should be designed and activated with *intentionality*, based on a detailed understanding of the learners and context in which they are used. As originally conceived (Wood et al., 1976), scaffolds are expected to be used dynamically—that is, in response to teachers' ongoing diagnoses of learners' needs (Smit et al., 2013). Although there are many different forms that scaffolds might take (computer-based, human tutors), the goals for scaffolds have remained relatively stable since first introduced, that is: (a) to limit the complexities of the learning task, and (b) to problematize (bring to the surface) those aspects of the task that students may ignore or gloss over. Given that learning in a PBL environment is often difficult for students, and that, without adequate support, they are likely to disengage (Lajoie, 2005), scaffolding tools and strategies provide the means to support learners at the moment of need, leading to engaging and impactful learning experiences.

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15

Designing for Effective Group Process in PBL Using a Learner-Centered Teaching Approach

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For the past 20 years, educators have been advocating moving from instructor-focused teaching to a new paradigm called learner-centered-teaching (LCT). In LCT, the instructor acts as a guide to facilitate students acquiring knowledge and skills (Felder & Brent, 2016). This evidence-based paradigm shifts teaching away from focusing on what the instructor does to how and what students learn. While problem-based learning (PBL) predates the phrase learner-centered teaching, it is a signature pedagogy within LCT approaches. PBL employs many LCT design principles (Blumberg, 2007; Weimer, 2013).

This chapter discusses specific LCT design recommendations for the group process within PBL. By design, PBL's processes use iterative group methods where the students progressively integrate more knowledge to solve problems. The purpose of this chapter is to describe the roles and responsibilities of instructors and students within the PBL group process to show how they are congruent with LCT. After a description of the iterative PBL group process, this chapter maps PBL onto LCT, emphasizing the specific aspects of this paradigm that relate to the PBL group process. Examples of effective group practices that improve group functioning and techniques to increase learning are discussed.

As instructors from many disciplines seek to adopt PBL, they are further supported in their efforts knowing that PBL is a higher education best practice. Superimposing PBL on the LCT model helps instructors see the worth of PBL and explains why and how it should be implemented. PBL is a prototype example of LCT because it creates a unified learner-centered environment for students (Blumberg, 2007).

PBL as an Iterative Group Process

PBL was introduced in the 1960s in medical education. It employed a hypothetico-deductive reasoning approach, which simulates the widely accepted scientific method (Barrows, Norman, Neufeld, & Feighner, 1982). Since then, it

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has been widely adopted in many disciplines, which has led to large variations in its implementation (Prince, 2004; Weimer, 2013). For example, some people use the phrase problem-based learning or PBL to mean any type of case study discussion without the emphasis on group process. Because of these differences in practices, this section describes the specific group process steps that the author considers to be essential for PBL to occur.

Fink (2003) mapped the chronology of in-class and out-of-class student learning activities to illustrate integrated course design. Starting with what happens on day one and then identifying all student activities throughout the course, the instructor maps the course's timeline. The instructor would place all out-of-class activities, such as finding resources, reading, studying, or writing, below a horizontal line. In a similar fashion, the instructor would place all in-class activities such as group discussions above this horizontal line. Using Fink's method, Figure 15.1 diagrams a sequence of iterative activities showing that in PBL courses, learning occurs both in class and out of class. In fact, the learning, just as the group process itself, is iterative, with each part reinforcing the previous learning. The iterative group process in which each aspect of a problem is discussed more than once is an essential aspect of PBL as shown in Figure 15.1. The following discussion elaborates on the steps in the figure using the identifying letters and numbers. All activities above the line would take place in small-group discussion sessions.

First Iterative Discussion

During all first iterations of the problem discussion (as shown in Figure 15.1 in Steps A, E, and I) students deliberate on the problem using what they collectively understand by applying their knowledge to this new problem or part of the problem. Through the group's interaction, they elaborate on their understanding while realizing that they lack some of the knowledge that is necessary to solve the problem (Schmidt & Moust, 2000). Students summarize what they know about the problem and what they need to learn to fully understand the problem, called learning issues (Hmelo & Evensen, 2000). Sometimes students find that they need to revisit previously learned material as well as identify new content that they need to learn. If students short-circuit this step and just jump to identification of learning issues, they have lost a learning opportunity to engage with the content in a meaningful way (Blumberg, Michael, & Zeitz, 1990).

Toward the end of the discussions on the problem, the students review their list of what they need to learn (Step A3) and begin to group them to form learning issues (Exley & Dennick, 2005). Then students divide the learning issues so that everyone will investigate different significant topics. This design guideline of dividing the learning issues serves several important group functions. It allows students to focus and study content in depth as opposed to everything superficially (Hmelo & Evensen, 2000), which leads to a richer group discussion when they come together again as each student contributes different information (Blumberg, 2005). Additionally, when students divide the learning issues it becomes easier to identify students who are not adequately prepared (Blumberg, 2007). Peer pressure, then, motivates all students to come prepared to do meaningful group work (Bean, 1996; Blumberg, 2007; Weimer, 2013).

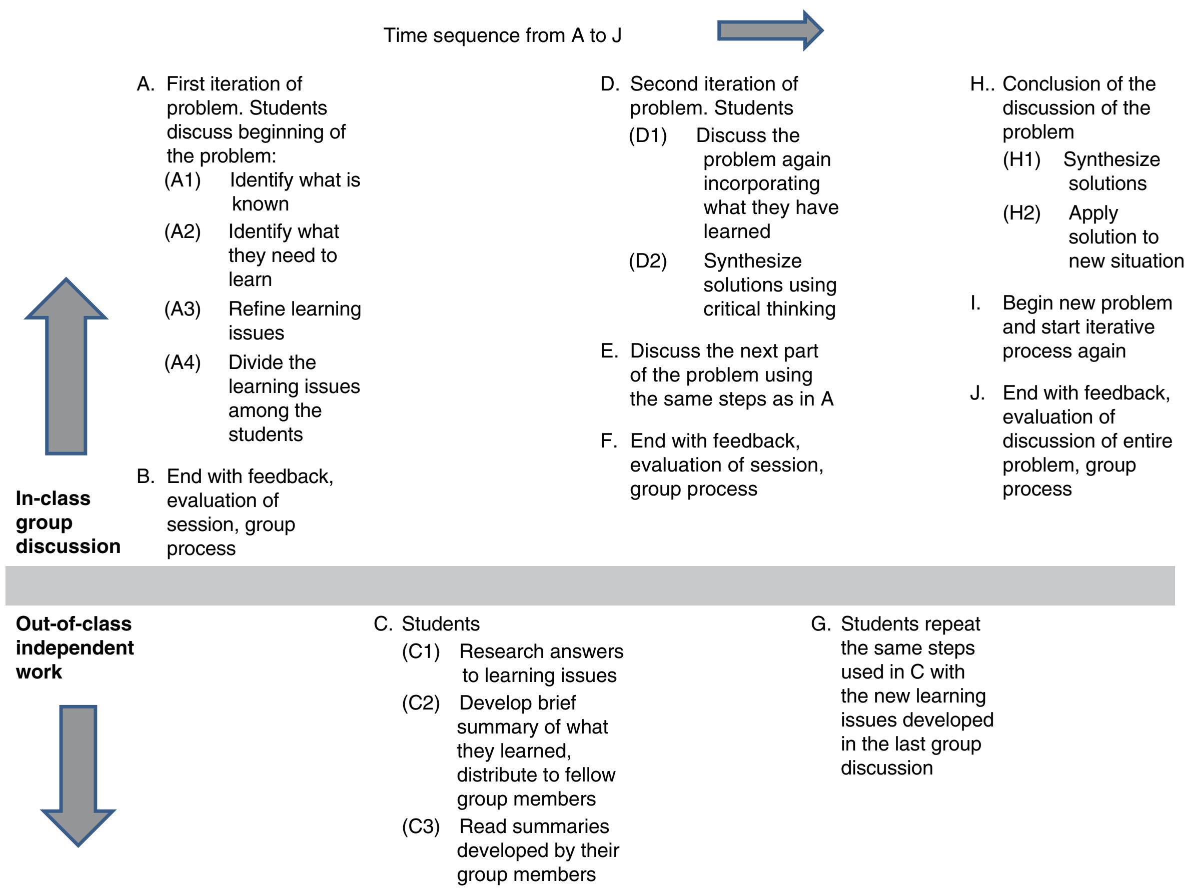

Figure 15.1 Iterative PBL Group Process.

Formative Feedback

At the end of every PBL small-group session the students should engage in brief formative assessment (Steps B, F, and J) (Blumberg, 2005, 2007). The group members should evaluate their group functioning, check on their progress toward solving the problem, comment on their collective and individual mastery of the content, and give each other feedback about their performance (Hmelo & Evensen, 2000). During this phase of the group process students can raise concerns about individual contributions, encourage noncontributing members to participate more, and help dominating students to allow others to speak more. Many group functioning problems can be averted early by employing the design principle of continuous feedback (Felder & Brent, 2016).

Independent Work Between Group Discussions

Between both class discussions of the same section of a problem, students research their learning issue(s) (Steps C and G). With the easy access to information via the internet, finding material is not difficult. However, students need to find information that is accurate, current, and free of bias through information literacy skills of identification and evaluation of appropriate resources (Association of College and Research Libraries, 2000).

Next, students synthesize what they have learned about their learning issue(s) to prepare for the next iteration of the problem discussion. Students have difficulty synthesizing information into a coherent summary (Blumberg, 2005). Therefore, Blumberg recommends a design technique whereby students develop a written, short summary of their synthesis of research (Step C2). While preparing these briefs is not always a required part of the PBL process, adding this step greatly facilitates group discussions. The process of integrating all the information into a short summary helps the students to engage meaningfully with the content and evaluate the importance of specific information (Blumberg, 2005). Depending on the learning issue and probably the discipline being studied, students may be encouraged to include summary tables, figures, or graphs. Students list full citations of their consulted resources. In addition to fostering a synthesis of the information, these briefs have other advantages (Blumberg, 2005). Asking students to write summaries repeatedly can improve their writing and synthesizing skills. They also become proficient with information literacy skills. Without these written reports, students are more inclined to read directly from resources without putting the content into their own words (Blumberg, 2005). Less motivated students do not want to be seen as unprepared and thus often rise to the occasion. When these briefs are shared with the students in their group, and everyone reads each other's briefs before class (Step C3), students come prepared to discuss the problem more comprehensively leading to richer discussion. Follow-up discussions are often more organized. The quality of these briefs overall may count as a small portion of the final grade, especially for undergraduate students. Finally, the collection of all of the briefs generated for a course forms a resource that students can use to review the material. The list of references cited can direct further reading on the topic.

Follow-Up Iterative Discussions

When students come back together to discuss the same material again, they share what they learned through discussion of the problem (Step D) and not through mini presentations to each other. Students ask each other clarification questions. The focus of these discussions is synthesizing the information from all of the students' research on their learning issues to solve the problem (Prince & Felder, 2006). By design, generally students discuss the same part of the problem twice, but if they or the teacher find that they still have unanswered questions, they may spend a third, brief session on this same part of the problem (Exley & Dennick, 2005). After concluding the discussion of the previously explored part of the problem, students begin the iterative cycle again by reading additional parts of the problem (Step E).

At the concluding discussion of the entire problem students demonstrate their mastery of the synthesis of all the content (Step H). Design techniques include applying their solution to a new, but similar situation (Hmelo & Evensen, 2000). In the health professions students may be asked to write a referral letter or summary note to a different health practitioner. Students may write an editorial advocating for more attention to a societal problem or appeal to a research agency for more funding for this problem. These final problem activities can be graded. In the same session, the iterative process commences again with a new problem.

Michael (2006) reviewed research from the neurocognitive sciences and psychology and summarized this research through principles of effective active learning. Two of these principles directly relate to the group process in PBL: more learning occurs when people learn with others than when they study alone, and when learners articulate explanations to themselves or their peers they acquire meaningful learning. Contemporary learning theories agree that effective learning is a socially mediated process where students meaningfully engage with the content while interacting with other people (Schunk, 2016). Knowledge is acquired through active engagement with the content, often through reflection on the ideas or discussing them. This allows learners to form their own understanding or meaning of the content (Schunk, 2016). These principles are the foundation of the LCT paradigm. The PBL iterative process just described employs LCT, which is discussed next.

LCT: An Evidence-Based Educational Paradigm

LCT offers an evidence-based conceptual framework to design and support the PBL group process. As a result of widespread research across many disciplines demonstrating its efficacy, LCT is considered a best practice in higher education (Doyle, 2011; Michael, 2006; Suskie, 2015 and Weimer, 2002, 2013). This research found that LCT fosters the acquisition of deep learning (Michael, 2006; Weimer, 2013).

LCT Design Guidelines Used in the PBL Group Process

Weimer (2002, 2013) defined five broad, essential dimensions of LCT: (a) the function of content (learning how and why to use the content); (b) the roles of the instructor; (c) the responsibility for learning, which is shared between instructor and students; (d) the purposes and processes of assessment; and (e) the balance of power between the instructors and the students. When implemented together, they form an integrated approach leading to better student learning outcomes (Weimer, 2013). Blumberg (2009, 2016) further refined these five dimensions into specific design guidelines. Table 15.1 lists the design guidelines of these dimensions of LCT that are used in PBL and where in the PBL group process each of these design guidelines are employed. Since the focus of this chapter is to describe design guidelines that relate to the roles and responsibilities of instructors and students within the PBL group process, the dimensions of the role of the instructor and the responsibility for learning are discussed in more detail than the other three dimensions.

The LCT Function of Content

While a primary purpose of content coverage is to build a student's knowledge base, the functions of content go beyond information acquisition as Table 15.1 shows. These functions are used in all steps in Figure 15.1 of the PBL group process.

The ongoing discussion of the problem allows students to actively engage to create their own meanings of the content. In addition, the group process allows students to form many associations with the content. All of these functions of content facilitate future learning. Professionals in field or clinical settings who supervise former PBL students say that these students ask questions and volunteer new knowledge more frequently than traditionally trained students (Blumberg, 2000). As will be discussed in the section on lifelong learning, graduates of PBL programs continue to learn and stay current in their disciplines.

Students, in non-PBL curricula often question why they are learning specific content or why they are required to take prerequisite courses for their majors. In PBL, students realize why they need to learn specific content because they use this material repeatedly in problem discussions; this makes the learning of content authentic. Since the students identify what they need to know as a result of the group discussions, they automatically see its relevance.

Critical thinking and problem-solving skills are nearly universally desired learning outcomes of higher education. However, these skills are content- or domain- and context-dependent including proper use of facts, concepts, procedures, rules, and algorithms (Schunk, 2016). The PBL process helps students to apply these content and context-specific, critical higher-order skills to real-world problems. Critical thinking is often employed to synthesize their problem solutions (Blumberg, 2005, 2007; Exley & Dennick, 2005; Prince, 2004). Summary end-of-problem exercises are especially good opportunities for students to demonstrate their critical thinking skills (Hmelo & Evensen, 2000).

Throughout the group process as described in Figure 15.1, the students practice and become skillful at discipline-specific methodologies. In PBL, students need to be able to read independently and comprehend what they read in the discipline of the course. In the sciences, where primary literature is often written using the IMRD (introduction, methods, results, discussion) format, students become skillful at recognizing what type of information will be found in each

Table 15.1 Blumberg's (2009, 2016) Design Guidelines of Learner-cCentered Teaching That are Emphasized During the PBL Group Process

Learner-centered dimension	**Specific design guidelines**	**Where this occurs within the PBL process. Steps are listed in Figure 15.1**
The Function of content. Content is more than a knowledge base. It also serves various functions in helping students become competent	Students are actively engaged in making meaning of the content	Entire iterative group process (Steps A–J)
	Students use content to facilitate future learning	Entire iterative group process (Steps A–J)
	Students know why they need to learn content	Entire iterative group process (Steps A–J)
	Students use discipline-specific critical thinking methods	Entire iterative group process (Steps A–J)
	Students learn to solve real-world problems	Entire iterative group process (Steps A–J)
	Students acquire discipline-specific methodologies	Entire iterative group process (Steps A–J)
The role of the instructor	States explicitly why the course is using PBL, the role and responsibilities of the students	Orientation to PBL Modeling expected behaviors Feedback, evaluation of session (Steps B, F, J)
	Uses teaching/learning methods that are appropriate for student learning outcomes	Entire iterative group process (Steps A–J)
	Creates a supportive environment for learning to occur	Orientation to PBL Entire iterative group process (Steps A–J)
	Uses activities involving student, instructor, content interactions	Entire iterative group process (Steps A–J)
	Motivates students to learn	Identification of learning issues (Steps A 2,3) Writing summaries (Steps C, G) Second iteration of problem (Steps D, H)

(*Continued*)

Table 15.1 (Continued)

Learner-centered dimension	Specific design guidelines	Where this occurs within the PBL process. Steps are listed in Figure 15.1
The responsibility for learning	Students have expectations that they will take responsibility for learning	Entire iterative group process (Steps A–J)
	Students acquire learning skills	Entire iterative group process (assessed during Steps B, F, J)
	Students cultivate habits of the mind	Entire iterative group process (Steps A–J)
	Students acquire information literacy skills	Independent out-of-class work (Steps C, G)
	Students self-assess their strengths and weaknesses	Feedback, evaluation of session (Steps B, F, J)
	Students engage in self-assessment of their learning	Feedback, evaluation of session (Steps B, F, J)
	Students become self-directed lifelong learners, use metacognitive skills	Entire iterative group process (Steps A–J)
Purposes and purposes of assessment	Students give and receive formative feedback	Feedback, evaluation of session (Steps B, F, J)
	Students engage in self- and peer assessment	Feedback, evaluation of session (Steps B, F, J)
	Students justify the accuracy of their statements	Independent out-of-class work (Steps C, G) Second iteration of problem (Steps D, H)
The balance of power	Problems are open-ended Identification of learning issues is somewhat open-ended depending on student interests and mastery of previous content	First iteration of content discussion (Steps A, E, and I)
	Students help to determine content to be learned	First iteration of content discussion (Steps A, E, and I)
	Students express alternative perspectives	Entire iterative group process (Steps A–J)
	Students realize their opportunities to learn	Entire iterative group process (Steps A–J)

Guidelines are organized according to Weimer's (2002) taxonomy of five dimensions of learner-centered teaching.

section. By careful reading of the results section, students master how to interpret graphs, figures, and tables. PBL students seek out comprehensive reviews and meta-analyses of the literature. Due to constantly discussing content, PBL students learn how to use the vernacular of the discipline they are studying.

The LCT Roles of the Instructor

Many steps of the iterative PBL group process use the five guidelines of the role of the instructor dimension shown in Table 15.1.

States explicitly why the course is using PBL, and the role and responsibilities of the students

Instructors need to give a more detailed orientation on how to succeed in a PBL course than they would in more traditional courses. Orientations may take more than one full class. During orientation and throughout the course, instructors should be available to answer questions about group functioning and how to maximize the learning opportunities.

During this orientation, instructors need to explain the rationale for why the course is using PBL. Knowing that PBL leads to better learning, greater retention of information, increased critical thinking, and development of lifelong learning skills can help students to accept their increased workload and different responsibilities in a PBL course (Felder & Brent, 2016). There are a few ways to explain the rationale for PBL. For example, instructors can play previously recorded short testimonials from former students. Another method that especially works with science students is for instructors to cite research evidence that PBL is a superior way to learn.

Instructors need to be explicit about appropriate roles and expectations. They should model how to perform various steps such as how to develop learning issues, critically evaluate information, and especially how to give feedback in a way that is supportive and constructive. Instructors need to explicitly define the criteria the students should use to assess their peers and to model how to give and receive feedback (Blumberg, 2009). Additionally, instructors should model and encourage good team communication skills. They can show a short video of a well-functioning group performing the various steps of the PBL process, and explain what the students are doing and why it is effective.

Uses teaching/learning methods that are appropriate for student learning outcomes

Such methods include selecting problems, modeling good learning issues, helping students identify appropriate resources, and fostering problem solving. Steps A–J of Figure 15.1 illustrate these appropriate teaching/learning methods.

As with all curriculum development, the process begins with specifying the desired learning outcomes. Next, the instructor brainstorms possible problem scenarios where students can discuss the content to achieve the desired content-related learning outcomes and selects one problem scenario or combines several smaller problem scenarios into a complex problem. Thus, the instructor develops or uses problems that are congruent with the identified, content-specific learning outcomes. The problem should be open-ended enough to allow students to develop and practice problem-solving and critical thinking skills. The instructor may employ techniques, such as embedded questions in the problem write-up that lead students to discuss the desired learning outcomes. Problems may include hypothetical dialogue between a trainee or entry-level employee and a supervisor where the supervisor reminds the trainee about the importance of a specific concept that may not appear so obvious to students. Some instructors write a facilitator's guide to problems that lists the domain-specific learning outcomes and relevant questions to raise to get students to discuss these learning issues (Allen, Donham, & Bernhardt, 2011). Students rotate serving as the facilitator in their groups.

Because poorly defined learning issues can lead to less learning and nonproductive discussions on the second iteration of the problem, an instructor should model well-developed learning issues. The instructor can illustrate well-developed learning issues during the orientation to PBL and can provide a sample problem with appropriate learning issues on the course's learning management system site. Especially with novice PBL students, the instructor should monitor the learning issues the students develop. Students can share their learning issues electronically toward the end of the group session with the instructor or teaching assistant for a quick check on the appropriateness of learning issues.

The instructor can help students develop learning issues that can be researched in appropriate sources. Good learning issues are manageable and defined so that the answer can be found through consulting resources. When students develop a large learning issue, which corresponds to several chapters in a book, they cannot synthesize all of the information and use it meaningfully in the next group discussion. Learning issues that are vague or too broad result in students being overwhelmed by how much they must research. In the health professions, where they are learning evidence-based decision making, students are encouraged to develop PICO questions. PICO stands for Patient problem or Population; Intervention of what the caregiver plans to do, i.e., diagnostic test or treatment; Comparison to an alternative intervention; and expected Outcome that the intervention might achieve. "For a patient with Tetracycline staining, will chair-side (ZOOM) bleaching as compared to over-the-counter White Strips decrease staining and increase tooth whiteness" (University of Southern California Health Sciences College, n.d.) is an example of a well-defined PICO question for which students should be able to find the answer by reading research studies or a summary of the literature. PICO questions can be adapted for other disciplines.

Problem-solving skills are common PBL student learning outcomes. Inquiry approaches, including PBL, which are derived from the Socratic Method emphasize the interconnectedness of knowledge acquisition and problem solving (Kelson, 2000). Instructors can foster the development of problem-solving skills in several ways. How the problem is constructed can encourage students to generate hypotheses, question assumptions, and reason logically (Blumberg, 2007; Felder & Brent, 2016). As instructors rotate through the class, working with specific groups, they can pose challenging, problem-solving questions.

Creates a supportive environment for learning to occur

Throughout the course, but especially in the beginning, the instructor must establish a supportive and safe environment for students to express alternative perspectives, raise hypotheses that are not correct, expose their lack of understanding, and trust other group members. Scaffolding can create a supportive environment for learning to occur. Most students become competent with most steps of the small-group process within a month (Blumberg, 2007). Comfort with giving and receiving feedback may take longer (Figure 15.1, Steps B, F, and J) (Weimer, 2013; Westberg & Jason, 1996).

Novice PBL students have steep learning curves because it is such a change from what they normally experience in more instructor-centered courses (Blumberg, 2007; Felder & Brent, 2016). Beginning PBL students are inefficient with the small-group process. Therefore, instructors may allow students to take more time with the first problem. Instructors may check in with all of the students more frequently and provide opportunities to seek the instructor's guidance more often in the beginning. Since they need to take much more responsibility for their learning, trust and work well in groups, beginning PBL students often experience discomfort, anxiety, and frustration with the process and their own ability to succeed (Blumberg, 2007; Felder & Brent, 2016). The instructor's role is essential in helping students become skillful and confident PBL learners as well as addressing these concerns directly. Citing evidence from previous students or the research literature often helps students to overcome their anxieties and assure them that the process works. Being explicit about roles and responsibilities helps to create a supportive environment for learning to occur.

An outstanding student in her first course in an entire PBL Master's degree program in public health came to the author after about a month of school to say that she was considering withdrawing from the program. Her reply when asked why was that the program was too much work and she was not able to keep up. Further conservation revealed that she was researching all of the learning issues for her group because she never trusted her peers to do a good job. The author convinced her to test whether her peers were indeed doing sufficient research to answer the questions and to begin trusting them. At graduation, she thanked the author for helping her to become a team player and to develop trust in her colleagues; she indicated that she knew she would need these cooperative skills and attributes in her career.

Uses activities involving student, instructor, and content interactions

Successful group discussions are predicated on instructors scaffolding students' engagement with the content and knowledge construction (Allen et al., 2011). Instead of giving information, instructors ask challenging questions, which require deep learning, critical thinking, and problem solving, to facilitate discussions (Hmelo-Silver, Duncan, & Chinn, 2006). Instructors also monitor group progress. They provide the scaffold for learning to occur even when the class size is so large that they cannot effectively listen to conversations in every group. Groups can give their instructor short summaries of their discussions. Students can take pictures of their documentation of group discussions and send them to the instructor. With large classes the instructor may have periodic meetings with group representatives to check on group functioning. This close monitoring is more important for novice groups and when groups are not performing well (Blumberg, 2007).

When an instructor recognizes that many groups are stuck and a little direct instruction would help, the instructor may call the class together and give a 5–10-min spontaneous informal presentation on a specific topic. An instructor can also assemble the entire class together briefly to check on their progress, ask critical thinking questions, and determine the level of understanding. These plenary sessions are effective toward the end of the first iteration or in the middle of the second iteration of the problem but are not shown in Figure 15.1 as they are not essential parts of the PBL group process. These sessions can also be used as a way for the students to attain closure on a problem.

If the entire curriculum uses PBL, students can fall into a pattern of how they discuss problems. To help break away from their usual routine and especially to assist groups where everyone does not contribute evenly, the instructor can suggest students rotate assuming different roles each session. Common roles include facilitator, devil's advocate, questioner, critic, summarizer, and recorder. Roles that require active listening and responding to others and not just adding new points include connector, appreciator, paraphraser of others, and umpire (Brookfield, 2013; Brookfield & Preskill, 1999).

The instructor can encourage students to visualize their collective knowledge by creating tables, diagrams, or concept maps (Novak, 1998). When people transform verbal knowledge to pictorial representations, they form additional associations with the content, while showing that they understand the content. Graphic representations force people to apply the content to a different context. A flow diagram can illustrate mastery of the inherent logic or progression in a cycle. Concept maps show the hierarchy of concepts. Compare and contrast matrices can help students to see the relationship among concepts. When students use these visual representations, they are engaging in critical thinking and problem solving.

Motivates students to learn

The small-group PBL process inherently motivates student to learn because the students identify what they need to learn themselves. Peer pressure or the desire not to be embarrassed in a small group fosters students to come prepared and to participate (Blumberg, 2007). Furthermore, an instructor can intrinsically and extrinsically motivate students to learn through their orientation to PBL, debriefing at the end of each session (Figure 15.1, Steps B, F, and J), and grading group and individual assignments (Felder & Brent, 2016).

Group assignments can motivate student learning. Prior to the first class the instructor should assign the students to groups and not let the students form their own groups (Felder & Brent, 2016). Generally, these groups stay together for the length of the course, i.e., a term or semester. The ideal size for these groups is five to six members to sustain discussions and to allow for diverse opinions (Westberg & Jason, 1996). With larger groups, such as above eight students, it is easy for lazy or unprepared students to hide and it is hard for all students to contribute. General rules for forming groups apply to PBL groups: try to avoid forming groups where one student is different from the rest of group such as one older, nontraditional student or one student of color (Felder & Brent, 2016). In these groups, the token student may feel a lack of comfort or constantly be asked to represent their identity group. For example, the single veteran may feel compelled to always express the feelings of veterans.

To maximize learning, the author likes to assign students to groups according to their abilities or achievement using the following rules: divide the class into thirds based upon overall GPA, SAT, or ACT scores for first-year students, or grades in a prerequisite course, or grades on a difficult presemester quiz. As much as possible, considering the suggestions in the previous paragraph, try to group the top third together. Top students get frustrated with unmotivated or unprepared students at the bottom of the class. High-performing students enjoy having similarly motivated and bright students in their groups. Next assign a few students from the middle third and a few students from the bottom third into their own groups. The rationale for putting these average and weaker students together is that those at the middle or bottom recognize the talent in the top performers and often let them do most of the group work in more heterogeneous groups. Sometimes the students who are in the bottom two quadrants improve their overall performance because they cannot hide in small more homogeneous groups. The instructor should spend more time with the average and weaker students. Of course, the instructor needs to monitor all the discussions and make sure all groups are challenging each other and engaging in critical thinking. This system works best when students are not part of a cohort of students and when different students come together in a course so that they do not know who the best and worse students are.

A review of the research on group functioning supports this ability-based grouping in college students (Cohen, 1994). For complex problem-solving tasks, such in PBL, giving explanations fosters learning for all students, but especially for the student doing the explaining. Generally high-achieving students offer the most explanations. The medium-achieving students often do not benefit as much as the poorer performing students in these groups because they do not take on the responsibility for giving explanations, instead allowing their top performers to do the heavy lifting. However, Cohen (1994) found that if a group is composed of the bottom two-thirds of the achievers, the medium achievers rise to become the group's explainers.

In cohort curricula, instructors can check with faculty members who taught these students before. They can provide insights into how individual students function in groups as well as students who do not work well together. While one of the functions of the group discussions is for students to learn to work with different people, individual conflicts can impede learning. Learning is, after all, the major purpose of the group process. Try to separate students who strongly dislike each other at least for one semester. Groups should be reassigned each semester, otherwise students remain in their comfort roles and do not learn different ways to work (Felder & Brent, 2016).

CATME (Ohland et al., 2014) is an easy to use online tool to form groups. This program lists many criteria for group formation. The instructor picks the relevant criteria and the program develops the groups. If the instructor tells the class that the groups were selected by a computer, complaining about who is in their group is reduced. This online tool also has peer assessments that are useful.

Because the roles of PBL instructors are so different from traditional didactic dissemination of information, instructors need to learn and gain confidence with PBL instructional methods. Even after training, it takes time and reflection on teaching behaviors to becoming skilled PBL facilitators. Perhaps the hardest role to learn is not to jump in when students are struggling and not to be too directive (Felder & Brent, 2016).

Responsibility for Learning

Through the PBL iterative process described earlier, students become very proficient taking responsibility for learning. Table 15.1 notes seven design guidelines that foster this responsibility. When students are in charge of their learning, they take their education more seriously and learn more than when instructors take greater responsibility for student learning (Weimer, 2013). Instructors play an active role in facilitating these design guidelines by explaining and modeling these skills and practices. They also give students feedback on how well they are acquiring these attributes.

Students have expectations that they will take responsibility for learning

Students learn that they need to proactively take responsibility for their learning during the orientation to PBL and when the instructor explicitly describes student roles and responsibilities. Three essential iterative steps in the PBL process foster students taking responsibility for their learning: identification of learning issues (Figure 15.1, Step A3), the out-of-class learning activities (Figure 15.1, Steps C and G), and self-assessment of their progress in solving the problem (Figure 15.1, Steps B, F, and J).

One technique that helps foster this responsibility as well as improve group functioning is for groups to develop a contract on the first day. This contract lists what students individually and collectively are supposed to do and what happens if group members do not live up to their responsibilities. Students can revisit their contract from time to time, revise it when necessary, and remind individuals who are not fulfilling their responsibility.

Students acquire learning skills

One of the inherent advantages of PBL over more didactic education is that it fosters the development and constant use of learning skills. The iterative group process of PBL nurtures the acquisition and mastery of these learning skills. Learning skills include time management, independent reading, access and evaluate information (discussed later in the section on information literacy), self-monitoring (discussed in the section on self-assessment), and judging (self-evaluation) when they have answered a question adequately or have gained enough knowledge or understanding to move on to new material. All of these learning skills are interrelated within the PBL process shown in Figure 15.1.

Students need to manage their time both within the group sessions and outside of the group meetings. In the beginning, students spend more time with each step, but soon learn how to be efficient. Given the huge amount of information readily available today, students need to learn how to decide what to read and how much time to devote to independent reading. Proficient PBL students can become so facile with these learning skills that they use them automatically.

Researchers have identified three approaches to learning (surface, deep, and strategic learning); but only deep learning always leads to enduring mastery and long-term retention of the content (Weimer, 2013). With surface learning, students memorize content often exactly as presented. They have not created their own meaning of the material and have not formed many associations with it. The surface approach often leads to short-term learning, and may be sufficient to get good grades on low-level multiple choice tests. However, students may not be able to use the material in new settings. With a deep approach to learning students make their own meaning of the content by putting ideas into their own words, applying the content to new situations or solving problems using the content. Instead of memorizing, students conceptualize the material by building models. Deep learning fosters a change in the way students see the real world (Weimer, 2013). Research conducted at various institutions in different cultures indicates that PBL students use more deep approaches than traditional students (Blumberg, 2000; Weimer, 2013). The strategic approach to learning is an adaptive tactic in which students will do what they need to do to meet expectations so as to get good grades. This approach is combined with either surface or deep learning, depending on the course requirements. With PBL, the strategic approach employs many of the learning skills discussed here.

Students cultivate habits of the mind

Habits of the mind provide people with skills to succeed in real-life situations, work with other people by allowing them to take another person's perspective, and solve everyday problems by thinking flexibly. Costa and Kallick (2008) identified 16 habits of the mind (see http://www.chsvt.org/wdp/Habits_of_Mind.pdf). PBL students master the majority of them throughout the PBL process. As a consequence of students practicing habits of the mind, they become more responsible learners. As the name implies, once they become habits, they tend to be used regularly. Using these habits also helps to foster success after graduation.

Students acquire information literacy skills

To research learning issues effectively (Figure 15.1, Steps C and G), students need to have information literacy skills. Successful PBL group discussions are predicated upon the mastery of the skills used in the five standards of information literacy in higher education: (a) determine what information is needed; (b) access this information effectively and efficiently; (c) critically evaluate the source of information and the information itself; (d) use information effectively to accomplish a specific purpose; and (e) access and use information ethically and legally to demonstrate understanding the economic, legal, and social issues surrounding the use of information (Association of College and Research Libraries, 2000). Furthermore, students need to learn how to distinguish when they need to read primary, secondary, and tertiary sources and how the information and currency of the information varies in these resources. Today's students need to be encouraged to refer to textbooks for material that is factual or has been known for a while and not immediately go on the web or to Wikipedia. Probably one of the hardest information literacy skills to learn is how to assess the bias of the author and determine if this partiality influences the objectivity of the information given. This is especially true when reading popular online websites. Instructors or librarians can teach students these information literacy skills.

Students self-assess their strengths and weaknesses

The purpose of this self-assessment is to gain insight to foster growth. During the feedback and debriefing at the end of sessions within their groups (Figure 15.1, Steps B, F, and J), students should verbally assess their strengths and weaknesses including how well prepared they were, how they functioned within the group, and their problem-solving and communication skills. While people gravitate to their strengths, students must be encouraged to work on their weaknesses. The PBL group should be a low-risk environment where students can try new roles and do uncomfortable things. For example, shy or nonconfident students might assume a leadership role within the group discussions. Students who feel uncomfortable with their synthesizing skills can volunteer to be the scribe, group reporter, or at the board summarizing discussions and capturing learning issues. While self-assessment helps students to take responsibility for their learning, it also relates to the purposes and processes of assessment, as discussed later.

Students engage in self-assessment of their learning

Throughout the PBL iterative process students assess their learning and determine what additional learning they require. This assessment involves different learning skills: adequacy of their search for the right sources, how well they are learning from their reading and from each other, how much they remember from previous learning, and how well they can apply their knowledge to new situations. While this is usually discussed during the feedback and debrief part of the group process (Figure 15.1, Steps B, F, and J), students should reflect individually to prepare for these debrief sessions.

Students engage in self-assessment of their learning using metacognitive skills. The PBL group process fosters the use of metacognitive skills, which are the deliberate awareness of cognitive activity or own one's thinking (Schunk, 2016). Table 15.2 lists the five main metacognitive processes and shows where PBL students use them (Ambrose et al., 2010).

Students become self-directed lifelong learners

Candy (1991) described a three-part model of self-directed learning: learning processes, learning strategies, and performance outcomes. Learning processes include defining what to learn, planning and operationalizing learning, and using information literacy skills. In PBL, students define what they should learn by developing learning issues. Learning strategies refer to the methods students use to process information leading to content understanding. Using metacognitive skills, as described earlier, is an effective learning strategy. Performance outcomes are either short term, as occurring during the course, or long term.

Table 15.2 Correspondence Between Metacognitive Processes and PBL Steps

Metacognitive processes (Ambrose, Bridges, DiPietro, Lovett, & Norman, 2010)	**Student roles within the PBL process (steps are listed in Figure 15.1)**
Assess task	Assess problem situation, consider course objectives, learners' goals (Steps A, D, H)
Evaluate current knowledge and skills, identifying strengths, weakness	Evaluate what is known about the problem, what needs to be learned (Steps A, C, D, G, H)
Plan realistic approach	Plan how to solve problem Develop learning issues (Steps A, E, I)
Apply various strategies to enact plan, monitor their progress along way	Solve the problem once armed with additional information Monitor whether they solved the problem, whether they have adequate information and whether they can apply their knowledge to new situations (Steps D, H)
Reflect on degree to which current approach is working, adjust if necessary	Debrief and provide feedback at the end of each session Discuss how well the group is functioning and how well they are learning, and make suggestions for improvement (Steps B, F, and J)

Research shows that the PBL process as defined here fosters the development of both the self-directed lifelong learning processes and learning strategies (Blumberg, 2000; 2007). Additionally, graduates of PBL programs retain knowledge better in the long term than graduates of more didactic programs (Blumberg, 2000; Weimer, 2013). When nonrecent graduates of a traditional medical curriculum were compared to cohorts who graduated from a total PBL curriculum, the PBL graduates were more aware of and used the most recently recommended regimens more than the traditional program graduates (Blumberg, 2000). This finding shows that PBL students having mastered self-directed learning skills continue to practice them long after graduation. The development and mastery of the self-directed learning processes and strategies is one of the universal benefits that students, faculty, administrators, and accrediting agencies recognize as an inherent value to PBL (Blumberg, 2000; Weimer, 2013). The increasing importance of self-directed learning in this information age may explain PBL's increasing popularity in higher education.

Purposes and Processes of Assessment

Table 15.1 identifies three design guidelines that relate to the purposes and processes of assessment. Within the PBL process, learning and assessment are integrated. Learning occurs with assessment and assessment happens throughout the learning process. Students can formatively assess the comprehensiveness of their knowledge and problem-solving skills as they discuss the problems. More structured feedback occurs at the end of sessions (Figure 15.1, Steps B, F, and J) when students provide formative feedback to each other. Adults need to assess themselves and others in their personal and professional lives. However, most people are uncomfortable with this evaluative process. One of the well-recognized benefits of the PBL process is that it gives students many opportunities to give and receive feedback (Weimer, 2013; Zimmerman & Lebeau, 2000). Students can assess themselves and their peers on the skills and performances identified in Table 15.3.

As problem discussions unfold, the students justify the accuracy of their statements when they express their own perspective as informed by their reading and discussions. Students learn to attribute ideas to others and must represent others' ideas accurately. Some students confuse facts with views. Throughout these discussions, students challenge each other to accurately convey information and to distinguish proofs from rough estimations or opinions. Especially in the scientific disciplines, students should use evidence-based decision making. This decision-making process requires that students justify the accuracy of their statements and offers opportunities for formative assessment.

The Balance of Power

In the PBL process, students assume greater power or control over their own learning than they would in didactic classes as Table 15.1 shows. When the instructor fosters a supportive environment and students accept responsibility for their learning and group functioning, this balance of power occurs naturally and comfortably.

While the instructor scaffolds the overall direction that problems can take by crafting the problem, or giving students objectives for each problem, ultimately the students can also steer the discussion in different directions. The PBL process gives the students the power to determine their own learning issues and how much emphasis they place on specific topics during their discussion of the problem. When students discover that they collectively cannot explain a theory or concept, they create a learning issue, although the instructor may have assumed the students knew the content. Depending on the interests of the students, they may decide to investigate unique learning issues.

Good problems are open-ended enough so that students can engage in discussions with various perspectives expressed. In some disciplines, especially in the social sciences or humanities, some problems may even encourage students to discuss controversial or contradictory ideas. In fact, a desired outcome of successful PBL group functioning is a balance of power where students are empowered to engage in cooperative learning.

Well-functioning groups create and continue discussions on multiple alternatives and keep the dialogue open while maintaining "substantive conflict" (Hmelo-Silver et al., 2006). Groups need to avoid closing down discussions too early, or allowing one forceful member to only consider one possibility (Allen et al., 2011). An example of premature closure on discussion of a medical problem would be when one group member was so convinced he knew the correct diagnosis that he shut down discussion of any other possible diagnoses.

Table 15.3 Appropriate Peer and Self-Assessments of Skills as Used in the PBL Process

A) Skills that are used throughout the PBL process			
Skill	Step(s) in the PBL process that especially focus(es) on this skill (steps are listed in Figure 15.1)	Appropriate use of peer assessment	Appropriate use of self-assessment
Collaborates on problem-solving activities by providing knowledge, insight, and integrating ideas that lead to a solution	Step H	X Students can comment on how helpful peers were to the collaborative problem-solving process	
Develops and uses habits of the mind		X	X
Develops and uses information literacy skills	Steps C and G	X	X
Engages with the content to make own meaning of it			X
Functions effectively in PBL group work, including takes responsibility for tasks, participation and flexibility in roles		X	X
Uses learning skills	Steps C, D, G, and H		X Students often have excellent insights into their abilities to become self-directed learners
Uses metacognitive skills (see Table 15.2)			X
B) Skills that are used in specific steps of the PBL process			
Skill	Where skill is used in PBL process	Appropriate use of peer assessment	Appropriate use of self-assessment
Demonstrates respect for others, especially people with different perspectives or coming from other cultures	Steps A, B, D, E, F, H, I, and J	X Ongoing interactions and observations can reveal subtle lack of respect	
Applies knowledge to problem	Steps A, D, H	X Students are not appropriate summative assessors for determining the accuracy and mastery of knowledge and skills. However, students can provide insights into their abilities	X
Presents ideas clearly	Steps A, C, D, G, and H	X	
Reflects on own strengths and weaknesses and progress	Steps B, F, and J	X Information from peers can inform self-assessment; peers can validate self-perceptions	X
Develops clear written documents	Steps C and G	X	

Adapted from Blumberg, 2009.

When PBL works well, students see the entire process as opportunities to learn. Students can go deeply into specific content and engage in critical thinking and problem solving. They come to group sessions expecting to learn and know that researching learning issues are worthwhile activities (Hmelo-Silver et al., 2006). Students usually take the PBL discussions seriously and attendance is not a concern. With technology, students can attend and participate virtually even if they are sick. When students miss classes, it is usually an indication that something is wrong with the group functioning or the individual student is having personal issues. PBL, as a signature pedagogy within LCT approaches, optimizes the opportunities for students to learn because the one who does the most work does the most learning (Doyle, 2011).

Summary and Conclusion

As this chapter shows, the PBL process is very consistent with LCT. When students identify what they need to know as a result of the group discussions, they see the relevance of content and are motivated to learn it. Since they actively engage in their learning processes and create their own meaning, they are able to use the content in new situations. Intentional design features of collaboration and the group process foster meaningful and lasting learning. The discussion of content also allows students to practice the language and thought process of the discipline being studied. The cooperative learning that is inherent in the PBL group process fosters academic success, increasing retention, and is correlated with positive student attitudes about learning (Springer, Stanne, & Donovan, 1999). The group process supports the development of communication and team skills such as negotiation (Allen et al., 2011). All group members must work together to keep everyone on track (Hmelo-Silver et al., 2006; Johnson, Johnson, & Smith, 1998).

The following evidence-based, learner-centered design guidelines used in PBL foster deep and lasting learning. The instructors should:

- Be explicit about why the course is using PBL, and the roles and expectations of the students.
- Ask students to develop a contract of mutual expectations and group function that fosters students taking responsibility for their learning and maintains good group function.
- Empower students to engage in cooperative learning and realize that the PBL process provides many opportunities to learn.
- Monitor group progress and help to facilitate discussions by asking questions that require deep learning, critical thinking, and problem solving.
- Allow students to struggle with content.

Furthermore, the instructor should encourage and model for students the following design practices:

- Develop good learning issues that are manageable and where the answer can be found through consulting resources.
- Synthesize their research into a brief summary and cite references.

- Give and receive feedback frequently.
- Develop the skills to take responsibility for their own learning.
- Visualize their collective knowledge by creating tables, diagrams, or concept maps.
- Use metacognitive skills including self-assessment of strengths and weaknesses and progress toward goal.
- Cultivate habits of the mind that help students to solve problems by thinking flexibly.

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16

The Role of Self-Directed Learning in PBL: Implications for Learners and Scaffolding Design

Xun Ge and Bee Leng Chua

Introduction

The twenty-first century is characterized by unpredictable changes, rapid growth in technologies, and easy access to a huge corpus of information. Given the context of a rapidly changing world, driven by globalization and technological innovations, learners in the twenty-first century need to develop competencies that allow them to meet the needs of the current landscape while anticipating emerging challenges (Partnership for 21st Century Learning, 2016). Educational scholars (e.g., Redecker et al., 2011; Scott, 2015; Tan, 2003) contend that education in the twenty-first century is characterized by a fostering of independent lifelong learning, assuming greater ownership of learning, learning how to learn from multiple sources and resources, learning collaboratively, and learning to adapt and solve problems.

The twenty-first-century competencies can be developed through a problem-based learning (PBL) curriculum that is inquiry-based and involves learners working independently and collaboratively to solve authentic real-world problems (Darling-Hammond, 2008). PBL challenges learners to become self-directed learners and problem solvers when teachers are there to facilitate their learning. Previous PBL studies have indicated that learners who went through PBL were better equipped with problem solving, critical thinking, reflective, and self-directed learning (SDL) skills (Barrows & Kelson, 1995; Sungur & Tekkaya, 2006). These empirical findings support PBL as a viable educational innovation to nurture twenty-first-century competencies in our learners, including SDL and problem-solving skills. Though empirical research supports the argument that PBL facilitates the development of SDL, there is still a need to delve into the definition of SDL and its epistemic, cognitive, metacognitive, and motivational demands placed on the learner within the PBL context. This understanding will guide educators and researchers to design scaffolding strategies within PBL to deliberately and intentionally facilitate and support the development of SDL.

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While it is commonly agreed that SDL is an essential competency of the twenty-first-century skill set, coming from a tradition where knowledge acquisition is dependent on the effectiveness of the transmission of information provided by the teacher makes it a challenge to change learners' beliefs and mindsets, and expect them to be self-directed learners overnight (Ovens, Wells, Wallis, & Hawkins, 2011). Therefore, cultivating learners' SDL and changing their perspective about their role in the learning process is at the core of PBL.

In this chapter, we acknowledge the mutual and interdependent relationship between SDL and PBL. PBL is a vehicle for developing SDL, and SDL skills help learners become better problem solvers. Defining the characteristics of SDL and understanding what SDL entails will help us design effective PBL environments that can facilitate SDL development. Thus, we explore the role of SDL in PBL and the role of PBL in SDL as a reciprocal and iterative process, with the ultimate goal of developing confident self-directed learners and creative problem solvers, who are competent to undertake the challenges of twenty-first-century problems. Various demands on SDL in PBL are identified: epistemic beliefs, motivation, cognition, and metacognition, and suggestions are made on using various strategies to scaffold learners in fostering their SDL. In addition, the role of learning technology in developing SDL in PBL is also discussed in terms of changing learners' epistemic beliefs and enhancing their cognitive, metacognitive, and motivational readiness. In conclusion, implications for future research on the role of SDL in PBL are explored.

SDL and PBL

SDL in PBL

SDL is rooted in adult learning theories, with particular relevance to workplace learning. According to Knowles (1975), SDL describes "a process in which individuals take the initiative, with or without the help of others, in diagnosing their learning needs, formulating learning goals, identifying human and material resources for learning, selecting and implementing appropriate learning strategies, and evaluating learning outcomes" (p. 18). In the real-world context of adult learning and workforce development, adult learners need to update their knowledge and master new skills on the job constantly in order to successfully perform their jobs. Therefore, it is crucial that learners take the initiative and self-direct themselves in their learning process.

Knowles (1975) discussed several assumptions about SDL. First, human beings grow in capacity and need to be self-directing as an essential component of maturing; therefore, learners take the initiative in making decisions about their own learning. Second, learners' experiences are rich resources that should be explored along with the resources of experts. Third, learners have different prior experiences and thus their prior knowledge varies; therefore, each individual has a somewhat different pattern of readiness from other individuals in terms of learning what is required to perform their tasks or becoming ready to solve their life problems. Fourth, human beings' natural orientation is task- or problem-centered, and therefore, learning experiences should be organized as task accomplishing or problem-solving projects. Fifth, learners are motivated by internal incentives such as the need for esteem (e.g., self-esteem), the desire to achieve or urge to grow, the satisfaction of accomplishment, and so on. These assumptions about SDL are in direct conflict with traditional learning, in which the teacher determines what to learn and how to learn instead of giving learners the autonomy to decide what they want to learn and using learner experiences as part of learning resources.

Since SDL is a natural process of human development and a way of learning, PBL is an encouraging approach to promote learners' problem-solving experiences and learn from their experiences. PBL is focused, experiential learning organized around the investigation, explanation, and resolution of meaningful problems (Barrows, 2000; Torp & Sage, 2002). In this process, learners are first of all presented with an authentic and ill-structured problem that is relevant to their learning goals. They work collaboratively to analyze the problem by identifying known information and unknown information; they must formulate their goals; they must be able to diagnose their learning needs, what they know, and what they do not know. They must identify and search for needed resources in order to solve the problem. As they acquire a better understanding of the problem, they need to develop an action plan, apply knowledge and skills they have learned, and select appropriate solutions or implement strategies to generate solutions. After completing the problem-solving process they must also evaluate problem solutions and reflect on their learning outcomes and experience. Throughout the problem-solving process, learners should be self-directed, managing their goals and strategies to solve PBL problems, and consequently, they will be able to develop lifelong learning skills as well (Hmelo-Silver, 2004; Sungur & Tekkaya, 2006). Reciprocally, PBL also fosters the development of SDL, which is one of the goals of PBL.

SDL Compared with SRL

SDL is often used interchangeably with the term self-regulated learning (SRL) due to many similarities between the two. Yet, these two concepts originated from two different disciplines and theoretical backgrounds. SDL originated from adult education literature (Kicken, Brand-Gruwel, van Merriënboer, & Slot, 2009), mainly focusing on adult learners and workplace learning, while SRL originated from the educational psychology literature, mainly focusing on learners within a school environment (Loyens, Magda, & Rikers, 2008; Saks & Leijen, 2014). Pintrich (2000) describes SRL as "an active, constructive process whereby learners set goals for their learning and then attempt to monitor, regulate, and control their cognition, motivation, and behavior, guided and constrained by their goals and the contextual features in the environment" (p. 453). This is similar to the definition of SDL whereby learners formulate learning objectives, monitor, and evaluate their own learning.

Despite the similarities between SDL and SRL, SDL is distinguishably different from SRL in that learners are intrinsically motivated, driven by the inner desire to achieve their lifelong goals, and making deliberate effort to gain or retain a defined area of knowledge or a skill, or to change in some other way (Tough, 1971). By comparison, SRL is often studied and described in the context of formal education, in which goals and tasks are usually set by the teacher. Although learners can also be guided by the teacher to set their own goals, the learners' goal in SRL is to manipulate their locus of control in order to achieve the predefined goals by the teacher (Loyens et al., 2008; Saks & Leijen, 2014). Some researchers consider SDL as a macro-level construct and SRL a micro-level construct concerned primarily with processes related to task execution (Saks & Leijen, 2014). In other words, SDL can be considered as a broader construct encompassing SRL as a narrower and more specific construct.

Demands on Learners for SDL in PBL

The components for SDL include cognitive, metacognitive, and motivational strategies, learners' epistemic beliefs of knowledge and nature of knowing, which influence their cognitive, metacognitive processes (Gu, 2016; Hofer & Pintrich, 1997) and motivational constructs (Buehl & Alexander, 2005; Mellat & Lavasani, 2011; Ricco, Pierce, & Medinilla, 2010). Chua's (2013) research on teacher education provided evidence that the collective set of beliefs, cognitive, metacognitive, and motivational strategies possessed by individual preservice teachers was crucial for determining how much one can benefit from PBL. The sections below discuss the epistemic beliefs as well as the motivational, cognitive, and metacognitive demands for SDL in a PBL context.

Epistemic Beliefs

PBL represents a paradigm shift in how learners view knowledge, learning, and instruction. Evidence shows that mindset change for learners is the primary concern in successfully carrying out PBL beyond the surface level. As Ovens et al. (2011) pointed out, learners often hold the consumers' view that learning is dependent on the effectiveness of the instructors' transmission, and it is the instructors' responsibility to deliver the information in better ways. When presented with ill-structured problem scenarios, which contain vague goals, insufficient information, and numerous constraints (Jonassen, 1997), learners often feel lost or helpless because they have been so used to being spoonfed through lectures and note-taking, as they have experienced in traditional learning environments. In an ethnography study of a group of graduate learners in a PBL computer science course, Ge, Huang, and Dong (2010a) noticed that some learners were concerned about the lack of paper–pencil examinations, what they perceived as progress tracking, and they did not consider the professor's constant monitoring and coaching on their projects and his formative feedback in the open learning environment as a form of assessment. Some learners indicated that they did not know how they were doing in this class due to a lack of test grades. Learners' perceptions about PBL subsequently affected their motivation and attitudes, which in turn influenced their volition for SDL and problem-solving performance in the PBL (Ge et al., 2010a). This is only one of the empirical studies indicating the issue of misalignment between students' epistemic beliefs and PBL expectations, which forces us to look into the influence of learners' epistemic beliefs in PBL.

Epistemic beliefs are learners' beliefs and thinking about the nature of knowledge and knowing, what knowledge entails, and how knowledge is constructed and evaluated (Bromme, Pieschl, & Stahl, 2010; Hofer & Pintrich, 1997; Pintrich, 2002). Several theories examine learners' level of epistemological development, including Baxter-Magolda's stages of epistemological reflection (Baxter-Magolda, 1987) and Perry's levels of intellectual development (Perry, 1970). According to Baxter-Magolda (1987), the levels of epistemological reflection progress from *absolute knowing*, where knowledge is fixed and obtained from authorities, to *transitional knowing*, where knowledge is partially fixed and needs understanding through research, reasoning, and deliberation, to *independent knowing*, where knowledge is not fixed and requires independent thinking, to the final stage of *contextual knowing*, where knowledge is contextualized. Perry's (1970) classification of intellectual development levels starts with learners having the dualistic view of knowledge, where it is a collection of facts and it is viewed as being right or wrong, to the relativistic view of knowledge, whereby it is fluid and not absolute. From the learning perspective, the development stages start with learners being a receiver of knowledge from sources of authority to learners assuming, affirming, and committing to the role of knowledge creator.

Prior studies have indicated that learners' epistemic beliefs of knowledge and nature of knowing influenced their cognitive processes of thinking, reasoning, and construction of arguments during their inquiry process (Gu, 2016; Hofer & Pintrich, 1997). Specifically, there seems to be a positive relationship between sophisticated and developed epistemic beliefs and SDL that requires the use of cognitive and metacognitive strategies (Choi & Park, 2013). Schommer and Hutter (2002) found that learners with more sophisticated epistemic beliefs used more appropriate learning strategies, justified their claims with solid evidence more effectively than their peers, and had higher academic achievement. Shin and Song's (2015) research indicated that learners with more advanced epistemological beliefs were better on solution development and monitoring and evaluation of their own learning. These empirical studies seem to argue that the level of sophistication of student's epistemological beliefs is related to cognitive style and learning strategies (Shin & Song, 2015; Songer & Linn, 1991).

In addition, research studies have shown that epistemic beliefs have direct effects on motivational constructs such as self-efficacy, task value, and interest (Mellat & Lavasani, 2011; Ricco, Pierce, & Medinilla, 2010). Specifically, according to Buehl and Alexander (2005), learners with more sophisticated beliefs had higher levels of motivation. As such, this points to an important understanding that the cognitive, metacognitive, and motivational scaffolds provided by educators within the PBL environment may be interpreted and used to benefit learners differently according to the different levels of sophistication of learners' epistemic beliefs.

Motivational Demand

Apart from epistemic beliefs, one must be motivated to use the strategies to regulate one's cognition and effort (Pintrich, 1988, 1989; Pintrich, Cross, Kozma, & Mckeachie, 1986) as a demand to fulfill SDL requirements. Motivation is defined as the force that energizes, guides, and sustains behaviors (Ormrod, 2011). The process of actively regulating one's cognition and effort, such as identifying and setting learning goals is an important process of SDL (Loyens et al., 2008), which is "the preparedness of a learner to engage in learning activities defined by himself or herself" (Schmidt, 2000, p. 243).

According to Ferrari and Mahalingam (1998), learners are motivated to learn when they value what they are learning and when learning tasks are meaningful. In addition, intrinsic motivation occurs when one is engaged in a task that is driven by one's own interests, challenges, and sense of satisfaction (Hmelo-Silver, 2004). When learners are tasked to solve problems that are relevant, interesting, and challenging, they are engaged in mastery goals rather than performance goals (Elliot & McGregor, 2001). With the focus on mastery goals, learners develop a deep understanding of the task, content, and skills acquired and this will facilitate the transfer of knowledge to another learning context and thus enhance the learners' level of self-directedness in their learning. Learners are also more motivated to learn when they believe they can control the outcome of their learning, which is clearly evident in PBL where the problem scenario provides the proximal and tangible goal of applying their knowledge to solve a real, concrete problem (Bandura, 1997). It is thus pertinent for us to look into the motivational aspect for SDL within the PBL context.

The self-determination theory (Deci & Ryan, 2000) indicates that three basic psychological needs must be satisfied for learners to be intrinsically motivated: *autonomy*, *competence*, and *relatedness*. Learners must have the sense of autonomy, that is, internal perceived locus of causality. Competence refers to feelings of competence (i.e., self-efficacy) during a task, which can enhance intrinsic motivation for that task. Relatedness refers to sense of belongingness, connectedness to others. It is, therefore, important to create a learning environment that allows learners to experience autonomy, competence, and relatedness. Furthermore, expectancy-value theory (Wigfield & Eccles, 2000) suggests that learners' achievement is mainly determined by two factors: expectancies for success and subjective task values. Expectancies for success are defined by a learner's beliefs about their ability in performing in an upcoming task, which Bandura (1997) defined as self-efficacy. Task values include *attainment value* (i.e., the importance of doing well in a given task), *intrinsic value* (i.e., enjoyment one gains from doing task), and *utility value* (i.e., usefulness, such as how a task fits into a learner's future plan). According to expectancy-value theory (Wigfield & Eccles, 2000), learners' perceived values interact to predict important outcomes, such as engagement, continuing interest, and academic achievement. Both self-determination theory and expectancy-value theory point to the essential need to engage learners in a SDL environment, where learners feel a sense of autonomy, belongingness, and relatedness, value their learning tasks, and feel supported in achieving their learning goals.

These motivation theories propose motivational demands for learners' SDL in PBL, including (a) sustaining their interest and desires for problem solving, (b) exercising their autonomy for problem solving, (c) believing in their abilities to perform learning tasks satisfactorily, (d) seeing value in their problem-solving tasks, and (e) striving for deeper learning rather than the want to outperform others (Deci & Ryan, 2000; Wigfield & Eccles, 2000).

Cognitive and Metacognitive Demands

PBL is an inquiry approach to learning that is organized around the analysis, validation, and resolution of context-rich and authentic problems (Torp & Sage, 2002). The development of effective problem-solving and self-directed skills includes nurturing the ability to apply appropriate cognitive and metacognitive strategies (Hmelo-Silver, 2004). According to Bassok and Holyoak (1993), this hypothesis-driven learning approach in PBL may influence how learning takes place. With this approach the learners need to tap on their prior knowledge and have awareness of what they know and do not know. Cognitive and metacognitive learning strategies are used to analyze problems, identify learning issues, and set learning goals. Learners will pace their learning, employ appropriate learning strategies, and acquire new knowledge to solve the problem presented to them. In this process, they need to monitor and evaluate their learning in terms of their learning objectives. This process makes their cognitive and metacognitive processes visible to themselves, peers, and facilitators. It allows monitoring and evaluation of learning, which is pivotal for SDL and effective transfer of knowledge and learning strategies to new situations. The study conducted by Chua, Tan, and Liu (2014) suggested the need for learners to engage in dominant cognitive functions, such as looking from different perspectives, generating ideas, making connections, and synthesizing their learning throughout the PBL process. It is pivotal that learners understand and are able to employ these cognitive strategies across the PBL cycle, which facilitates the development of SDL among the learners.

SDL places a great demand on learners' metacognition. Long (2000) emphasized the important role metacognition plays in SDL. He indicated that when learners are self-directed in their learning, they are aware of the important aspects of the cognitive processes employed in learning and thus actively resorting to metacognition. On the other hand, we argue that when learners are more metacognitive by being self-aware and self-regulatory in their PBL process, their SDL skills are more enhanced or developed. Such metacognitive processes are required for solving ill-structured problems (Ge & Land, 2003) in PBL where learners not only initiate learning, but also determine learning goals and make decisions on what to learn and how to learn, which are part of the metacognition required by SDL (Savery, 2006).

As discussed earlier, SRL is a micro-component of the broader SDL. In order to develop SDL, the learner's awareness of their learning and the conscious effort of self-regulation must be facilitated and reinforced. Therefore, principles and strategies for supporting SRL are useful and applicable to designing scaffolds to support the broader SDL process. Scaffolds designed to support students' goal setting, planning, monitoring, and evaluating of learning progress, which run through the entire problem-solving process (Zimmerman & Campillo, 2003), are an important component of PBL.

Scaffolding SDL in a PBL Environment

PBL situates learners in authentic, unstructured, and complex problems. Such a complex problem-solving process requires scaffolding to assist learners in making their thinking visible, managing their inquiries, and evaluating and reflecting on their learning (McLoughlin & Luca, 2002; Quintana et al., 2004). Scaffolding is traditionally defined as the process whereby a teacher or a more knowledgeable other provides cognitive and motivational support to allow learners to complete tasks that would otherwise be difficult (Wood, Bruner, & Ross, 1976). It is well documented that scaffolding has always been considered a major component of the PBL environment (Barrows & Tamblyn, 1980).

Researchers have recognized that learners often experience problems with PBL, leading to adaptation difficulties or resistance to the approach (Nolan & Nolan, 1997a, 1997b; Slevin & Lavery, 1991) due to a lack of SDL skills (Kicken et al., 2009). Instructors working with PBL often assume that learners already possess SDL skills or they will simply develop those skills in a PBL environment that requires them to direct their own learning (Kicken et al., 2009). Kicken et al. (2009) argued that in the early stages of PBL, it is critical that learners are supported in the development and use of SDL skills. It almost seems to be a catch-22 dilemma: PBL develops SDL skills while these skills are required to successfully engage in the PBL experience. Indeed, we understand the dilemma but we also note the reciprocal relationship between PBL and SDL. The ultimate goal of PBL is to develop SDL and problem-solving skills, as well as other twenty-first-century skills. In this chapter, we suggest scaffolding guidelines that are design principles in a PBL environment to develop learner's SDL. The scaffolding is specifically discussed in terms of motivational, cognitive, and metacognitive scaffolding, as well as management of epistemic beliefs.

Scaffolding Change in Epistemic Beliefs

Through their design of learners' learning environments, strategies, and activities, as well as their mediation of learning, instructors need to facilitate a change in learners' epistemic beliefs on the nature of knowledge and knowing. According to Buehl (2003), the five core beliefs are *structure of knowledge*, *stability of knowledge*, *sources of knowledge*, *nature of knowledge acquisition*, and *ability to acquire knowledge*. Instructors need to provide opportunities and space for learners to explore their beliefs surrounding (a) structure of knowledge (e.g., Is knowledge simple or complex? Compartmentalized or connected?), (b) stability of knowledge (e.g., Is knowledge unquestionable and definite or not fixed?), (c) sources of knowledge (e.g., Does knowledge arise from personal experience or from external sources?), (d) nature of knowledge acquisition (e.g., Is the process of acquiring knowledge gradual or instantaneous? Is it effortless or does it require hard work?), and (e) ability to acquire knowledge (e.g., Can this ability be developed over time or is it fixed?) (Buehl, 2003; Buehl & Alexander, 2005). Essentially, there is a need to facilitate a shift in learners' beliefs regarding the stability and nature of knowledge, to understand that knowledge can be certain or tentative, and that as well as it being "given" to them, they can actively construct their own knowledge. The valuing and internalization of what learning encompasses, together with a focus on learners' roles as active learners taking responsibility for their learning process (Lieux, 1996), are all necessary for PBL. It is also essential that learners understand the complexity of knowledge and believe that their ability to acquire knowledge can be developed over time and with experience.

Specifically, according to Perry (1970), learners have reached a higher level of epistemic beliefs when they accept multiple perspectives on information sources, see the need for the sources to be critically examined, view knowledge as contextual, accept themselves as one among many legitimate sources of knowledge, perceive knowledge as relative, and accept the responsibility and commitment to make judgments and decisions. Such a level of epistemic beliefs is the goal we should aim at when facilitating learners' SDL. Suggested approaches to scaffold learners' epistemic developments include providing opportunities for them to articulate their learning intentions and goals, requiring them to evaluate and justify the reliability and validity of information sources, asking them to substantiate their judgments and decisions, and allowing them to question the contextual and cultural assumptions, beliefs, and history of information sources (Jonassen & Marra, 2004). Table 16.1 presents specific guiding questions and scaffolding foci for epistemic beliefs to facilitate SDL in PBL.

Motivational Scaffolding

The characteristics of PBL enhance learners' motivation in learning. These characteristics include (a) the authenticity of the problem to trigger interest, challenge, and curiosity (Belland, Kim, & Hannafin, 2013; Chua, 2013; Parsons & Ward, 2011), (b) the perceived value and meaningfulness of the task presented (Belland, Ertmer, & Simons, 2006; Chua, 2013), (c) autonomy bestowed to the learners by allowing multiple solutions to be presented through viewing the problem in multiple perspectives and giving learners the ownership to formulate learning objectives throughout the whole inquiry process (Belland et al., 2013; Deci & Ryan, 2000; Ryan & Deci, 2000a, 2000b), and (d) the collaborative nature of PBL, which fosters the feeling of belonging and relatedness among the learners as well as the tutor (Deci & Ryan, 2000; Osterman, 2000; Ryan & Deci, 2000a, 2000b).

Indeed, the theoretical promises of PBL demonstrate its potential to intrinsically motivate learners in their learning. However, more often than not, the complexity and unstructured nature of the problem overwhelm learners, cause frustration, and foster the feeling of incompetence, all of which impede learning (Chua, 2013; Tan, 2003). Thus, a considerable amount of thought and effort must be put in by PBL educators to scaffold the affective and motivational engagement of learners, especially in the arena of self-directedness within the PBL environment, which is more often than not being ignored.

Motivational scaffolds for self-directedness within PBL can include (a) intentional crafting of the problem scenario to trigger relevance and meaning (Hung, 2008), (b) strategies to establish perceived task value (Hung, Bailey, & Jonassen,

Table 16.1 Guiding Questions for Designing Scaffolds to Address Various Demands in Epistemic Beliefs, Motivation, Cognition, and Metacognition to Facilitate SDL Within the PBL Environment

Demands	Guiding questions	Scaffolding foci
Epistemic beliefs	• What are learners' beliefs and understanding of knowledge and learning prior to their SDL within a PBL environment? • Is knowledge a collection of facts that is either right or wrong? Or is knowledge contextualized and there are multiple perspectives to it? • Is our learners' role that of a knowledge receiver or a creator of knowledge? • Do our learners claim their authority and accept themselves as one among many legitimate sources of knowledge?	• Ascertaining learners' level of epistemic development prior to their SDL to determine the strategies used to advance the level of sophistication in their epistemic beliefs • Facilitating learners' development to a higher epistemic belief by – Allowing learners to analyze the problem scenario from multiple perspectives – Guiding learners to question contextual and cultural assumptions when analyzing the scenario – Empowering learners to formulate learning objectives based on their perspectives – Necessitating learners to justify the reliability and validity of their information sources and substantiating their judgments and decisions
Motivation	• Can the problem scenario trigger learners' interest, challenge, and curiosity? • Do the learners see the meaningfulness and the relevance of the solving the problem scenario? • Can we empower learners to own their learning? • Do the learners feel competent in their SDL journey? • Do we foster the feeling of relatedness among the team members as they work to solve the problem presented? • Do we stimulate positive emotions such as sense of satisfaction and being comfortable working as a team, and minimize negative feelings such as being stressed or overwhelmed?	• Crafting problem scenarios that are interesting, meaningful, and relevant to their current and future life applications • Guiding learners to an aspect of the problem that they are curious about and passionate to solve • Empowering learners to formulate their learning objectives and exercise autonomy to direct and document their problem-solving process • Facilitating the feeling of competence by – Providing feedback regularly on their SDL progress toward achieving their learning goals – Affirming their efforts and achievements at different PBL stages throughout their problem-solving journey • Fostering the feeling of relatedness among the team members by – Allocating time for ice-breakers activities for the team members to know each other better – Emphasizing the value of collaboration for deep learning rather than competition whereby effort is spent to outperform each other

Table 16.1 (Continued)

Demands	Guiding questions	Scaffolding foci
Cognition and Metacognition	• Is the problem scenario too complex and ambiguous for our learners? • Are the learners able to tap on their prior knowledge to identify what they know and do not know? • Do the learners possess the cognitive and metacognitive learning strategies to analyze the problem scenario, identify learning issues, set learning goals, and thus self-direct their own learning? • Do the learners possess the cognitive and metacognitive abilities to make judgments and decisions in their problem-solving process and evaluate their own learning?	• Considering learners' prior knowledge and their cognitive and metacognitive abilities to determine the level of complexity and ambiguity of the problem scenario • Assess learners' readiness for PBL and help them with needed preparation for the upcoming SDL activities • Pacing learning activities using question prompts at each PBL stage to facilitate SDL. For example, at the problem presentation stage, question cues include "What are your thoughts on the scenario?," "What are the facts and assumptions you identify from the scenario?" • Designing templates such as the KNL chart "(What do you **KNOW**," "What do you **NEED** to know and "**LEARNING** issues)" to scaffold learners' thought process and identify fundamental resources to guide learners' SDL • Nurturing learners' metacognition through their reflection on their SDL process

2003), (c) efforts to promote mastery goals (Belland et al., 2013; Elliot, 2005), (d) approaches to develop and strengthen the feeling of competence (Deci & Ryan, 2000), (e) strategies to facilitate learners' autonomy and sense of ownership, (f) efforts to sustain learners' interest and engagement in learning (Hung, 2011), and (g) processes to stimulate positive emotions and minimize negative feelings (Smith & Cook, 2012; Sulaiman, Atan, Idrus, & Dzakiria, 2004). For example, according to Belland et al. (2013), scaffolding strategies to establish task values include helping learners see the relevance of solving the problem at hand to their current and future life applications (Su & Reeve, 2010) as well as guiding learners to select an aspect of the problem that they are curious about and passionate to solve (Palmer, 2009; Patall, 2013). In order to strengthen learners' ownership of learning, opportunities can be given to them to identify their learning goals and exercise their autonomy to direct and document their thought processes (Loyens et al., 2008). In addition, this visibility of learning processes allows learners to chart their journey toward the attainment of their learning objectives, and provides concrete evidence of their progress and growth, thus increasing their feelings of competence. To promote positive emotions, instructors should emphasize collaboration rather than competition, promote the feeling of relatedness among learners (Deci & Ryan, 2000), and highlight the importance of deep learning rather than the need to outperform their peers. Table 16.1 presents specific guiding questions and scaffolding foci for motivational scaffolding to facilitate SDL in PBL.

Cognitive and Metacognitive Scaffolding

In PBL, learning is driven by rich, authentic problem scenarios with appropriate levels of complexity. Such problems trigger process and allow learners to reflect on the challenges and complexity of real-world problems within the safety of their classrooms. However, it is noteworthy that learners may be overwhelmed by the complexity of the task presented, and learning may be hindered by the limited processing capacity of the individual human mind, which may cause frustration that could interfere with learning (van Merriënboer, Kirschner, & Kessler, 2003). To facilitate learning, scaffolding must be put in place to intrinsically motivate learners and provide needed guidance to help them accomplish the tasks that would have been impossible without scaffolding. Contrary to the belief that PBL is an unguided approach to learning, the schema of PBL process represented by the iterative PBL cycle provides guidance to learners by breaking down the problem-solving processes into different PBL stages. This allows learners to focus on different components of the tasks, which are relevant to the learning objectives at each PBL stage (Hmelo-Silver, 2006). Thus, problem solving becomes more manageable to learners.

Cognitive and metacognitive scaffolding of SDL occurs through the use of various strategies, such as question prompts, resources, templates, and technology-enhanced cognitive tools at every stage of PBL. These scaffolds provide learners with mental support and guidance for the cognitive and metacognitive processes during PBL inquiry and knowledge creation process. They also force learners to focus on important problem-solving processes such as problem representation, generating solutions, constructing argumentations, monitoring, evaluation, and reflection (Ge & Land, 2003).

Question prompts have been well documented to scaffold learners' cognitive and metacognitive processes during PBL (Ge & Land, 2003, 2004). The expert's way of thinking is made visible through questioning, which is an effective way to model SDL skills and problem-solving strategies to learners (Hmelo-Silver & Barrows, 2006). To scale down the complexity of the problem presented, question prompts, such as "What are your thoughts on the scenario?," "What do we already know and what do we not know about the problem?," "What are the primary problems?," and "How do you define the goals?" can be presented to the learners. These question prompts help learners establish facts, question assumptions, and structure thoughts. Similarly, during the "Discovery and Reporting" stage of PBL, question prompts such as "Describe what you have found…," "Elaborate on what you have learned…," and "How would you connect what you learned to…" can facilitate learners to make connections and synthesize knowledge they have acquired. Through questions, learners are forced to organize information and elaborate their thoughts in search of answers. In a question–answer cycle between the facilitator and the learners, which van Zee and Minstrell (1997) described as a *reflective toss*, learners are engaged in the reflective thinking process. Questions support learners' metacognition in planning by activating prior knowledge and attending to important information, in monitoring by actively engaging learners in their learning process, and in evaluation through reflective thinking (Ge & Land, 2003, 2004).

Question prompts help learners perform the given problem-solving task, and at the same time help them to understand the cognitive and metacognitive processes that underpin the completion of the tasks (Hmelo-Silver, 2006). With question prompts to scaffold learners' intellectual discourse, learners are enabled to acquire the kind of inquiry and learning processes required in PBL, which, therefore, reduces the cognitive demands on learners (Hmelo-Silver, Duncan, & Chinn, 2007).

Summarizing the discussion above, we have developed principal guidelines for designing scaffolds to address various demands—epistemic beliefs, motivation, cognition, and metacognition—in order to facilitate SDL within the PBL environment, which are presented in Table 16.1.

The Role of Technology in Supporting SDL in PBL

Technology can serve as cognitive tools to provide scaffolding (Ge, Planas, & Er, 2010) to supplement or enhance the instructor's scaffolding, especially in situations when human scaffolding is not immediately available. In the literature, human scaffolding has been identified as *soft* scaffolding, while technology scaffolding has been identified as *hard* scaffolding (Saye & Brush, 2002). In soft scaffolding facilitators are able to provide flexible and adaptive scaffolding by responding with feedback based on learners' responses, prior knowledge, and experience. The human facilitators are able to follow up with questions and create a question–answer cycle between the facilitator and learners (van Zee & Minstrell, 1997). Hard scaffolding refers to the relatively fixed nature of scaffolding, such as canned feedback, which is often found in the traditional computer tutoring system (e.g., Lajoie, 1993; Ge et al., 2012). However, technology-supported learning environments can be designed to adapt to learners' problem-solving needs and respond to their questions more dynamically through human interactions via social media technology (Ge et al., 2012) and online conferencing applications, such as Skype and Google Hangout.

The literature suggests that technology can play at least three crucial roles in supporting SDL in a PBL context: (a) serving as cognitive tools to provide scaffolding (Jonassen & Carr, 2000; Lajoie, 1993; Lajoie & Azevedo, 2000), (b) encouraging access to resources and restructuring of information (Goldman-Segall & Maxwell, 2002), and (c) providing a platform for collaboration (Goldman-Segall & Maxwell, 2002; Jonassen & Carr, 2000).

The Role of Cognitive Tools in SDL

Cognitive tools are defined as tools that assist learners to complete cognitive tasks that would have been impossible without this support (Jonassen & Carr, 2000; Lajoie, 1993; Lajoie & Azevedo, 2000), often in the context of computer-supported learning environments. According to Lajoie (1993), cognitive tools share the following cognitive functions: (a) supporting cognitive processes, such as memory and metacognitive process; (b) sharing cognitive load by providing support for lower-level cognitive skills so that resources are left over to support higher-order thinking skills; (c) allowing learners to engage in cognitive activities that would be out of their reach otherwise; and (d) allowing learners to generate and test hypotheses in the context of problem solving. As discussed earlier, SDL has high demands for both cognition and metacognition, and therefore cognitive tools may help to develop SDL in numerous ways.

In the past few decades, researchers have specifically examined the role of question prompts embedded in a learning technology system to support student learning. Some researchers (e.g., Ge & Land, 2003; Ge et al., 2010b) used question prompts to help learners go through an ill-structured problem-solving process in order to generate solutions. In the aforementioned studies, question prompts served cognitive and metacognitive functions in supporting learners in problem representation, self-evaluation, and self-reflection in PBL. They supported problem representation at both individual and group problem levels by directing learners' attention, identifying needs and information sources, formulating goals, and determining self-limitations. Additional evidence (e.g., Ge, Chen, & Davis, 2005; Kauffman, Ge, Xie, & Chen, 2008) further confirmed that question prompts embedded in a computer-supported PBL environment can help learners to articulate their thinking, construct arguments, and justify their solutions, and monitor their problem-solving processes. Question prompts also engage learners in self-evaluation and self-reflection, which are important to the SDL processes. When learners are prompted to evaluate and reflect their problem-solving performance, their thinking is made visible (Brown, Collins, & Duguid, 1989) to themselves and their peers as well, which allows them to see the gaps among their thinking, expert thinking, and peers' thinking. This process helps learners to formulate their learning goals and identify their weaknesses, as shown by Ge and colleagues' (2010b) study. As a cognitive tool, question prompts assist learners in every stage of problem solving, including conceptualizing the problem space and reflecting upon their problem-solving processes (Lajoie, 1993).

The instructor's feedback is essential to PBL regarding learners' problem-solving performance and their learning progress (Fiddler & Knoll, 1995; Huang, Law, & Ge, 2016). Research shows that feedback can be a vehicle to help learners self-regulate their learning and fine tune their learning process toward their goals (Pintrich, 2000), which facilitates learners to develop SDL skills in a large SDL scheme. Technology can be used to support SDL not only by providing feedback, but also by facilitating learners to process feedback through various techniques, such as providing prompts, online discussion, and video feedback (Goldman, Derry, Pea, & Barron, 2007). Feedback may be provided as fixed or canned feedback through computers, or as adaptive feedback through human interaction mediated by computers (e.g., Ge et al., 2012) or videos (Goldman et al., 2007). However, simply providing feedback is insufficient. Research shows that learners often process feedback at a superficial level (Huang et al., 2016); thus, scaffolding is needed to help learners process the instructor's feedback more deeply and effectively.

Access to Information and Resources

In addition, technology supports SDL by not only providing access to resources and information, but also helping learners with information-searching skills. As SDL literature suggests, SDL skills are required for learners' effective functioning in a system of on-demand education (Kicken et al., 2009). Learners are required to diagnose their learning needs in light of given performance standards, formulate meaningful goals for their own learning, diagnose and monitor performance, identify resources for accomplishing learning objectives, develop and use a wide range of learning strategies appropriate to different learning tasks, and carry out a learning plan systematically and sequentially. In support of identifying resources for accomplishing learning objectives, it is critical to help learners develop SDL skills in developing effective strategies for information searching and usage. In a qualitative study about learners' online searching in the PBL context, Jin and her colleagues (Jin, Bridges, Botelho, & Chan, 2015) found that first-year undergraduate learners in health sciences had difficulty coming up with effective strategies for selecting relevant information and useful and quality articles to address their problem-solving tasks when faced with the volume and complexity of the information provided by their search results. It was observed that learners generally lacked the skills of mapping academic journal articles against problem scenarios, forming connections among pieces of information, and applying knowledge in articles into meaningful problem-solving cases (Jin et al., 2015). This study indicates that scaffolding is needed to help learners develop SDL skills in information searching to successfully represent problems in PBL.

The Role of Collaboration Platforms in SDL

Technology provides an online platform for learners to collaborate and engage in the following PBL tasks: establishing common ground, resolving discrepancies or conflicts, negotiation, and reaching consensus (Hmelo-Silver, 2004). Such peer interaction activities facilitate SDL for the following reasons. First, online collaboration allows learners to share information, resources, and understanding, which help the group to develop a deeper understanding of the problem and identify the goals. Second, in an online PBL collaboration environment, learners are guided to ask questions, explain their ideas, make comments, provide feedback, and construct new knowledge (Webb & Palincsar, 1996). This process helps learners to reflect on their learning process and experience, including identifying their learning needs, strengths, and areas for improvement. Third, the online collaboration platform provides a means for learners to gain multiple perspectives and tap into the human resources from peers in the PBL online community (Hmelo-Silver, 2004). Lastly, the online collaboration platform helps to makes peers' thinking visible so that students can self-direct their learning while motivating each other to excel in PBL.

Conclusions and Implications

This chapter offers a new perspective to the current existing literature on SDL, which is an important construct and essential component in PBL. This chapter discusses the three key aspects or demands for SDL in PBL, and based on these assumptions we propose scaffolding considerations to address these demands. SDL is a complex process that encompasses the epistemic beliefs of what it entails, in addition to cognitive, metacognitive, and motivational aspects of learners' engagement. Thus, it is necessary for facilitators to initiate a mindset change in learners and prepare them to be ready to engage in SDL for knowledge creation and personal growth. It is also necessary for researchers to investigate learners' epistemic beliefs and their influence on their ability to self-direct their learning, which has been underinvestigated in the past research. Moving forward, we have a lot to accomplish in the SDL research in association with PBL. For instance, in order to provide effective scaffolding, it is important to assess learners' readiness for SDL in several aspects, including their epistemic beliefs, motivation, and cognition and metacognition, and to assess their progress in these three aspects in the PBL curriculum. There is a need for more research to specifically identify what are the pertinent cognitive, metacognitive, and motivational demands for SDL in order to help instructional designers identify and target the areas where learners need most scaffolding and to help educators deepen their understanding of learners' learning and facilitate their SDL within the PBL context. Conversely, "much more research is needed to better understand how, when and why PBL fosters the development of self-directed learning" (Blumberg, 2000, pp. 224–225).

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17

Types and Design of Assessment in PBL

Mark A. Albanese and Georgia L. Hinman

Introduction

Problem-based learning (PBL) began in medical education in the late 1960s and since then has become a major force in health profession education and even in the broader educational world. Its organization around problems and delivery in small-group format offer special challenges for both the assessment of the participants in PBL (students and facilitators) and assessments of PBL programs and curricula. Because it has the longest history in medical education and there is a strong tradition of research in medical education, medical education has a rich literature on techniques for assessment in PBL. While we drew on the literature far beyond medical education in providing sources for this chapter, the large majority of studies come from the medical education literature.

Assessments have generally been classified into two types: formative and summative. Formative assessment has been defined as the wide variety of methods that teachers use to conduct in-process evaluations of student comprehension, learning needs, and academic progress during a lesson, unit, or course. What makes an assessment "formative" is not the design of a test, technique, or self-evaluation, per se, but the way it is used—i.e., to inform in-process teaching and learning modifications.

Summative assessments, by contrast, "are used to evaluate student learning progress and achievement at the conclusion of a specific instructional period—usually at the end of a project, unit, course, semester, program, or school year. In other words, formative assessments are *for* learning, while summative assessments are *of* learning" (Glossary of Education Reform, Great Schools Partnership, 2014, para 3). Assessment has been defined in some instances as strictly formative, with evaluation reserved for summative purposes. In our treatment, we use assessment as an overarching term referring to measurement of one of the many components of an educational process and whether or not it is formative or summative is in reference to how the results are used.

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In this chapter, we consider assessments of programs, courses, and curricula as well as student assessment. We will first discuss formative and summative assessment in detail. This is followed by a section on the different assessment instruments that have been used in PBL, indicating their use in formative or summative assessment or both.

Formative Assessment

PBL has a lot of moving parts that must work together for the experience to be effective. Small groups need to be composed of students who all contribute constructively to working on the problem material; groups need access to study space, the library and other resources; small-group facilitators need to be prepared for their role; problem material must be designed for sequential disclosure as students make progress, etc. If any of these moving parts don't move adequately, it is important for students to be able to provide this information to the course leadership for correction.

Course/Curriculum-Level Formative Assessment

What constitutes a course in PBL can be quite different from a course in a traditional curriculum. A PBL course can be a unit within a larger course or an entity that stretches beyond semesters or even years. PBL courses generally have an administrative component of instructors (course directors/coordinators) who organize the learning experiences and provide educational resources, particularly the problems that underpin the entire PBL process, recruit, train and monitor facilitators, and coordinate course activities with the larger curriculum. The latter is particularly important if the PBL course is only one component of a larger curriculum that largely follows a more classical lecture-based structure. For course/curriculum-level formative assessment purposes, Barrows (1985) recommends that the course director/coordinator meet weekly with student groups to receive feedback on the course. Modern technology enables students to report issues as they occur in real time through email, texting, or posting to the course's learning management system. Students should be encouraged to report issues that are detracting from their learning experience as early as possible. The course director/coordinator should also meet with the small-group facilitators at least once at the beginning of each new case to orient to the case and coordinate allocation of resources. Although it is difficult to coordinate, weekly meetings with facilitators to get feedback on how the different PBL groups are progressing should also be considered.

Formative Assessment of Facilitators

Facilitator assessment needs to be carefully thought out and even more carefully conducted. Facilitators are sometimes volunteer faculty or retirees; often they are active faculty, but their reward for being a facilitator is not seen as being competitive to what they receive for other activities such as consulting, patient care, and research. In such environments, the option for replacing poorly functioning facilitators may be limited or even nonexistent. The purpose of the assessment is then, for all practical purposes to help the facilitator improve. As such, care must be exercised in how information is collected and provided back to the facilitator. Student evaluations and peer assessments are the two most common means of formative facilitator assessment.

Student evaluations of facilitators

Student evaluations are often considered the best source of information about facilitator performance. After all, they are the main recipients of facilitator efforts. However, students are not always circumspect about how they evaluate the instruction they receive and can be harsh in their comments. They also may have expectations that conflict with the goals of PBL. Students often want to have questions answered by the facilitator, which goes against the expectations for how a facilitator should function in PBL. Further, poor student evaluations can be demoralizing for facilitators. If there are few options for replacing facilitators who do not do well, the feedback they receive needs to be constructive, helping them to improve their facilitation skills.

Depending upon circumstances, student ratings may need to be kept confidential by the course director. In all circumstances, the course director should review all student comments before providing them to facilitators. Student comments that are inflammatory or caustic need to be edited if not excised. In some cases, the course director would do better to synthesize constructive recommendations from student comments rather than provide the actual comments to facilitators.

On the flip side, students can feel at risk when they evaluate their facilitator. Facilitators often grade students and students may feel that if they give negative ratings that the facilitator may reduce their grade. As a consequence, student evaluations should be blinded to the facilitators and the student ratings should never be given to facilitators until all of the facilitators have submitted their grades. For maintaining student anonymity, it is probably best to withhold student ratings until ratings from at least 20 students are obtained. Generally, this will require combining results from two to four groups, depending upon PBL group size.

Peer review of facilitators

Faculty generally are loath to have their peers think them inadequate in any area, even if teaching is considered a low priority. This will motivate most faculty to improve their performance as a facilitator, even if they feel inadequately rewarded for doing so. Peer evaluation is probably best (and easiest) implemented if the PBL sessions are video recorded. The sessions can be reviewed at the peer assessor's convenience and there can be multiple peers involved, if the situation calls for it. The video can also be reviewed with the facilitator to illustrate points in the review.

Having peers sit in and observe live sessions with students can be done, but it will be disruptive to group dynamics and faculty often do not have the flexibility in their schedule to be observers of live sessions. If live observations are done, it takes a certain amount of time before the observer melds into the background and the behavior of both the facilitator and students returns to its natural state.

Assuming few observers would have the time for this integration to occur as it could take sitting in on multiple sessions, the alternative is for the observer to ask both the students and facilitator if they considered the session to be typical or representative of how the sessions went. And, if not, how it differed from a typical session. This request should probably be made in writing and held in confidence.

Formative Assessment of Learners

The focus of formative assessment is to give students a sense of the progress they are making and areas where they need to improve. Within the PBL model, formative assessment can occur at different intervals such as weekly (Nicholl & Lour, 2012), monthly, or at the end of a case (Navazesh, Rich, & Tiber, 2014). When grades are assigned to formative assessments, they need to be low stakes at most.

Just as important, formative assessment provides feedback to the facilitators, instructors, and program on the effectiveness of the learning goals for the learner, thus allowing for immediate corrections in the learner's education. With PBL heavily dependent upon interactions among students, it is critically important that students work effectively as a team and that the assessments provide feedback on the group process.

Design features

One of the goals of the developers of PBL was to break the steering effect that assessment had on learning. It is not uncommon for students to ask if material will "be on the test." And, if the teacher responds that it is not, the material is at risk of being discounted by students. The challenge for formative assessment is to avoid the steering effect, yet motivate students to take low-stakes feedback to heart. One approach is to make review of feedback an expectation of the course. Receiving and responding appropriately to feedback is an important step in becoming a self-regulated learner and this should be impressed upon students from day one. To reinforce this point, the course director should meet with students individually after the first PBL unit is complete and all feedback provided to students. In this meeting, the course director should go over the feedback the student received and ask how the student responded to the feedback. If the student responded in an inappropriate manner, the director should describe an alternative and more productive response. It should also be clear that students should address how they responded to feedback in their self-assessments. In the following sections, methods of assessing the various components of PBL are considered.

General considerations

The challenge in assessing small groups is in dissecting individual student work from the work of the other students and how it affects the group's success. Given the complex mix of contributions at any given time, it will be most accurate if done in close proximity to when it occurs. Thus, it has been recommended that formative assessment occur after each tutorial session; with assessments made by facilitators, peers and self-assessment (Sahoo, Myint, Soe, & Singh, 2013).

Formative assessment may assess the process of PBL groups, the communication that occurs, interactions, participation, self-awareness, responsibility, preparedness, problem solving, contribution to the group, respect, attitudes, analysis, etc. The list of what to assess can be overwhelming. The challenge is to make each assessment sufficiently brief that it does not wear down the evaluator. Assessments also have to be seen as valued and useful, otherwise they will not be taken seriously by assessors and the feedback assessors provide will not be useful. Further, if the assessments are too long, they will gradually become less and less complete, which again will cause them to lose their effectiveness. If there is a long list of relevant qualities that need to be assessed, a system of matrix sampling can be implemented. In such a system, the assessments vary in the qualities they measure such that over five or so assessments all of the desired qualities are assessed and then the cycle repeats.

Formative Assessment of Group Process

Within the PBL group, group process assessment encompasses student contributions to the group milieu, interactions among group members, and group functionality (Kamp, van Berkel, Leppink, Schmidt, & Dolmans, 2014). Process skills can be assessed both formatively and summatively (Romito & Eckert, 2011). Process feedback by peers (student group members) can have a positive impact on student communication, motivation, collaboration, and behavior (Dominick, Reilly, & McGourty, 1997; Geister, Konradt, & Hertel, 2006), act as an intervention to improve individual student contributions (Dominick et al., 1997), and improve academic achievement (Kamp et al., 2014). It has been suggested that how feedback is received depends on one's ability to reflect (Eva et al., 2012; Sargeant, Mann, Sinclair, Van der Vleuten, & Metsemakers, 2008). Combining midterm peer process feedback with reflection has been found to increase student positive perceptions of the group process, which has increased the quality of contributions to the social climate of the group (Phielix, Prins, Kirschner, Erkens, & Jaspers, 2011).

Formative Assessment of Group Products

Group products include such things as case presentations, original projects, and written reports. If the various PBL groups are given assignments that result in a relatively uniform product, the task of evaluating them will be easier and the result more reliable than if each group is able to exercise latitude in creating their own product. Group products will usually be better and more reliably assessed if expectations are clear and a timeline for their completion is available from the outset. Because facilitators may feel conflicted by virtue of their being part of the group and facilitating the product development, it may be preferable to have nonfacilitator assessors evaluate the products. The biggest challenge with assessing group products is uniformly and reliably evaluating their merits.

Case presentations merit special consideration. They generally occur following submission of the final report or it might be the final report. Depending upon the design of the program, students may decide who will present and what to present. This may result in the different group members giving portions of the report. Some programs randomly choose which group member presents the case. This helps hold all students accountable and facilitates group cohesion as they prepare for the presentation (Brady, Caldwell, & Pate, 2013). Further, random selection of presenters establishes an environment where students know that they can achieve their own goals only if their other group members do also, which is a key feature of cooperative learning. A comprehensive meta-analysis found cooperative learning to be substantially more effective than competitive learning (Qin, Johnson, & Johnson, 1995).

Most often, the facilitator evaluates the presentation and gives feedback to the students. If possible, the presentation should be video recorded. This can be helpful for providing feedback and, if the grade awarded to the group, or any individual, is challenged, the recording can be reviewed by other faculty to evaluate the merits of the challenge.

Formative Group Performance Assessments

Because groups can approach their PBL assignments in unique and very different ways, there have been methods developed to assess group performance in relatively standard ways.

Triple jump

The primary goal of a triple jump exercise is to assess clinical problem-solving and self-directed learning skills (Painvin, Neufeld, Norman, Walker, & Whelan, 1979). In a triple jump exercise, students discuss a written clinical scenario and identify the related learning goals, review the learning materials individually, and return to their group to present their conclusions and judge their own performances (Matthes, Look, Hahne, Tekian, & Herzig 2008). Variations in time to complete the exercise exist along with variations in the exercise itself. Videotapes of patients have been used (Foldevi & Svedin, 1996) as well as case discussions and interactions with standardized patients (SPs, are individuals who may or may not have a medical problem who are trained to give a realistic presentation as a patient). Triple jump exercises have been less used for grading purposes because they are time consuming, limiting the number of scenarios that can be evaluated and as a result scores tend to be contextually bound to the specific problem assessed.

4-step assessment task

The 4-step assessment task (4SAT) is designed for both formative and summative assessment of reasoning ability, group process, and individual learning outcomes (Zimitat & Miflin, 2003). Based upon a patient case, Step 1 involves individual work identifying key features, generating hypotheses of possible causes of the presenting signs and symptoms, possible biological/molecular mechanisms, and describing how they will refine their hypotheses. During Step 2 students work together to produce a list of top 10 learning issues identified. This process is observed and rated by the facilitator and an observer, and feedback is provided to the group. Step 3 encompasses learning activities and independent study. For Step 4, students take a written exam based on the top 10 issues. Formatively, students receive feedback within 1 week; as a summative assessment, the 4SAT acts as a composite score in addition to an Objective Structured Clinical Examination (OSCE—a multistation exam where a student must demonstrate a skill at each station) and essay questions.

Formative Assessment of Individual Students

Giving a grade to individual students for formative purposes is primarily to give feedback to them about their progress in the form they will receive in their ultimate grade. Because grades are generally the "coin of the realm," giving feedback as it would be received at the end of the course is likely to be maximally motivating for the poor performers and generally least likely to be misinterpreted. Given that the bulk of student work in PBL occurs in groups, disentangling the contributions of individual students from group work requires careful thought since it can inadvertently cause competitive or other types of uncomfortable and unproductive situations to arise.

Peer review of students

When students are part of the assessment process, it facilitates their self-directed skills (Ballantyne, Hughes, & Mylonas, 2002). However, prior to providing peer feedback students must be trained in how to provide and receive constructive feedback as these are skills that not all students have mastered, nor maybe even formally experienced. Peer feedback done poorly or taken badly can produce interpersonal conflict, which could undermine the group's success (Cooper & Carver, 2012).

Peer assessment can take the form of a narrative or checklist. Unfiltered unstructured narrative feedback has great potential for being misunderstood. While there are ways to structure narrative feedback to make it less likely to be damaging, checklist feedback is less risky and can be tailored to provide a measure of the institution's core competencies. The literature provides positive, neutral, and negative consequences of peer assessment. Dannefer and Prayson (2013) found that students valued peer feedback because the specificity of its information was useful for improving performance; however, Cooper and Carver (2012) found students had difficulty providing constructive feedback to their friends. Compared with self-assessment, peer assessment offers a greater likelihood of providing accurate formative information (Papinczak, Young, & Grove, 2007). That being said, Kamp et al. (2014) found that the quality of individual contributions to the tutorial group did not improve after receiving peer feedback. While peer feedback has the potential to be of value, it must be carefully and thoughtfully done.

Facilitator assessment of students

PBL is heavily dependent upon interactions among students and the facilitator. The quality of the facilitator can determine the effectiveness of the PBL session (Pease & Kuhn, 2012). Facilitators are in a unique position to provide formative data on such skills such as communication, teamwork, participation, interpersonal skills, and self-evaluation abilities (Mubuuke, Louw, & Van Schalkwyk, 2016).

It usually is best for student evaluations by facilitators to be collected using some type of standard form. A standard form (generically referred to as an instrument) helps to focus the assessment and draw the assessor's attention to the most salient features to be assessed. The two main types of questions used on these instruments are forced choice and narrative. Instruments using forced-choice responses give options that the respondent selects from. The simplest forced-choice type question is the checklist. The assessor simply checks the answers that most correspond to what they believe to be the appropriate answer. An example of a checklist question for a facilitator rating of a student might be:

How would you describe the student's interactions within their group (check all that apply):

___respectful	____pleasant	____dictatorial	____engaged
___intimidating	____combative	____divisive	____organized
___helpful	____distant	____facilitative	____disorganized
___authoritative	____useless	____directive	____efficient

A second type of forced-choice question that is commonly used is the Likert-type rating scale. An example of this might be:

The student worked collaboratively with other group members:

____Strongly agree
____Agree
____Disagree
____Strongly disagree

Narrative responses simply provide space on the form for the assessor to write their comments. Generally, it is a good practice to allow assessors to provide this type of option for adding detail to explain their forced-choice selection.

PBL uses individual formative assessment measures to document student progress in meeting performance standards in a competency-based grading model. It is suggested that when behavior is observed, using narrative feedback provides specific and rich data that are not easily ignored compared to rating scales where behaviors are abstract and not connected to the context (Dannefer & Prayson, 2013). Nendaz and Tekian (1999) suggest using a variety of instruments to document growth and provide feedback to students. Individual scores and subscores by discipline provide good feedback; adding the component of class comparison data allows students to calibrate their performance to other students. Many of the formative measures can also be modified and used as summative assessments. Care should be taken with measures that require evaluation of peers and self when grading is involved.

Portfolio

A portfolio is a repository of work products and accomplishments. Electronic portfolios are becoming a common approach for students in the health sciences to store their work products as well as the grades and other assessments they receive. In total, it provides a resource for the student to present their accomplishments in great detail. The use of a portfolio or other electronic repository for providing feedback enables students to view feedback in real time and across time, thus providing both formative and summative assessment. Students can use feedback to document their performance or for reflection or to show growth over time. The advantage of an electronic portfolio for faculty is the ability to access it at any time when it is convenient for them to provide their feedback and the ability to allow students to respond directly to formative feedback. Altahawi, Sisk, Poloskey, Hicks, and Dannefer (2012) reported using formative portfolios, in the absence of grades, to facilitate student learning, take in constructive feedback, and to provide an opportunity for self-reflection. When portfolios are used it is suggested that schools implementing PBL have students meet with a mentor, advisor, or faculty on a regular basis to review gathered documentation and discuss progress toward the school's competencies.

Self-assessment

One of the goals of PBL is for students to develop self-directed learning skills. A key component of achieving this goal is the ability to accurately assess one's strengths and weaknesses and identify ways to address one's weaknesses. Self-assessment is then a key to achieving self-directed learning skills. However, the value of self-assessments for anything beyond formative uses is suspect. At the very least, if there is anything at stake from providing self-assessments, there is an obvious conflict of interest.

Studies of self-assessment have found they tend to be relatively inaccurate such that poor performers tend to overestimate their performance and high performers tend to underestimate their performance (Kruger & Dunning, 1999; Ward, Gruppen, & Regehr, 2002). The tendency for this pattern to emerge is fairly pervasive across skills. As a consequence, using self-assessments in grading may penalize the high performers and give undeserved increases in grades to the poorest performers (lowest 25%). Langendyk (2006) found similar results until students reached their third year of school, when most students were performing at a satisfactory level; only then were they more able to accurately self-assess. While self-assessment is a good activity to have students experience, it should be used with great care and not used as part of the calculation of grades.

Tests/examinations

The main advantage of tests, particularly those composed of multiple-choice items, is that they can cover a lot of content in a relatively short amount of time. While tests have been criticized for failing to align with the goals of PBL, many PBL programs find utility in them for formative assessments and for preparing students to take their licensing examinations. Frequent progress tests have been particularly helpful and widely used in PBL (Albanese & Case, 2016). Tio, Schutte, and Meiboom (2016) found that students were able to identify and remediate gaps in their knowledge after using an online test/feedback system where students could immediately: see the items they answered incorrectly along with the correct answer, review their scores by discipline, and compare their score to the average per test and longitudinally. Thus, testing with feedback can be a powerful formative tool students can use to identify and fill in gaps in their knowledge.

Summative Assessment in PBL

Summative assessment in PBL occurs at multiple levels: student, group, course, and curriculum. The goal of summative assessment is to determine to what extent the goals of the program/curriculum are met and it relies on information that is accumulated during or collected after completion of the learning experience. For students, their grade is the ultimate summative assessment. It is the overall judgment of how well they performed and whether or not they achieved the goals of the course. Sometimes students receive separate grades for their group work and their individual achievement.

PBL courses and an overall PBL curriculum summative assessment can range from stakeholder review of the course (accomplishments of students, efficient delivery of course materials and instruction, and student and facilitator evaluations) to experimental designs with control groups. Unlike formative assessments, which are designed for real-time use in instruction, summative assessments are future focused and/or externally directed. They are used for revising course materials for future use, arguing for resource allocations, and, sometimes, serve for presentations at professional meetings and scholarly publication. Unlike formative assessments that are low or no stakes, summative evaluations generally are medium to high stakes. By this we mean that summative assessments determine if students pass a course, or whether a course gets the same or more resources in the coming year or whether a professor is able to publish the results of their teaching efforts in a form that gets them academic credit for promotion. If the summative assessments are used for presentations and publication, they need to employ especially rigorous methods, including, ideally, control groups and random assignment to treatments. Because summative assessments have real consequences, they need to attend to reliability and validity issues to a greater degree than for formative assessments. In the final section of this chapter, we go over the different measures that are commonly used for summative assessment in PBL.

Summative Assessment: Grading

Grading students in PBL has to avoid undermining group work, especially if cooperative learning methods are used. For example, competitive grading with a fixed quota for the highest grades (e.g., reserve honors grades for the highest 16%) can leave students unwilling to help other students for fear they would disadvantage themselves.

Additionally, distinguishing individual performance on a group project is difficult and generally imprecise. Perhaps the best approach is to have each student state the precise contributions they made to the PBL group on the final PBL report and then have each member of the group initial each contribution and sign the final document attesting to the accuracy of the contributions stated.

A pass–fail grading system is most compatible with the philosophy of PBL. However, many faculty and students alike believe that a pass–fail grading system does not provide the motivation for or recognition of achieving excellence. To recognize excellence, an honors grade is sometimes added beyond pass.

The other concern is that faculty are often reluctant to award failing grades. To distinguish poorer performance in a way that faculty are likely to use, a marginal or low pass grade is sometimes used as a buffer between fail and pass.

Because there are stakes in what grade students receive (e.g., whether they have to repeat the course, whether they get into the residency of their choice), grades need to be built from the most reliable and valid data available. The typical grading system uses as much of the data available as possible and weights it all pretty much the same. Performance on a case, test, or other measure at the beginning of the course is treated the same as performance in the closing moments. If, however, the goal is for students to achieve a level of competence, then performance at the end of the course when they should have achieved their highest competence level should be given the greater weight. If end-of-course competence is to be weighted more than performance earlier, much effort needs to be placed into assessing that competence. The measures used need to be as reliable and valid as possible. For example, a course might conclude with a final progress test and OSCE exam where a student must demonstrate a skill at each station to demonstrate skills. Performance on these two assessments might count for 50% of the course grade, while all previous measures in combination count for the other 50%.

The problem with grading is the dynamic tension between reliability and validity. Reliability is generally improved when combining results from as many samples of performance as possible. Validity is maximized when the measures best assess the competencies being taught. Thus, reliability is likely to be maximized by incorporating all of the performance data across the course, while validity is likely to be maximized by focusing on end-of-course measures.

As usual, there are trade-offs to both approaches. If all information is combined with equal weight, early assessments that are rudimentary developmental stages of competency will receive equal treatment to later assessments that are end-stage competencies, and early stages may not provide a consistent picture of final competencies. If later assessments, like a single day of intense assessment, are heavily weighted, the stress of the day can be overwhelming for some students and if a student has a "bad day," an unrepresentative performance can have catastrophic consequences. There are valid arguments for both approaches, but the main consideration is that, to foster cooperation and teamwork, grading needs to be criterion referenced at all levels. If any grade element is fixed quota, it will work against students working cooperatively.

Summative Assessments: Program or Course Measures

Student ratings are the most commonly used summative assessment measures, however student satisfaction has generally been considered a relatively weak form of evidence. Success in achieving program goals and objectives by students is generally considered a stronger form of evidence than is student satisfaction. For PBL curricula in many of the health science areas, the preceptor ratings of students are commonly employed. For entire curricula, the ratings of graduates and the residency supervisors of the graduates have also been useful (Hojat, Gonnella, Erdmann, & Veloske, 1997). Performance on objective examinations, especially licensing examinations such as the United States Medical Licensure Examinations (USMLE step examinations) and the National Council Licensure Exam for nursing (NCLEX), can also serve as summative evidence; however, they have been criticized as being not very sensitive to the types of skills that PBL is attempting to develop.

Generally, one is better off using a range of different types of measures to evaluate a program and PBL is no exception. Each type of measure used generally has its own weaknesses, but in aggregate the weaknesses can average out. Longitudinal databases, such as portfolios, can be especially valuable for summative evaluation.

Summative Assessments: Measures of Students

Evaluating student performance in PBL, especially for summative purposes, is one of the most challenging issues. We will give a brief overview of selected methods that have been used. For each, we will describe it and then briefly note major strengths and weaknesses. For readers who are interested in more detailed descriptions of methods used to evaluate students in PBL, we would refer you to Nendaz and Tekian (1999). For an excellent reference on how to write test items and the strengths and weaknesses of various approaches to student assessment, we recommend Case and Swanson (2001), a free online manual.

Multiple-choice exams

The use of multiple-choice examinations is common because of the ease of scoring. Generally, there is no better way to cover a wide range of content more efficiently. Although multiple-choice tests have been criticized for their limited ability to assess problem solving, the primary skill that PBL is designed to promote, there are those who believe that well-written multiple-choice questions are quite capable of assessing problem-solving skills. At the very least, writing of such sophisticated questions is a very complex skill, one that is unlikely to be mastered by many faculty without specific training.

Case clusters are a form of multiple-choice question where several multiple-choice questions are drawn from the same patient presentation/case/scenario. Case clusters use approximately three multiple-choice questions drawn from the initial patient presentation. The number of multiple-choice questions used depends upon the goals of the case and the complexity of the cognitive skill being assessed (Case & Swanson, 2001).

A potential problem with these types of items is that they tend to have higher correlations with one another than they do with questions drawn from different cases. This will tend to inflate the internal consistency reliability estimate (e.g., coefficient alpha) for these items over what it would be if each multiple-choice item was drawn from a different case. Over the entire test, there needs to be at least 11 or more different cases to obtain a result that has acceptable generalizability (Petrusa et al., 1991). The most important consideration, however, is whether the entire mix of multiple-choice questions meets the overall test design—a critical factor in building the content validity argument for the examination.

A form of multiple-choice examination called the Progress Test (PT) has been used relatively widely in PBL (McHarg et al., 2005; van der Vleuten, Verwijnen, & Wijnen, 1996; Willoughby, Dimond, & Smull, 1977). A PT reflects the end objectives of the curriculum and samples knowledge across all disciplines and content areas relevant for the professional degree. The number and types of items used and administration frequency for PTs have been quite variable. PTs used at Maastricht were composed of 250 true–false questions while the McMaster PT contained 180 multiple-choice questions. The Maastricht PT is administered four times per year to all students in the medical school, while McMaster administers theirs three times per year in 3-hr settings, to all students. PT scores have been found to have a high correlation with clinical reasoning ($r = .93$) (Boshuizen, van der Vleuten, Schmidt, & Machiels-Bongaerts, 1997) and test–retest reliabilities over successive administrations ranging from .53 to .64 and correlate approximately .60 with licensing test performance (Blake et al., 1996).

The main problem with a PT is that it can be inefficient. Neophyte examinees can spend much time attempting questions they can only hope to guess upon (advanced clinical questions) and advanced examinees spend time answering questions with content they have already mastered. However, programs using PT have found its benefits outweigh its inefficiency.

The most critical issue pertaining to the functioning of a PT is that every item should map to some point in the curriculum. Some items should be mapped to knowledge, skills, and abilities learned early in the curriculum such that students on entry can answer them at only chance levels, but those who have completed the first year should answer them with high levels of success. Similarly, some items, such as those with a heavy practical component might be answered at only chance levels until students have advanced to the higher levels of the program. Once students reach the point in the curriculum where a given item has been mapped, they should have achieved the competency and have a high probability of answering the item correctly and their performance should remain high on that item for the remainder of the program. A PT program can be critically important for a school adopting PBL, particularly if they find the passage rate on a licensing examination declines. For a more extensive treatment of progress testing for use in PBL, see Albanese and Case (2016) and Heijne-Penninga, Kuks, Hofman, Muijtjens, and Cohen-Schotanus (2014).

Essay and modified essay questions

Essay questions provide the least structure and have the potential to offer insight into the thought processes underlying choices when confronted with a patient problem. However, a student who is not very skilled at writing essays could appear to be less accomplished than they are simply because they do not write well.

A form of essay called the modified essay question has been used to assess PBL. It consists of a standardized series of open questions about a problem in which the information on the case is ordered sequentially. Students receive new information only after answering a certain question (Verwijnen et al., 1982). Saunders, McIntosh, McPherson, and Engel (1990) varied this format by covering nine areas of primarily internal medicine content.

The advantage of the essay-type questions is in their relative ease of construction. The disadvantage is the complexity and time to score it. Graders need to be given clear criteria for assigning grades and their consistency in grading monitored as fatigue sets in. If multiple graders are used, consistency between graders also needs to be monitored. Ideally, at least two graders should grade each paper and the multiple grades averaged for the final grade awarded.

Simulations

Increasingly high-definition patient simulators (HDPS) are being used by the majority of medical schools and teaching hospitals in training health professionals and interprofessional teams. HDPS are controlled by computers and use life-size mannequins. HDPS bring emotional realism to the patient case while providing a safe and nonthreatening learning experience (Halm, Lee, & Franke, 2011).

Grading simulations can be as complex as grading essays, or more so depending on whether the process used to arrive at the end state is part of the grade. Whereas making the correct diagnosis or managing the patient appropriately might be relatively easily graded, evaluating the steps getting there when there might be any number of decision points with any number of choices possible at each decision point makes grading the process challenging.

Objective structured clinical exams

Objective structured clinical exams (OSCEs) are performance-based examinations in which students rotate from station to station (Harden, Stevenson, Downie, & Wilson, 1975). At each station, students are required to do a particular task or sequence of tasks. Stations often use standardized patients, computer simulations, literature search facilities, mannequins, and other types of "hands-on" experiences. There are two general types of OSCE stations, the long and short type. The long type can take up to a couple of hours to complete each station and is very extensive. The short type is much more focused and stations generally take from 10 to 15 min.

There are two preferred ways to score student performance on the OSCE, checklist, or holistic scoring. Checklist scoring involves breaking down the steps required to successfully complete the station so that the assessor simply checks them off if they occurred. Sometimes each of the steps can be evaluated on a multi-point scale. The holistic approach depends upon a "clinical judgment" of the quality of the examinee's performance. The assessor provides a single grade to the examinee on a multipoint scale relative to their judgment of the quality of the performance. The checklist method has the advantage of being relatively reliable since each check mark requires performance of a very specific action. The amount of judgment required is relatively small for each check mark. This approach also makes it easier to have nonspecialist assessors. However, the checklist method has been found to have problems. First, experts tend to be much more efficient and not to do all of the steps that would be expected of a novice. Scored by the number of checkmarks, novices will often score higher than experts. A second problem is that if the sequence in which the steps occur makes a difference, it will not be reflected in the checklist approach. A chaotic shotgun approach in choosing steps will get the same score as an approach that is methodical, as long as they get the same check marks. The holistic approach addresses these criticisms, but it is somewhat less reliable since it depends upon global assessor judgments. This also makes it important to have expert assessors at some point in the grading process.

The strengths of the OSCE are its face validity and standardized experience for all examinees. There are relatively few other ways of assessing complex skills and abilities such as communication skills with the same degree of standardization and reliability. The primary limitation of the OSCE pertains to its cost. It requires substantial infrastructure to administer: personnel to recruit, train, and manage standardized patients and facilities, at least 11 places to put the stations, usually examination rooms, and money to pay the standardized patients.

Peer evaluations

The competitive nature of grades makes peer evaluations contain at least some level of conflict of interest. Complicating matters further, if a cooperative learning model is being used, students are expected to teach their peers. If they are expected to teach and evaluate their student peers, the two activities can be antagonistic. And, if after peer assessments, students are expected to come back and continue to work in their small groups, group dynamics can be disrupted. If peer evaluations are used for grading students, care should be exercised. Peer assessments of the teaching contributions to colleagues may be a better application than they would be for assessing learning accomplishment and group contributions.

Facilitator evaluations

Several instruments have been proposed to assess facilitator perceptions of student performance but they vary quite markedly in their length and the frequency of use. Hebert and Bravo (1996) proposed Tutotest, a 44-item standardized instrument designed to assess medical students' skills and attitudes during PBL sessions. The Tutotest requires approximately 24 hr of observation of student behaviors but very little training to use. Landouceur et al. (2004) proposed a somewhat shorter instrument composed of 31 items, but this is still a formidable burden for facilitators. Several investigators have explored use of forms with five or fewer items (Chaves, Baker, Chaves, & Fisher, 2006; Eva et al., 2007; Sim, Azila, Lian, Tan, & Tan, 2006). The longer forms have generally been recommended for use at the end of a unit, while the shorter forms have been recommended for use at the end of each session (e.g., a unit usually covers a major topic and occurs over a 2–6-week period while there are often 2–3 sessions per week). Thus, an instrument completed at the end of each unit will have one assessment completed every 2–6 weeks, while one completed at the end of each session will have from 4 to 18 assessments completed by the end of a unit. The latter approach has been found to improve the psychometric properties of the resulting scores.

Clinical reasoning measures

Clinical reasoning measures generally have not been used for assessing PBL (or any educational interventions). They generally are complex and the results are hard to grade. However, that may be changing as automated essay grading by computer becomes more sophisticated. A brief review of these measures may be useful if the future holds methods for grading them in a more controlled and reliable manner.

Bierer, Dannefer, Taylor, Hall, and Hull (2008) developed the Concept Appraisals, which combine multiple-choice questions with essay questions that ask learners to provide a narrative interpretation of the mechanisms behind or reasons for the findings in a clinical scenario. Wood, Cunnington, and Norman (2009) describe what they call a Clinical Reasoning Exercise in which learners are asked to write a single paragraph explaining the mechanisms behind a particular patient problem. These paragraphs are then graded by independent raters.

Concept maps are a drawing by a learner that relates the different elements involved in a presenting problem to one another to show how they relate. It incorporates basic sciences concepts as well as elements of the patient's clinical presentation. McGaghie, McCrimmon, Mitchell, Thompson, and Ravitch (2000) demonstrated that students' maps regarding pulmonary physiology concepts became more coherent as a result of participating in an instructional unit on respiratory physiology, and the maps became more similar to maps developed by their instructors. Unfortunately, the maps of experts differ significantly depending on the discipline of the expert, thus complicating the task of developing a "gold standard" for grading students' concept maps (McGaghie, Boerger, McCrimmon, & Ravitch, 1994).

Advanced clinical assessments

Patient care, internships, and other types of practical experiences do not always provide the breadth of opportunities that students need to develop expertise in the required range of problems needed for competency. This is particularly true for important problems that are relatively uncommon. PBL then becomes a mechanism for plugging the holes created by the vagaries of practical experiences. PBL combined with simulators can enable learners to safely develop expertise for problems that would be too complex and/or dangerous to be attempted by a neophyte, even with supervision. For more advanced learners, examples of assessments of clinical competence that can be employed are the Mini-CEX (Norcini, Blank, Arnold, & Kimball, 1995; Norcini, Blank, Duffy, & Fortna, 2003), Script Concordance tests (Brailovsky, Charlin, Beausoleil, Côté, & van der Vleuten, 2001; Lubarsky, Charlin, Cook, Chalk, & van der Vleuten, 2011), and oral examinations (Anastakis, Cohen, & Reznick, 1991).

Summary

Assessment of programs and curricula as well as individual students in PBL presents special problems. The intimate nature of the instruction, being in small groups with one or two facilitators, makes the evaluation of student performance potentially disruptive to group processes. Further, since the instruction is contained within a small group, small-group functioning becomes a critical variable in how well the instruction is delivered. This poses particular problems for overall program assessment because PBL group is rarely considered in analyses of performance; perhaps this is because small groups get recomposed periodically during the curriculum. It is probably rare that students would stay in the same group for more than a particular unit of instruction. However, if group compositions are maintained for any substantial period of time, how they function will have an effect on the outcomes, so group membership needs to be considered in analyses.

Probably the single best recommendation we could make for assessment in a school adopting a PBL curriculum is to consider implementing progress testing. It is not uncommon for schools adopting PBL curricula to experience a decline in their passing rate on the licensing examination. Norman, Neville, Blake, and Mueller (2010) report how McMaster University found the PT to be a solution to high rates of failure on the Licentiate of Medical Council of Canada (LMCC) toward the end of the second decade of their existence. LMCC board failure rates reached 19%, more than four times the national average by 1989. They initially adopted the practice test for the LMCC developed by the University of Toronto and subsequently developed their own PT as a long-term solution. Failure rates immediately dropped to 5% and scores on the LMCC continued to rise over the next decade. Thus, the PTs provided a means of keeping students progressing toward the general competencies of the profession, while still enabling them to have the benefits of the self-directed learning and small-group problem-solving elements so valued in PBL.

McMaster has recently spearheaded the International Partnership for Progress Testing (IPPT), which has partnered with three schools from North America, Europe, and Australia to provide online progress testing (IPPT, 2017). Another alternative for LCME (Liaison Committee on Medical Education) accredited schools might be to use the Comprehensive Basic Science Examination (CBSE) of the National Board of Medical Examiners.

No matter how one decides to ultimately implement PBL, it is important that as they design their assessments they keep clearly in mind what they are trying to accomplish and not get distracted from their goal.

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18

Technology Applications to Support Teachers' Design and Facilitation of, and Students' Participation in PBL

Brian R. Belland

Introduction

Problem-based learning (PBL) can be a powerful tool in a wide range of classrooms and other instructional settings due to its promotion of highly desired outcomes, including problem-solving skills (Lian & He, 2013; Prosser & Sze, 2014), argumentation skills (Belland, Glazewski, & Richardson, 2008; Kuhn, 2007), and deep content knowledge (Pourshanazari, Roohbakhsh, Khazaei, & Tajadini, 2013; Strobel & van Barneveld, 2009). These learning outcomes align well with the emphases of the Common Core and the Next Generation Science Standards (Belland, 2017; Krajcik, Codere, Dahsah, Bayer, & Mun, 2014). Also, addressing PBL problems has the potential to be perceived as authentic by students (Fredholm, Savin-Baden, Henningsohn, & Silén, 2015; Hung & Chen, 2007). But PBL can also be highly taxing for teachers, who need to (a) devote much time before teaching a PBL unit to design the unit and associated support strategies (Ertmer & Simons, 2006; Nariman & Chrispeels, 2015), and (b) manage and enhance the learning processes of many different students who by design are not doing the same things at the same time (Belland, Burdo, & Gu, 2015; Hung, 2011). Managing and enhancing the learning processes of students within PBL requires a skill set that can take much time and effort to learn (Belland, Burdo, et al., 2015; van de Pol, Volman, & Beishuizen, 2010; van de Pol, Volman, Oort, & Beishuizen, 2014). Students can also struggle to adjust to the autonomy that engaging in PBL provides (Fredholm et al., 2015; Loyens, Magda, & Rikers, 2008). Specifically, they can struggle to find, organize, and synthesize information (Moust, Berkel, & Schmidt, 2005; Simons & Ertmer, 2006), engage in effective group work (Henry, Tawfik, Jonassen, Winholtz, & Khanna, 2012; Redshaw & Frampton, 2014), and develop and defend solutions (Belland et al., 2008; Jonassen, 2011b). Smartly designed technology can help students and teachers overcome challenges related

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to PBL (Belland, 2014; Hmelo-Silver, Derry, Bitterman, & Hatrak, 2009; Hung, 2011). By technology, I mean *processes* and *tools* that can be used to address problems (Finn, 1960). Just as in PBL, student learning is centered around an authentic, ill-structured problem, the very act of setting up a PBL unit and facilitating it can also be considered a form of problem solving that can benefit from the use of technological tools and processes to leverage teacher and student abilities. According to this chapter, technology to support PBL can be divided into two forms—support for PBL teachers, and support for PBL students.

Plan of Chapter

Responding to the burden that teachers and students new to PBL often perceive, this chapter discusses technology applications that can be used to (a) design instruction for PBL, and (b) help students achieve maximal success in PBL. In so doing, it draws on the importance of the theoretical foundations of PBL in the use of technology with PBL, as well as the expansion of PBL to other subject matters and education levels.

Critical Considerations when Designing and Engaging in PBL

Developing PBL Instruction that Contributes to Adaptive Motivation

Adaptive motivation can be defined as the willingness to exert cognitive effort toward addressing learning goals (Belland, Kim, & Hannafin, 2013). Researchers often assume that students will be motivated when teachers use PBL, but this is not the case, due to inadequate effort to establish task value, promote expectancy for success, promote mastery goals, promote belonging, promote emotion regulation, and promote autonomy (Belland et al., 2013). Establishing task value and promoting expectancy for success are grounded in the expectancy-value and self-efficacy traditions of motivation, and suggest that students will not deploy effort toward learning tasks unless they are interested in the topic (Hidi, 2006; Renninger & Hidi, 2011), see inherent value arising from the completion of the learning task (Turner & Schallert, 2001; Wigfield & Eccles, 2000), and believe that they will successfully complete the learning task (Bandura, 1997; Wigfield & Eccles, 2000). Promoting mastery goals means inviting students to measure success by the extent to which they thoroughly understand the content they were learning, rather than by the extent to which they outperformed other students on tests or other tasks (Ames & Archer, 1988; Covington, 2000; Pintrich, 2000). Promoting belongingness is seen as an essential prerequisite for motivation according to the self-determination theory (Deci & Ryan, 2000; Deci, Ryan, & Williams, 1996). Helping students manage negative emotions and leverage positive emotions that arise due to learning tasks is crucial to maintaining an adequate learning approach (Kim & Pekrun, 2014; Pekrun, 2006). Last, it is important to allow students to make meaningful choices and otherwise conduct learning activities out of their own will, thereby enhancing autonomy (Deci & Ryan, 1987; Reeve, 2009; Su & Reeve, 2010).

Within PBL, students work in groups to address ill-structured problems, defined as problems that have more than one solution and more than one solution path (Jonassen, 2011a). Addressing ill-structured problems is diametrically different from addressing well-structured problems in that the desired end state, what is needed to solve the problem, and how to solve the problem are not readily apparent when presented with the problem. This requires a high level of persistence and motivation. In this way, solving ill-structured problems requires a high degree of self-direction of learning (Jonassen, 2011a; Loyens et al., 2008). There is not one set process that must be followed to address a given PBL problem. Rather, for any given PBL problem, there are many solution paths that one could follow (Jonassen, 2011a). There are also many potentially valid solutions, and the validity of solutions is established through argumentation (Jonassen, 2011a).

Developing PBL Instruction That Fosters Access to Cultural Knowledge

In the process of addressing ill-structured problems, PBL students specify content that they need to learn, learn the content, report back to their groups, and synthesize learned information to address the central problem. In this way, learners assimilate cultural knowledge through interaction with tools and other people—a process described by cultural–historical activity theory (Jonassen & Rohrer-Murphy, 1999; Leont'ev, 1974; Luria, 1976). Cultural knowledge can include ways of thinking about particular phenomena or strategies used in particular contexts (Engeström, 2000, 2009). For example, cultural knowledge among physicians in a particular emergency room may include strategies for stitching wounds, taking into account the ergonomics of the emergency room set up, supplies that are generally available, time constraints, and the general approach used among the team. Central to activity theory is a focus on mediated action—action that is mediated by the learner's goal and through interaction with other individuals and tools (Engeström, 2000; Roth & Lee, 2007). Cultural knowledge can be embedded in tools through their design, potential affordances, and language used to convey functionality and information. Goals affect how learners perceive and interact with tools (Belland & Drake, 2013; Jonassen & Rohrer-Murphy, 1999). In perceiving a technology or other tool, individuals consider their goal and what can be accomplished using the tool, and in so doing construct a sign representing the tool and use the tool accordingly (Barthes, 1994; Belland & Drake, 2013; Wertsch & Kazak, 2005).

Technologies to Aid PBL Teachers

The Challenge

Developing and facilitating a PBL unit is a complex endeavor, in that consideration must be given to (a) developing a compelling central problem that students have the potential to find authentic and that has the potential to lead students to learn target knowledge and skills (Hung, 2006; Jacobs, Dolmans, Wolfhagen, & Scherpbier, 2003), (b) setting up a method to present the problem (Balslev, de Grave, Muijtjens, & Scherpbier, 2005; de Leng, Dolmans, van de Wiel, Muijtjens, & van der Vleuten, 2007), (c) developing and deploying strategies and tools to support student learning (Belland, Burdo, et al., 2015; Ertmer & Simons, 2006; Hmelo-Silver & Barrows, 2008), and (d) setting up and deploying a method to conduct dynamic assessment of student learning (Belland, French, & Ertmer, 2009).

Developing a PBL unit requires that attention be paid to developing a compelling central problem that can drive student learning and setting up a system by which student learning processes can be supported. It is critical that students see value in addressing the problem, but the problem also needs to be ill-structured and invite students to learn the content that they need to learn (Belland et al., 2013; Wigfield & Eccles, 2000). Within medical education, central problems of PBL units are often chosen from among a list of patient cases that touched on the medical knowledge that was the aim of the unit (Barrows, 1985). Attaining buy-in from students is not considered to be an issue—after all, all medical students presumably chose to apply to and enroll in medical school so that they could address interesting medical problems (Hughes Caplow, Donaldson, Kardash, & Hosokawa, 1997). Thus, if a class needed students to learn about biochemistry, a problem could be selected in which abnormalities in biochemistry contributed to a disorder. In studying factors related to the disorder, students learn biochemistry. In short, in medical education, PBL instructors choose from a relatively constrained set of problems—those involving human health—and addressing most is likely to be perceived of value to medical students, an important part of motivation (Wigfield & Eccles, 2000).

PBL spread to many subjects and levels of education because of the success that PBL graduates were having in terms of deep understanding and problem-solving abilities (Hmelo-Silver, 2004; Savery, 2006). But the new content areas and education levels did not share a relatively homogenous student population all of whom were preparing for the same career path (Dolmans & Gijbels, 2013). Thus, the design of PBL could no longer be anchored solely in typical problems encountered by students once they graduated, because such problems would range widely among students who pursue different career paths. Rather, the design of PBL, including that of PBL problems, in such contexts needed to be anchored in learning and motivation theory, as well as the field of practice to which students aspire. This is important because instructors needed to consider the extent to which potential problems could (a) help students learn target knowledge and skills, and (b) elicit strong motivation on the part of students. Likewise, it is important to reference learning and motivation theory when developing supports for teaching and learning within the context of PBL because, in PBL, one endeavors to engage learners in the cultural practices of members of the target profession (Belland & Drake, 2013; Belland et al., 2013; Jonassen & Rohrer-Murphy, 1999; Schmidt, Rotgans, & Yew, 2011).

From the perspective of facilitating PBL units, it is important to note that, in PBL, teachers assume a role of guide to student learning, rather than knowledge provider (Hmelo-Silver & Barrows, 2006; Torp & Sage, 1998). One way that teachers can most help students in PBL is by prompting them to question their own understanding (Hmelo-Silver & Barrows, 2006; Hung, Harpole Bailey, & Jonassen, 2003). This role can be quite difficult for teachers to assume, both from the perspective of learning the required skills and also the dispositions to use them (Belland, 2012; Ertmer & Simons, 2006).

Developing a compelling central problem

The process of choosing PBL problems in medical education can in some ways be seen as more well-structured than choosing PBL problems outside of medical education in that in the former case, one is limited to problems that involve medical health and involve in some way the topic of instruction, be it anatomy, biochemistry, or reproductive health. Relying on researchers to work with teachers to develop PBL units does not support teacher autonomy, privilege teachers' knowledge, skills, and experience, and is not efficient or scalable (Reeve, 2013; Skaalvik & Skaalvik, 2014; Stefanou, Perencevich, DiCintio, & Turner, 2004). Thus, it is important to provide tools and processes with which teachers can create PBL problems.

Student motivation during PBL is not ensured simply by virtue of addressing ill-structured problems. Rather, instructors need to make sure that motivation theory informs the problem creation process. For example, students will not necessarily find value in addressing a PBL problem. To find addressing it to be valuable, they must find it to be both interesting and that addressing it successfully can bring about outcomes of value. From the perspective of promoting mastery goals, problems should be crafted and presented to students such that they see resolving the problem in a satisfactory manner as a more important goal than performing better than classmates. So this is tied in with the importance of establishing attainment value of solving the problem, but it also stipulates that the attainment value should be seen as higher than the value of performing better than classmates. One way to do this is not to foster competition among groups for the best problem solution (Belland et al., 2013). Given that PBL problems are ill-structured, no problem solution can really be deemed the best (Jonassen, 2011a). Rather, the process of PBL can be couched as part of a greater dialectical argumentation process, in which each group's solution can be seen as incorporating at least one element of the "true" solution (van Eemeren et al., 2014; Roth, 2012), and it is the job of the groups to collectively merge their solutions into a meta-solution at the end of the unit.

Setting up a method to conduct dynamic assessment and provide customized support

Formative assessment is key to teachers' provision of one-to-one scaffolding in that it helps teachers determine the exact support that students need at the given time, and provide just that (van de Pol et al., 2010; Wood, Bruner, & Ross, 1976). Scaffolding was originally defined as one-to-one support that helped toddlers build pyramids with wooden blocks (Wood et al., 1976). But soon after, researchers questioned whether computer tools could also fulfill the scaffolding function (Hawkins & Pea, 1987). Computer-based scaffolding has never been seen as a sole source of student support, but rather as a complement to one-to-one teacher scaffolding (McNeill & Krajcik, 2009; Saye & Brush, 2002).

But determining the concepts and skills upon which dynamic assessment should focus, and how dynamic assessment should proceed is not something that can happen in the moment in which dynamic assessment is conducted. Rather, it should happen in the design of the unit. This is challenging in that addressing PBL problems does not require a uniform set of content knowledge and skills. That is, depending on the problem solution path that is selected and the division of the problem solution tasks among group members, individual students may require different sets of content knowledge and skills.

One of the most difficult aspects of facilitating a PBL unit is engaging in the type of support customized through dynamic assessment that is the highlight of teacher scaffolding (Belland, 2012; van de Pol et al., 2010; Wood et al., 1976). In K–12 settings, it is entirely normal to have a classroom of 30 students and one teacher. Even if students are working in groups of five, there would be six small groups, and each group would likely be going in different directions at the same time. Within the same group, different members will be going in different directions. This is desirable and to be expected, and in many ways it makes teacher scaffolding even more important.

One cannot expect to achieve optimal motivation simply through unit design and the design of tools for students to use during PBL. For example, student struggle is a natural part of engaging in PBL (Belland et al., 2008; Simons & Ertmer, 2006). In fact, if students do not struggle at all, one may question whether the central problem was in fact ill-structured and/or at the appropriate difficulty level. This can lead to academic emotions such as anger, which can inhibit effective engagement with the central problem, effectively leading students to shut down (Kim & Pekrun, 2014). Support for emotion regulation can be designed into computer-based scaffolds (Belland et al., 2013). But PBL instructors should take care to help students cope with negative emotions that arise during PBL, and maximize positive emotions such as pride (Kim & Pekrun, 2014).

Processes and Tools to Address the Challenge

Tools to develop a compelling central problem

To design PBL problems, one can use the 3C3R model as a starting point (Hung, 2006). According to the model, one needs to consider the content to be taught, contextual information that should be embedded in the problem, and how connections can be made between the target PBL problem and other problems to be addressed as well as other curricular material. One also needs to consider the types of researching, reasoning, and reflection processes in which students would need to engage to address the problem. When considering the content to be addressed, it is crucial to consider standards that need to be addressed as well as what students may find to be authentic, as PBL problems can never be considered inherently authentic, but rather can only be deemed authentic by individual students after they compare such to their own goals and experiences (Barab, Squire, & Dueber, 2000; Belland et al., 2013; Hung & Chen, 2007). For example, students in the intermountain west, USA, may find a problem centered on the association between snowmobiles and avalanches to be authentic, whereas students in Florida would likely not. On the other hand, if the students are not interested in snow sports, then the chances that they would find the problem to be authentic are slim (Hidi, 2006; Renninger, 2009).

But using the 3C3R model is not enough. From the standpoint of designing technology tools to help with the development of PBL units, the idea of cultural knowledge is key (Belland & Drake, 2013; Jonassen & Rohrer-Murphy, 1999). On one hand, the cultural knowledge that one wishes students to gain becomes a substitute for behavioral learning objectives. This is because instructional designers and instructors need to arrange instructional support to help learners assimilate the cultural knowledge. But at the same time, cultural knowledge is really nothing like a behavioral learning objective, in that it is not something that can be easily seen or even conceptualized, and it is not something that can be easily converted into an assessment item. Furthermore, it cannot be neatly broken down into subobjectives and/or an information processing analysis, as is called for by traditional instructional design (Dick, Carey, & Carey, 2001; Smith & Ragan, 1999). For this reason, traditional instructional design cannot be used to design technology tools for PBL.

Since a traditional task analysis cannot be done when designing instruction to help students acquire cultural knowledge, one needs to use an alternative instructional design strategy for scoping the problem and scoping and sequencing instructional support. One way to think about this is through modeling. Specifically, one can develop an initial problem and model (a) the cultural knowledge related to the field of study or practice that students should acquire through participation in PBL, and (b) different phenomena related to addressing the initial problem, including interaction processes that students will use, approaches to planning and implementing problem solving, goals students have while addressing the central problem, and affordances of tools (Akhras & Self, 2002; Belland & Drake, 2013). The goal is that the models begin to converge through an iterative cycle of model revision. As the models are revised, the central problem will be revised.

Technology can play a key role in the modeling process. Using concept mapping tools such as simplemind ("Simplemind," 2015) or bubbl.us ("Bubbl.us," 2017) can allow instructors to map connections among different problem elements, cultural knowledge that it is hoped students will gain, interaction processes students will likely use, goals students will likely have, and tool affordances. Such concept maps can be compared to see where they (a) overlap and intersect, (b) should be fleshed out further, or (c) need to be streamlined. Through this process, critical problem elements can emerge, and the central problem may emerge (see Figure 18.1 for an example).

Tools to present the problem

Various technologies have been used to present PBL problems, including video cases (Balslev et al., 2005; Chan et al., 2010; de Leng et al., 2007) and written cases. The key purposes of such problem presentations include fostering interest in the problem and informing students of key factors involved in the problem. Presenting problems in video and written cases has the advantage of being replicable, and instructors can ensure that just the right amount and kind of information about the problem is given to students. This way, all class sections get the same

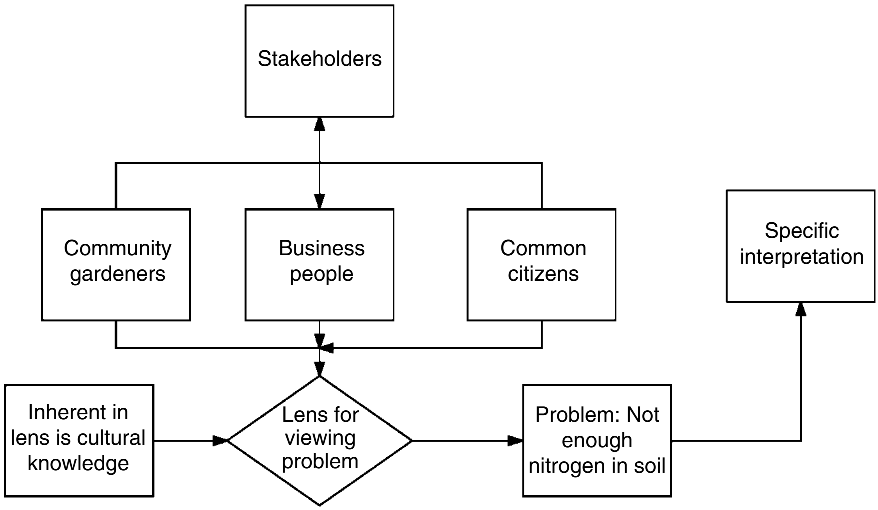

Figure 18.1 Example of Modeling to Design a Problem Related to Soil Quality.

information to start off, and it can be ascertained ahead of time that there is neither too little nor too much information about the problem given to students.

Tools to conduct dynamic assessment and provide customized support

In a lecture-based classroom, it is relatively easy to ascertain whether students are getting it. After all, if the teacher is lecturing about A, B, C, then he or she simply needs to quiz students on A, B, C. In a PBL classroom, it is not so simple. First, students can be learning about different content at different times, and that is okay. The key in PBL is to consider and model the types of actions informed by different goals that students might endeavor to undertake, and what types of affordances they may be looking for in tools. One can consider this according to the framework of creating process, situation, motives, and affordances models (Akhras & Self, 2002; Belland & Drake, 2013), which was discussed earlier. This can help teachers anticipate the types of indications that students are on the right track and "getting it" and indications that students are off track and in need of support. For example, when addressing what is the most productive use of a plot of land when considering soil quality and location, teachers may model several possible goals that students may have (e.g., determining the suitability of the soil sample for growing crops or supporting buildings) and associated processes in which they may engage (e.g., testing soil for nutrients and pollutants, examining soil zone maps). Within this process, teachers need to think about indicators that students are proceeding successfully or unsuccessfully. This involves generating a list of concepts and skills involved in each learning path in which students may engage. One can do so using concept mapping tools like bubbl.us ("Bubbl.us," 2017) and simplemind ("Simplemind," 2015).

But it is unreasonable to expect teachers to be able to track the extent to which students are struggling /or progressing vis-a-vis process, situation, motives, and affordances models for each student individually in a 30-student class. One teacher simply does not have the time or resources to do so. Technology can help by setting up a system that text mines student writing to identify strengths and weaknesses in relation to the situation, process, motives, and affordances models related to the unit task (Erkens, Bodemer, & Hoppe, 2016; Papamitsiou & Economides, 2014). In its simplest form, this involves checking students' writing for the existence of n-grams (writing segments) that are associated with pertinent constructs (Akkarapatty, Muralidharan, Raj, & Vinod, 2016).

One way that the process by which students engage in a PBL unit emerges is through students' consideration of motives and affordances (Belland & Drake, 2013), but also crucial is the strategy that is bootstrapped by the teacher. This can be outlined through computer-based scaffolding, which is discussed in greater detail in the "Technology tools to aid unit participation" section in this chapter. Broadly speaking, PBL typically involves processes of defining the problem, determining and pursuing learning issues, gathering and synthesizing information, and developing and defending a problem solution (Belland et al., 2008; Hmelo-Silver, 2004). Within the PBL learning process, self-direction is key (Loyens et al., 2008). But this does not mean that one should simply provide an overall goal to students and expect them to take it from there. Rather, one should provide a framework that breaks down the overall PBL process and invite students to engage in those subelements. This can be seen perhaps most prominently in the Learning by Design (Kolodner et al., 2003) and Anchored Instruction (The Cognition and Technology Group at Vanderbilt, 1990) approaches. These are admittedly not pure PBL approaches, but there is much to be learned from their approach to segmenting the learning process. Breaking the process into distinct, iterative stages representing such processes as brainstorming, gathering and synthesizing information, making initial designs, sharing work, gathering feedback, and redesigning helps to make the learning process more manageable by encouraging students to focus their self-direction efforts to micro-processes, rather than macro-processes. But when designing this, one needs to consider the types and levels of cultural knowledge that the students have, both individually and in cooperation with their group mates and while using the cultural tools already present in the classroom. This is so that the subprocesses being promoted to facilitate engagement in the PBL process do not conflict with learners' existing schemata. This can result in overscripting, which can harm learning performance (Dillenbourg, 2002). For example, meta-analysis results indicate that effect sizes were statistically lower when learners engaged in group work while solving an ill-structured problem were provided collaboration scaffolding than when they were not, perhaps due to collaboration scripts conflicting with existing schemata about effective collaboration (Andreassen, Kim, Lefler, Belland, & Walker, 2016).

A more efficient way for teachers to identify students who need additional support based on their responses to scaffold prompts is to use machine learning to flag individual students who are struggling unduly, based on automatic grading of student responses. Machine learning would be needed because students are engaging in mediated action, and so the exact actions they take could vary on the basis of different motives and affordances of different tools with which the students are interacting. Thus, there is no one "correct" or "incorrect" action or response for any given scaffold prompt. The results from machine learning would not be used to automatically formulate feedback to be provided to students, but rather would be information to which teachers could refer to determine which students need help. Accordingly, teachers could then help students who most need help. However, machine learning of students' scaffold inputs would only be partially capable of diagnosing students' current abilities, as cultural knowledge is often tacit, and may not inform all that students articulate. Once they go to the students in question, teachers would need to pose probing questions to further elucidate students' current abilities.

To gather information on student emotions so as to know who needs most support, teachers can use eye tracking and facial recognition (de Lemos, Sadeghnia, Ólafsdóttir, & Jensen, 2008). This no longer requires expensive equipment—Microsoft Project Oxford API does this (Microsoft, 2015), and this can lighten the load for teachers in managing the academic emotions of students. This can also be linked to the machine learning algorithms to which text mining is linked.

Technologies to Aid PBL Students

The Challenge

Addressing the central problem

To address a PBL problem, students need to (a) characterize the discrepancy between what is and what should be, (b) specify and find learning resources to understand the problem better, (c) synthesize and use the learning resources to develop a potential solution, and (d) justify the solution with evidence by way of premises (Belland et al., 2008; Loyens et al., 2008; Perelman & Olbrechts-Tyteca, 1958). Beneath each of these actions lie several key abilities, including qualitative modeling, self-directed learning, problem-solving ability, and argumentation ability. Qualitative modeling refers to representing problems in terms of entities, actions, and how the actions affect the entities (Anzai & Yokoyama, 1984; Chi, Feltovich, & Glaser, 1981; Larkin, McDermott, Simon, & Simon, 1980). Self-directed learning refers to the ability to set learning goals and devise and carry out plans to address the goals (Bolhuis, 2003; Loyens et al., 2008). Problem-solving ability means the ability to define the problem, and determine how (a) the problem entities are interacting, (b) such interactions deviate from the ideal state, and (c) conditions can be arranged to allow the interaction among the problem entities to approximate the ideal state (Bodner, 1991; Jonassen, 2011a). Argumentation ability refers to the abilities to back up claims by way of evidence (van Eemeren et al., 2014; Perelman & Olbrechts-Tyteca, 1958) and critically evaluate the extent to which claims are backed with evidence (Glassner, Weinstock, & Neuman, 2005; Kuhn, 1991).

Collaborating effectively

Furthermore, success in PBL requires effective collaboration (Belland, Glazewski, & Ertmer, 2009; Lindblom-Ylänne, Pihlajamäki, & Kotkas, 2003; Lohman & Finkelstein, 2000). But it would be a mistake to think that one can list out the skills required to be successful in PBL, and teach those in succession. Listing the skills would be an exercise in futility, and even if it were not, teaching the skills in succession would be antithetical to the idea of PBL. In PBL, the problem should drive learning, not the other way around.

Processes and Tools to Address the Challenge

Tools to help students address the central problem

The nature of ill-structured problems means that students cannot find answers to the driving question or the unit problem simply by reading a source. Rather, addressing a PBL problem requires critical synthesis of information from multiple, credible sources. This, in turn, requires two things—ability to evaluate the credibility of sources and ability to synthesize disparate pieces of information (Bråten, Ferguson, Strømsø, & Anmarkrud, 2014; Britt, Richter, & Rouet, 2014). In short, one needs substantial information literacy.

One way in which such support can be operationalized is in the form of computer-based scaffolding. From a macro-perspective, scaffolding can be seen as a tool that makes problem solving more manageable by removing complexity that is not central to learning goals, while leaving intact and highlighting levels of complexity that are central to learning goals (Reiser, 2004). From a micro-perspective, computer-based scaffolding can focus on supporting student learning and performance in many different areas (Belland, 2017). For example, it can help students (a) with things to consider when solving the problem, (b) with strategy, (c) question their own understanding or progress, or (d) be motivated (Belland et al., 2013; Hannafin, Land, & Oliver, 1999). It can focus on supporting argumentation (Belland, 2010; Belland, Gu, Armbrust, & Cook, 2015; Cho & Jonassen, 2002), problem solving (Ge & Land, 2003; Kim & Hannafin, 2011), and information evaluation and synthesis (Raes, Schellens, De Wever, & Vanderhoven, 2012; Wolf, Brush, & Saye, 2003). For example, the *Connection Log* invites students to respond to question prompts first individually and then as a group, taking them through the PBL processes of defining the problem, determining, finding, and organizing needed information, making claims, and linking evidence to claims (Belland, Gu, et al., 2015). Another computer-based scaffold asks college-level computer science students questions to help them identify programming goals, and bootstraps a strategy for helping them accomplish the goals (Lane, 2005). Computer-based scaffolding can be designed to enhance students' information literacy. For example, the Big Six framework (Eisenberg & Berkowitz, 1990) was used to inform a revision of scaffolding embedded into the *Persistent Issues in History* network (Wolf et al., 2003). This helped students to question their own understanding.

Meta-analyses of computer-based scaffolding (Belland, Walker, & Kim, 2017; Belland, Walker, Kim, & Lefler, 2017; Belland, Walker, Olsen, & Leary, 2015) and scaffolding in intelligent tutoring systems (Ma, Adesope, Nesbit, & Liu, 2014; Steenbergen-Hu & Cooper, 2013, 2014; VanLehn, 2011) indicate that students using scaffolding outperform control students. Indeed, the magnitude by which students using scaffolding exceeded the performance of control students was at least 0.4 SDs at the concept, principles, and application levels (Belland et al., 2017). Pre–post gains on tests of cognitive skills was at least $g = 0.74$ at the concept, principles, and application levels (Belland, Walker, & Kim, 2017).

From the perspective of motivation theory, students need to be willing to deploy effort toward addressing the central problem, and engage accordingly. Through the thoughtful design of technologies to support participation in PBL, teachers can enhance student motivation during PBL. One way to do this is through consideration of motivation and emotions alongside cognition in the design of computer-based scaffolding (Belland et al., 2013). Belland et al. (2013) described methods to design computer-based scaffolding that supports motivation and cognition.

Considering the use of technologies in a public demonstration of student work may serve to enhance feelings of self-efficacy among students as they get public recognition of their hard work and accomplishments. This may also boost feelings of connectedness. If the problem being addressed is of local relevance for example, communicating the results of students' problem solving processes to prominent community stakeholders can also enhance feelings of connectedness and self-efficacy.

Tools to help students collaborate effectively

Within the CSCL (Computer Supported Collaborative Learning) literature, there is much work on tools to help students collaborate effectively, termed collaboration scripts. Collaboration scripts are based on the premise that engaging in effective collaboration entails following a set process by which one can engage with a problem and with group mates also addressing the problem (Atmatzidou & Demetriadis, 2012; Kollar, Fischer, & Hesse, 2006; Wecker et al., 2010). Such scripts support students in distributing tasks, responding to and integrating group mates' contributions into a group consensus, and ensuring that no one individual's perspective dominates discussion (Atmatzidou & Demetriadis, 2012; Kollar et al., 2006; Wecker et al., 2010). Collaboration scripts can often be tailored to a particular unit or problem, but there have been some efforts to create reusable collaboration scripts that can be used with a variety of units and problems (Wecker et al., 2010).

Conclusion

As PBL spread to contexts outside of medical education, new challenges emerged in the design and facilitation of PBL units, as well as participation in PBL. To address such challenges, it was necessary to apply theories of learning and motivation to the design of tools and processes to support PBL in nonmedical school contexts. Specifically, designers could not rely on an assumed interest on the part of students in addressing a constrained set of problems related to the human body. Rather, they needed to actively consider methods to design problems and learning processes to appeal to students' interest, perceived value, self-efficacy, task value, goal orientations, autonomy, and belongingness. They also needed to consider the cultural knowledge residing in small groups and how new knowledge emerges within the group knowledge building that is inherent to PBL. Technology plays a vital role in supporting these processes through such tools and processes as conceptual modeling, provision of formative assessment data, and computer-based scaffolding. Tools and processes can help instructors and designers develop PBL units, including the central problem and dynamic assessment strategies.

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Section IV

PBL in Practice: Case Studies

Introduction

Problem-based learning (PBL), with its various models and interpretations, has been adopted as an innovative teaching and learning method and curricular philosophy or model at the institution level, program level, course level, and module or lesson level. While its first program-level implementation was 40 years ago at McMaster University in Canada and then at Maastricht University in The Netherlands for medical curricula, PBL has now been used in various other disciplines (e.g., medicine, engineering, business, pharmacy, education, etc.), for different age groups (adults, young adults, children) and content domains. Nevertheless, despite its rapid proliferation, the implementation of PBL at various levels and with various educational goals and formats continues to be challenging. This section of the handbook is a collection of case studies that aim to offer examples of PBL in practice. The authors of the case studies provide a detailed description of how they conceptualized, designed, implemented, and evaluated PBL in the fields of engineering education, medical education, business education, science education, teacher education, and K–12 education to demonstrate how PBL is used at various levels, in various age groups and disciplines.

In Chapter 19, “Learning and Assessing Problem-Based Learning at Aalborg University: A Case Study,” Kolmos and her colleagues present university-level PBL implementation strategies. As a full-scale PBL and project organized university, Aalborg University (AAU), Denmark, has kept and developed its PBL model in nearly all educational programs within the humanities, social sciences, health and medicine, engineering, and science. Kolmos and colleagues explain how the project work model of PBL, which accounts for 50% of the students' time, is designed and implemented at the university level. They further explore the implementation challenges at the institutional level, and explain how engineering and science programs developed and implemented various methods to

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prepare students for the demands of engaging in the collaborative project-based learning environment. The authors go into the details of the models they used and the challenges they faced and the strategies they used to transform the challenges into learning opportunities.

Similarly, but within the discipline of medicine and health sciences, in Chapter 20 "PBL in Medical Education: A Case Study at the Université de Sherbrooke," Bédard provides a detailed description of the Université de Sherbrooke's innovative three-phase approach to conducting PBL in the medical program. Bédard presents the major changes that have taken place in the Université de Sherbrooke's medicine and health sciences program since 1987, the year that PBL was implemented. After analyzing the evaluation data, Bédard concludes the chapter by showing what impacts new trends in medical and health sciences education have had on the program.

As the early adopters of PBL in management education, Hallinger and his colleagues in Chapter 21 "Seeing and Hearing is Believing, But Eating is Knowing: A Case Study of Implementing PBL in a Master of Educational Management Program," describe the use of PBL in an online graduate degree program in Hong Kong. Hallinger and his colleagues use one course as an example to demonstrate how PBL was used to design an online International Executive Master of Arts in educational management (IEMA) course that aimed at a target audience of English-speaking school leaders and aspiring school leaders working in the Asia Pacific region. They provide detailed explanation of how the course was designed using problem-based computer simulations that engaged students in solving a set of high-fidelity, complex, dynamic management problems. After analyzing the design and implementation of PBL in the online management course, Hallinger and his colleagues offer the findings of their innovation and discuss the feasibility and effectiveness of PBL in the context of the online executive Master degree program in East Asia.

In Chapter 22 "PBL Capstone Experience in Conservation Biology: A Self-Regulated Learning Approach," English and Kitsantas explain how PBL was used in designing an undergraduate capstone course in conservation biology that employed a project-based learning approach. For the design of this course, English and Kitsantas specifically focus on promoting self-regulated learning (SRL). In addition to providing detailed explanations of how the course was designed and implemented, the authors present evidence that illustrates how students demonstrated a high level of SRL and that the course experience was positive.

In Chapter 23 "Promoting Ambitious Teaching and Learning through Implementing Mathematical Modeling in a PBL Environment: A Case Study," Suh and Seshaiyer use classroom episodes to examine how teachers designed mathematical modeling tasks in the context of PBL in the elementary grades, and some of the important pedagogical practices and mathematical norms that were needed for students to fully engage in the process as mathematicians. The case study reports on the part of a larger 3-year exploratory research project that sought to research and evaluate the effects of professional development (PD) in mathematical modeling for elementary mathematics teachers. The results of the study show that, through the practice of mathematical modeling lessons, teachers recognized several important pedagogical practices and mathematical norms that needed to be established in their classrooms, including establishing norms for collaboration and participation.

Finally, in Chapter 24 "A Case Study of Project-Based Learning of Middle School Students Exploring Water Quality," Novak and Krajcik explore a semester-long seventh-grade, project-based learning curriculum, where students investigated a driving scientific question. The case study provides a detailed account of how students engaged in an investigation using the driving question. It illustrates features of project-based learning, provides evidence of how such environments can support students to develop an integrated understanding over time, and shows the critical role that teachers play in shaping such environments.

The case studies section offers excellent examples that could guide future designers, practitioners, and researchers in conducting PBL at a different level and for various contexts, content, and age groups.

19

Learning and Assessing Problem-Based Learning at Aalborg University: A Case Study

Anette Kolmos, Pia Bøgelund, and Claus Monrad Spliid

Introduction

Aalborg University (AAU), Denmark, was established in 1974 as a reform university with a problem-based and project-organized pedagogical approach. Throughout all semesters, the original model involved students working in project teams for half their study time. For the other half of their time, they work with traditional course activities (lectures and assignments). Half of the courses are closely linked to the projects and assessed in group-based project exams, and half of the courses have individual exams. A project period is normally one semester, and for each semester, there is a theme with overall learning objectives framing the students' projects (Kolmos, Fink, & Krogh, 2004).

As one of the reform universities, AAU has kept and developed the AAU problem-based learning (PBL) model in nearly all educational programs within the humanities, social sciences, health and medicine, engineering, and science. However, the development has not been linear. On the contrary, there have been many internal as well as external drivers influencing the direction. One driver is the power of the disciplines, particularly in the history of the first-year program, also called the basic year. There is a clear trend going from an interdisciplinary approach to a much more disciplinary approach, and the pendulum has not yet swung back, as it has at other universities (Neville & Norman, 2007). The interdisciplinary or disciplinary-dominated approaches influence the PBL process—especially regarding the students' possibilities to choose problems to work on in their projects. The learning involved in the identification of a problem in a societal theme might be very different from that in the identification of problems within a narrowly formulated technical theme. However, the projects are comprehensive, and the project always has to cover more than just one discipline. In the Danish PBL tradition, 42 years ago as well as now, students identify and formulate their own problems for the projects. The problems are, therefore, integrated into a project-organized and team-based learning process.

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Table 19.1 Differences Between the Seven Jumps and Project Phases, Modified After (Kolmos & de Graaff, 2014)

	Seven Jumps (Gijselaers, 1996)	**Project phases (Algreen-Ussing & Fruensgaard, 1992)**
Problem analysis	1) Clarify terms and concepts not readily comprehensible 2) Define the problem 3) Analyze the problem and offer tentative explanations 4) Draw up an inventory of explanations 5) Formulate learning objectives 6) Collect further information through private study 7) Synthesize the new information and evaluate and test it against the original problem. Reflect on and consolidate learning	1) Initiating a problem (the trigger for the problem—what starts it) 2) Problem analysis (analysis of the problem—for whom, what, and why) 3) Definition and formulation of problem (specification requirement)
Problem solving		4) Problem-solving methodologies (overview of possible solutions and assessment of impact) 5) Demarcation (argumentation for the choice of solution) 6) Specification of requirements 7) Solving the problem (carry out the solution—construction/design/further analysis) 8) Implementation (prototype and sometimes real systems) 9) Evaluation and reflection (impact, effect, and efficiency of solution)

As the AAU PBL model is organized on the institutional system level, it might be very different from the case with other universities that did not start out with a PBL curriculum. Globally, there is a general issue that PBL is mostly implemented at the course level and not at the system level, which concurrently creates a lack of a more systematic introduction and learning of PBL skills (Kolmos, Hadgraft, & Holgaard, 2016).

What might also be special for AAU is the fact that the PBL model carries features of both problem-based learning—problem-based learning in the sense that students have to identify problems and analyze problems—and project-organized learning. In the project-organized approach, students have to work out a common product at the end of the project process, most commonly a project report.

Over the past 20 years, the problem-based and project-organized models have merged when new institutions are applying PBL principles. Analyzing the learning principles behind the Maastricht PBL model and the Aalborg PBL models, they are very much alike, but the organization of the learning process differs (Kolmos & de Graaff, 2014). Normally, in a case-based PBL system, Seven Step procedures—or similar—are used, whereas there are project phases in the project-based models (see Table 19.1). Therefore, the process skills will accordingly differ as these reflect the elements in the learning process. With the problem-based cases, what the students have to do at each step in the Seven Step procedure is well formulated. Of course, more open cases with ill-structured problems create more challenges for students.

With the project phases, the scope of the problems will of course also determine the process—with a narrow problem it might be easier to carry out analysis and solution phases. However, in the AAU PBL model, projects are normally quite challenging because the identified problems have a considerable complexity and are worth 50% of the credit points (de Graaff, Holgaard, Bøgelund, & Spliid, 2015).

The PBL Skills Course in the First-Year Program

From the very beginning, the first-year curriculum at the Faculty of Engineering and Science has contained PBL learning outcomes in addition to discipline outcomes, and students have been assessed according to these outcomes. There is a systematic introduction and learning of PBL skills, supported by faculty, and, throughout the first year, these PBL skills are assessed. This is a very special feature of the Aalborg PBL model. Many other PBL programs claim that students learn PBL skills and competencies; however, not very many programs include support and assessment of students' PBL skills.

The first-year program within engineering and science has as one of its overall objectives for students to learn to work in a PBL system—with more specific learning objectives for each of the three projects during the first year. A core driver for the development of the teaching and learning of PBL skills has been to develop meaningfulness in studies for students. In general, the learning of PBL skills is very complex, involving learning of individual behavior, and students often find the course content banal and unnecessary. This tension has increased over the years as the students' prerequisite competencies at enrollment have changed. During the 1970s and 1980s, there were almost no PBL experiences in the K–12 system, whereas later, students had some experience, although not with such comprehensive, collaborative projects as practiced at AAU. So, there are still transformation issues for students coming from a predominantly individually oriented high school system to a collaborative university system.

Since the early 1980s, there has been a course at the Faculty of Engineering and Science aiming to provide an introduction to the Aalborg PBL model and, most importantly, to facilitate the development of students' PBL skills (PBL skills course). Today, this course consists of three important activities:

1) course activities addressing a series of relevant topics, such as project management, collaboration, methodology for problem analysis, and conflict management;
2) student work on a written collaborative process analysis;
   assessments
   a) individual assessment of acquired knowledge, skills, and competencies from the course;
   b) a joint group assessment based on the process analysis.

The purpose of this chapter is to describe and analyze the different approaches to teaching and learning PBL skills that have materialized over the years at AAU. The aim is to extract lessons learned for others, especially other institutions that wish to incorporate learning and assessing PBL skills at a system level.

Methodological Approach

In order to frame the different approaches to teaching and learning PBL skills, the history and the theoretical development of this PBL course have been analyzed. Key persons in the system have been interviewed, study regulations analyzed, and focus group interviews with lecturers and facilitators in the field used for validation. The following elements have been focused on in the data collection: (a) the learning environment, with participants responsible for teaching PBL skills or with significant influence on the development of the course and the learning; (b) the group of faculty members, in the first year, who had an influence on the implementation of the PBL skills course and the learning outcomes; (c) the learning approach, understood as the philosophy and theoretical foundations of the teaching, the relationship between the course and the project activities, and the focus on individual vs. collective learning, the specific learning activities involving course structure, and support possibilities; and (d) the report output of the process competencies and finally how these competencies have been assessed.

The analysis identifies three different phases for teaching and learning PBL skills—although time-wise with some overlap. The first phase is an instructional phase covering the years from 1974 to 1994, where the focus is on getting started and defining the basic contents of a PBL skills course. Next, is the second phase, an experiential learning phase covering the years from around 1994–2006, where the focus is on sorting out the theoretical foundations of the course and getting the students to experiment. Finally, the third phase is an instrumental phase covering the years from 2006 to 2015 where the focus is on how to accommodate changes and pressures coming from external trends and initiatives (see Table 19.2 for an overview). The analysis indicates that we have a pendulum going between a more instructional approach and a more student-centered approach, however with different variations.

The following sections will outline the identified issues in more detail. Due to the development, different phases highlight different elements. Thus, phase one will focus more on the specific learning activities, whereas phase two will focus more on the learning approach and philosophy, and phase three will focus more on the educational and political impact of a change in the learning environment. Each of the identified approaches has its own challenges both in terms of student learning and assessment. The development of the PBL skills course was taken care of by a group of engaged teachers in the first phase, whereas a more formalized research group on PBL and engineering education research was in charge during the last two phases.

In the Conclusion, we will identify challenges for further developments and outline the lessons learned throughout the phases and their implications for implementing these curriculum elements in other systems.

Phase 1: Instruction

From the very beginning at AAU, the learning of process-oriented skills for handling the project process was part of the official curriculum. Among faculty, there was much tension in the first years, as AAU had integrated two engineering

Table 19.2 Issues of Learning Environment, Learning Approach, and More *Specific* Learning Activities in Three Phases

	Learning environment	Learning approach	Learning activities
Phase 1: Instruction (1974–1994)	Responsibility: facilitators and course lecturers	Experience-driven instruction	Course lectures Co-supervision
	Learning organized in interdisciplinary theme-based "large groups"	Course linked to project and course facilitators	Project diary Process description
	Managed by interdisciplinary faculty groups and collaborative planning	Collective focus	PBL skills assessed as part of the group-based project exam
Phase 2: Experiential learning (1994–2006)	Initiatives and responsibility: students, course lecturers and facilitators	Facilitated experiential learning based on evidence from practice	Course lectures Co-supervision
	Learning organized in discipline-based semester groups	Course linked to project and project facilitators	Structured reflection by analyses of collected data Process analysis
	Managed by disciplinary faculty groups and collaborative planning	Collective focus	PBL skills assessed as part of the group-based project exam
Phase 3: Instrumental learning (2006–2015)	Responsibility Course lecturers and facilitators	Compelled Instruction	Course lectures Consultants
	Learning organized in discipline-based semester groups	Course linked to project	Individual written assessment of course Process analysis
	Managed by discipline-based coordinators	Individual and collective focus	PBL skills assessed as part of individual or group-based project exam

schools. There were also mixed feelings about PBL, and some of the academic staff members were directly against the new educational model. So, the study regulations were quite significant for the change of the study activities.

The overall objectives for the basic year were essentially unchanged from 1974 to 1995 and stated that students should acquire, among other things "…skills in independent problem-formulation and problem-solving" as well as "…skills in collaboration and communication" (Den Teknisk Naturvidenskabelige Basisuddannelse, 1974–95). These objectives constituted the clear basis for the efforts to provide students with sufficient knowledge and skills to fulfill the requirements for analyzing and solving more complex project processes in further studies at the technical departments. These departments, on the other hand, assumed that students were fully competent in the abovementioned skills mentioned after the first year, which, therefore, were given no further attention. The assumption proved wrong according to semester evaluations, and it took time to realize that process skills cannot be perfected over a 1-year period (Algreen-Ussing, 2016).

Learning Environment

Approximately 100 students were administratively assigned to a large "main group" with an attached group of facilitators from various academic backgrounds (although a majority were technical specialists) and a coordinating secretary. The secretary played an important role in securing communication and transparency among students and facilitators—essentially being the administrative and social pivot. Group size was predominantly six to eight students, and each project group had their own group room. Regular meetings including students and staff allowed formative assessment of all factors influencing the learning processes. Through these peer assessment forums, students gave feedback on lectures and facilitators and other resource issues. The main responsibility regarding PBL was left to the facilitators. Guidelines for the facilitator were gradually elaborated, and short seminars introduced new staff to the essential roles—although based on voluntary participation. However, the regular (formal and informal) meetings among facilitators set the scene for the sharing of experiences and testing of improved or alternative approaches.

Learning Approach

At the time when AAU was established, there were no courses at all on learning PBL skills. Although facilitation and feedback were the essential components of the Aalborg model, specific project-related courses were gradually incorporated into the curriculum to support student acquisition of the overall objectives. During the late 1970s and early 1980s, most time spent on course development was used for building up a conceptual framework of problem-based project work as this was a new teaching and learning practice and therefore had no language. Teachers of the PBL skills course were initially volunteers with an interest in this area, and they started to build up the content of a new subject and did not really concentrate on how the students acquired the content.

As students' shortcomings in managing the project process persisted, the associated courses were, over time, refined and extended to be more closely aligned with overall objectives, but the consistent focus was tools for managing the working process (i.e., project structure, work plans, and time schedules). From an early focus solely on written communication (reporting and illustrating), oral communication and project work were later added, while the final versions included group dynamics and scientific methodology for problem analysis and problem solving.

The course was a project unit course (PE course), meaning that there were no formal participation requirements for this type of course. However, the PE courses supported the project and were assessed in the group-based project exam. Also of importance for the students' acquisition of PBL skills was the fact that one of the two facilitators assigned to each group would have a special eye for contextual and process-related issues of the group work, whereas the main facilitator would safeguard the technical disciplines.

Learning Activities

The learning activities largely consisted of coursework organized for each semester, including consultancy available when groups needed assistance. An ongoing debate concerned the timing of the lectures in relation to the progression of the project work. It proved an impossible task to meet every single group's need on time, and the course itself developed an approach with introductory lectures followed by a consultancy with individual groups.

The first course—the Communication course—was a short course, which, from the very beginning, supported engineering students in delivering appropriate project reports with technical and academic rigor. One part of this course was focused on the sketching and drawing of necessary graphical illustrations of technical details, which had also been part of curricula in the previous engineering colleges. Another part of this course focused on the organization of the report and the oral presentation. The teachers who taught the course also functioned as consultants for the project groups during the first and second semesters, and, for the project exams, the teachers delivered an extensive critique intended to benefit student reporting in subsequent semesters.

During the early 1980s the course gradually expanded into two separate courses: "Sketching, Drawing and Communication" and "Communication and Project Work." The Communication and Project Work course focused on the project process and thus addressed the two central points stated in the purposes for the basic year. The contents included lectures and exercises on:

- project initiation, needs assessment, problem analysis, problem formulation, problem delimitation and problem solving;
- time schedules, work plans, notes, diaries, and drafts;
- communication models and oral communication, as well as written communication skills.

Again, the course lecturers were available for consultations, and they provided comprehensive feedback on the first semester report's communicative state prior to the project exam.

The supporting recommended literature was basically produced by course teachers, and, over time, more and more elaborate tool books were published—in line with the abovementioned course development. The study guides also listed supplementary literature, which elaborated on the main issues in more detail (i.e., problem orientation, project pedagogy, problem-solving techniques, scientific methods, group dynamics, and group psychology). Students were prone to use the materials as manuals and, therefore, some found them to be too simple and insufficient, while others thought they were too elaborate and abstract. The course activities sought to address this in various ways.

In the project groups, two tools, in particular, supported the acquisition of PBL skills. One was the project diary—a necessary tool for the project groups to keep track of the group's work during the different project phases. The purpose of the project diary was to describe the group's work process so that the group got used to working that is deliberate and planned. This was done in such a way that a continuous adjustment could naturally take place. The other tool was the process description, which, by the end of the project period, was a comprehensive assessment of the project work's pedagogical progression. This was a required hand-in for the project exam documenting the experience and achievement of participating in an educational approach intended to lead to increased independence, responsibility, and consciousness in work. The project diary became an aid for the preparation of the process description.

Assessment of PBL Skills

As was pointed out earlier, the specific assessment of process skills was based on a half-hour discussion of the project process as documented in a short written process description.

On a general note, toward the end of phase 1, many students valued the PBL skills course, the consultations, and the feedback, while others found the course itself of little value and irrelevant, partly because of the assessment format and partly because students had poor conceptions about engineering skills. Semester evaluations testified that students and facilitators alike consistently reported difficulties with problem formulation and academic reporting. The facilitators saw their primary function as securing academic achievements through the project's technical (and to some extent societal) analyses, while the reporting was a secondary function. In general, facilitators also had poor conceptions of engineering skills and had little concern for the project process and the intended process outcomes. Study board recommendations and external examiners from industry continuously stressed the need for improved commitment from both teachers and project facilitators—consistently regarding their roles to be of vital for student achievement.

Phase 2: Experiential Learning

During the 1990s, the PBL skills course was renamed and redefined, and a new research group drove the development on PBL and Engineering Education. The name of the course changed to Collaboration, Learning, and Project Management (CLP). The learning objectives also changed from being an introduction to PBL to facilitating the learning of PBL competencies or what was also called process competencies. Thus, the process description changed to "process analysis" in name, indicating that students should really reflect on their own learning process and indicate factors that could be improved in their next project process (Algreen-Ussing & Dahms, 1995; Algreen-Ussing & Kolmos, 1996).

Learning Environment

The learning environment changed drastically during this period. The basic year started out as an interdisciplinary introduction to all engineering and science programs. During this first year, the students had to choose their special line of study. However, the departments felt that there was overload in the entire program and wanted to have more specific discipline content in the first year. This resulted in program-specific main groups, which had a tremendous impact on the PBL approach in terms of the types of problems that the students worked with and the learning environment. With the interdisciplinary main groups and themes, collaboration among all disciplines was necessary, while, with the disciplinary main groups, the themes became narrower and the collaboration in the project groups perhaps easier in the sense that there was a prerequisite understanding of the scientific language.

On the other hand, a process was initiated to strengthen the PBL approach in this phase. Driven by the head of the study board, initiatives were taken to develop the PBL practice, and academic staff members were trained by Professor John Cowan, who gave inspiration for the further development of the PBL skills course (Cowan, 1998). The existence of a specific group of dedicated PBL researchers created its own momentum to strengthen the PBL competencies of the students.

Learning Approach

The PBL skills course was developed to integrate much more reflection and experimentation. However, this change was not so easily done as the course content was mostly about tools and delivered in an instructional mode. If the course were to facilitate reflective learning of collaborative project practices, it also needed to be taught in a reflective mode. So, the teaching and learning approach, as well as the theoretical understanding of learning, had to change, and the change was made by building up practice learning with reflection theories. Reflection methods were integrated into the PBL skills course, and the pedagogy in the course was changed so the students always had to reflect on their experiences, which could be used as material in their process analysis, and Kolb's learning circle was used for putting reflection into a learning context (Cowan, 1998; Kolb, 1983; Schön, 1983).

At first, however, the more theoretical approach did not work. As it was applied to the learning, the elements of reflection of experiences, conceptualization, and experiments were followed as linear phases. The engineering students reacted, and student evaluations indicated that this was boring and theoretical. Thus, the suggested idea was to turn the learning upside down and start with letting the students create their own experiments and then let them reflect. Theoretically, the Kolb approach to learning was combined with Schön's approach of "reflection-in-action" and "reflection-on-action" (Schön, 1983). "Reflection-in-action" is a process where reflection and experimentation are intertwined and take place at the same time. "Reflection-on-action" is reflection at a distance, and it contains an element of evaluation of former actions, like the reflection in Kolb's learning circle. So, the new idea was to introduce reflection on a much more day-to-day basis, using experiments with practice as the vehicle for reflections upon learning. For engineering students, this created motivation as they were asked to experiment and be creative with their own collaborative processes.

Cowan (1998) emphasizes that reflection is related to practice and experiences, and, for each reflection process, there is a before-reflection, an in-reflection, and

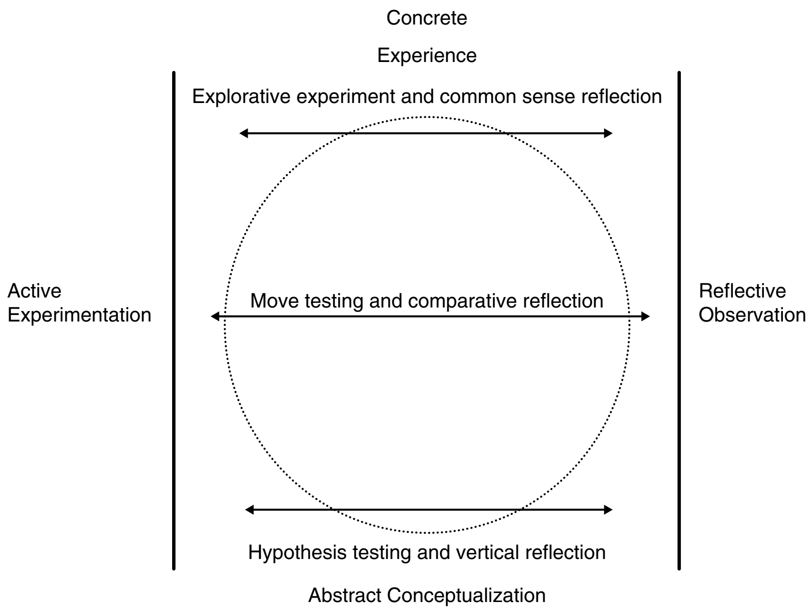

Figure 19.1 Learning model developed to understand the theoretical approach to the PBL skills course CLP (Kofoed, Hansen, & Kolmos, 2004).

an on-reflection. Schön (1983) correspondingly approaches reflection and experiments as merging processes, and he talks about three types of experiments, which all include reflections: the *Explorative Experiment*, the *Move Testing Experiment*, and the *Hypothesis Testing Experiment*. All three types of experiments are part of reflective practice, so the practitioner jumps from one type to the other depending on the purpose—as illustrated in Figure 19.1. The Explorative Experiment is "when action is undertaken only to see what follows, without accompanying predictions or expectations" (Schön, 1983, p. 145). The knowledge is often tacit, and it is basically a trial-and-error process when the experience does not lead to a reflective process, or it could be called common sense. The Move Testing Experiment combined with Comparative Reflection involves a purpose to see what comes out of this. Thus, there exists a "before" the reflection and purpose and therefore also a baseline to analyze the effect and implications. In this learning process, the learner compares one move to the other move; it could also be called Comparative Reflection.

The last type of experiment/reflection action is *Hypothesis Testing* or *Vertical Reflection* across various levels of abstractions. This is like a traditional experiment with formulated objectives and more complex hypotheses consisting of different variables and involves basically a type of research process. It is different from the previous types in not only having a purpose but also having a set of parameters, which guide the learning process. This level of reflection with a predefined set of parameters is based on conceptualization, which differs from the two previous types of reflection. The Explorative Experiment and Move Testing are based on "'what if" thinking, which is mainly intuitive and creative. A more structured analysis of the actions might not be necessary: it is basically a question of trying something out. With Hypothesis Testing, a level of conceptual awareness and knowledge is needed as hypotheses are based on sets of variables and possible relations among variables.

At best, the PBL researchers and teachers tried to initiate a change in reflection mode from more common sense reflections to comparative and vertical reflections in this phase.

Learning Activities

The topics in the PBL skills course, such as project management, collaboration with a facilitator, and collaboration internally in the groups continued, but there were also new topics, such as setting learning objectives and reflection on the learning process, to learn how to learn collaboratively. The supporting recommended literature was essentially a toolbook elaborating the project process and its generic objectives and activities alongside project management logic and procedures. With the onset of the digital era materials became accessible on the university intranet, and some lecturers developed their own home pages with program-specific materials. Students preferred easily accessible manuals with instructional guidelines rather than reflection-based facilitation.

The process description was changed to process analysis, and it became a much more important part of the curriculum. Therefore, it was obvious to change the course to support the students' development of their process analysis and the learning of process skills and competencies. Most of the overall learning activities continued but with new names (e.g., the project diary was renamed the project log, and the project description was renamed process analysis) with the intention that students should really study their own learning process more systematically.

As indicated in the section above, the teaching and the learning methods changed into forms with much more active learning where the students had to come up with their own ideas for how they wanted to manage the process and had to document this and use the documentation in their process analysis. Consequently, many new tasks were developed with the intention of letting the students experiment much more and at different reflection levels. For example, the students were given tasks where they had to explore project planning by doing a Gantt chart, carried out Move Testing Experiments by doing Gantt charts with a special purpose or even a conceptual plan and explained an upcoming project process by an overview of the entire project process. The students developed their own project management system, and, in the group rooms, many types of creative solutions were found—even washing lines hung with various chapters of work. Furthermore, the students faced the challenging tasks of learning how to collect data on their projects and learning process (e.g., they collected Gantt charts from different weeks and compared them), or used group communication diagrams and collected data from various weeks to identify their communication patterns and how they developed (Kolmos & Kofoed, 2002, 2003).

This approach worked, and, during this period, teams went from having a few pages of unsystematic and descriptive analysis of student work processes to having from 15 to 30 pages of comparative and interpretative process analysis. The students were engaged and encouraged to create their own system and to collect data on the process, which motivated the students. Their work on this analysis created issues in some cases as the facilitators for the project report (discipline) complained that it took the students' attention away from the subject outcomes.

Assessment of PBL Competencies

The process analysis was assessed as part of the project examination. As previously, the course lecturers wrote comments to the process analysis before the examination and, in special cases, formulated questions for the examination. Formally, nothing changed with regard to the evaluation of the PBL competences. They were still evaluated through the project examinations. The groups would still present their process analysis as part of their presentation, and the contextual facilitator, primarily, would ask questions to inflict reflection and learning among the students in the group. The kind of discussions and reflections one would be able to observe at a project examination, and the extent to which the students would be motivated to deal with PBL learning issues, would, of course, be substantially different.

At the same time, however, as the PBL research group on PBL and Engineering Education took off to professionalize the students' learning of PBL competencies, other drivers made sure that this development would not get off the ground. Around the turn of the century, things happened, both externally and internally, which would dramatically affect the PBL course and the possibilities for the students to put their own independent stamp on their learning.

Phase 3: Instrumental Learning

The third phase was dominated by a lot of external and internal political, economic, and curriculum changes impacting the learning of PBL skills. Externally, in 2006, a Danish political decision marked the starting point for a new era in the learning of PBL skills at AAU. The group-based exam was abolished (Parliament, 2005). The focus on individual examinations put process competencies, like learning, argumentation, and discussion, under pressure as collaboration was meaningless to assess individually (Kolmos & Holgaard, 2007). This was a rather serious setback for the learning philosophy of PBL at AAU at that time. However, the decision was changed again, and the method was reinstalled in 2013 (Dahl & Kolmos, 2015). Also, the Bologna process had an impact on the assessment activities as the Danish Educational Ministry developed a new grading scale in 2007 in order to align education with the European and international grading scale (Undervisningsministeriet, 2007), which was based on the fulfillment of predefined learning outcomes. Finally, an important factor was the economic situation. On the one side, there was an increase in students, and, on the other side, there was a decrease in economic resources.

Internally, there were drivers for changing the curriculum structure, and an internal reform changed the original PBL model from a one consisting of project and PE courses, which were all assessed by a comprehensive group-based project exam with individual assessment and study unit courses, which had an individual exam, to a model of four units—a project of 15 ECTS and three parallel courses of five ECTS each. This came with another significant change at AAU when a new organization and a new set of academic regulations for the first-year programs were launched. A "*school structure*" for the different programs was established allocating more decision-making power to individual discipline-based environments, and common rules for the first-year programs were replaced by more individualized rules for each program (Kolmos, Holgaard, & Dahl, 2013; Moesby, 2016).

Learning Environment

The learning environment and the PBL culture both were under pressure. During this period, AAU nearly doubled the number of students from around 11,000 to more than 20,000 (Aalborg University, 2016). This also involved an increase in faculty members with no prior experience in PBL due to an increased share of international faculty members and due to mergers with educational institutions and departments lacking a PBL approach (Bøgelund & Dahl, 2015). Due to the economy, more students were pooled together in one course, from around 40–70 students to around 120–220 students per class.

The PBL culture and the more integrated understanding of project processes were increasingly handled with more structured lectures in a mass education approach. Despite the pooling of students from different programs into larger class sizes, more lecturers were needed to cover the demand. The new lecturers were predominantly recruited among staff already involved with first-year programs and among recent graduates, securing a solid foundation of the PBL culture. Efforts were made to coordinate initiatives and mutual mentoring in an attempt to nurture and share creativity and resources.

Even the students entering first-year programs changed significantly during this period. They increasingly became more knowledgeable about project-organized learning since some of the Danish high schools used this teaching approach, and social media changed the daily life of group work and how the students interacted and collaborated (Rongbutsri, Ryberg, & Zander, 2012).

Learning Approach

As all courses had to fit into the new course model of three parallel courses of five ECTS each, for the PBL skills course, in particular, the new set of academic regulations led to major changes. The new model with 3×5 ECTS courses led to a PBL skills course, which, in principle, no longer had to support the project process. Still, student groups had to submit a process analysis for the project examination, and they also had to be assessed in the PBL skills course through an individual written exam. A further complication was that the PBL skills course was merged with a contextual oriented course (Science, Technology, and Society) into what was named a PV course to gain a volume of 5 ECTS. This new course entity embraced problem- and project-related issues (e.g., how to carry out stakeholder analysis and how to interview project-relevant persons).

This led to a disconnect between the course and the project exam as even the PBL skills lecturers became more focused on the course and the course exam than on the relevance for the project process.

The changes also implied that the PBL skills course and the process analysis were somehow separated since the process analysis was to be evaluated together with the project. Other relevant changes were that group-defined learning objectives were replaced by predefined learning objectives, and the control of each single program was entrusted to a semester coordinator from the specific discipline in question.

These economically and politically induced changes remained more or less the same during the entire period. In 2012, however, a new government was elected in Denmark, and the group exam was reinstalled. It was no longer necessary to conduct an individual project examination of each single student, and group exams become the norm again.

What all these trends imply for the learning and assessing of PBL skills is a pressure toward more standardized lecture-led general instruction away from student-led experiments in specific project-related situations. All things considered, this affects the possibilities of creating discussions and carrying out exercises—two of the most important pedagogical instruments to facilitate PBL skills (Spliid, 2016).

Learning Activities

Most of the learning activities have continued—with a higher degree of the discipline mode than the integrated PBL culture mode—as reflected in the learning materials. The PBL course teacher acquired a much more central role as the driver of the learning process, and the student groups were not as motivated as they were in phase 2. Group experiments ceased to exist; the groups focused much more on what was expected from them by the facilitators and the exams.

A new feature of the PBL skills course was two to four consultations (each lasting 30–50 min) with every project group during the first semester project period. This supplementary effort by the course lecturers to link the course objectives and contents with the ongoing reality has been well received by the groups, and the accompanying dialogues are evolving from the groups' unresolved concerns leading to a wider understanding and appreciation of knowledge and skills thus facilitated. Another initiative on the part of the lecturers has been written group-based test exams, which have also been well received by the groups.

In 2010, the Moodle learning platform was established and had since supported all learning activities. It became more and more evident that only a minority of students prepared for lectures or accessed the materials on a regular basis. Without an authorized book with a built-in project and PBL logic, students were left to comprehend the project process through experience as most reading materials was pooled from many sources, resulting in fragmented and discipline-like focus areas. On the other hand, the digital platform supplied an expanded variety of resources meant for self-study (Dahms, Spliid, & Nielsen, 2017).

An increased diversity among the student body has accentuated the need for introducing ways of dealing with differences—be they factual, collaborative, methodological, communicative, or cultural. As the increasingly individualistic, competitive, and focused students have less experience with collaboration and knowledge sharing, more activities are focused on activities highlighting this dilemma and providing tools for resolving the inherent and inevitable stalemates, disagreements, and conflicts (Hutters, 2004).

All in all, the teacher level and the individualistic level were strengthened at the expense of the collaborative level as concerns the learning activities.

Assessment of PBL Skills

As a consequence of the PBL model reform, assessment of the PBL skills changed substantially in the third period. The process analysis was still evaluated through the project examination, but the weight given to this evaluation turned out to be much more modest. Also, due to the fact that the contextual facilitators no longer participate in the project examination of the first semester, only in the second semester are PBL skills evaluated through a written, individual exam, graded passed or not passed, which urges the students to exert themselves as little as possible and hinders an explicit collaborative learning process from taking place.

To a much higher degree, the course lecturers and, especially, the discipline-based facilitators increasingly set the agenda in phase three. PBL skills were treated like any other technical skill, which can be taught and assessed more traditionally. Taking into consideration that an increasing number of the technical facilitators are inexperienced and untrained in the learning philosophy of PBL, and some semester coordinators are new to the specific culture and learning environment in the first-year programs, a lot of what has been established during phase two has withered away in phase three. On a positive note, leveling of the different programs through, for example, predefined learning objectives and an increased level of conceptualization and internationalization within the subject of PBL creates a more robust and qualified body of knowledge—although one of the very important PBL learning principles is at risk: the participatory and democratic approach.

The Future

Despite a strong periodical headwind, the Aalborg PBL model has survived and developed. There are still a lot of risks. For example, will the university have to cut resources, which will also involve less space? The principle "one group, one room" is being replaced by a "timeshare" principle for many programs. Instead of being anchored in a physical room, group work might be anchored in a mixed mode of a virtual and face-2-face space. This might support and reinforce a more individualistic trend in which more emphasis is put on acquiring individual skills, and, consequently, individual portfolios might be a supplementary future vehicle for learning the skills of PBL at AAU.

On the other hand, the management level wants to revitalize the PBL approach, and PBL has become a criterion in the internal accreditation of all educational programs. The new management has initiated a new strategic plan "Knowledge for the world" for the period 2016–2021, and PBL is pointed out as being one of these characteristics (Aalborg University, 2015). The vision states that "AAU is internationally recognized for our problem and project-based learning and the documented results of this learning method" (Aalborg University, 2015, p. 15), and the action plan points out that all schools must ensure "the integration of PBL as an explicit learning objective in the curricula and regulations of all study programs" (Aalborg University, 2015, p. 17). It continues to explain that here is a "systematic introduction to PBL to students in all study programs" (Aalborg University, 2015, p. 17) while the department heads "will prepare a plan for and ensure the on-going upgrading of the PBL and IT competencies of teaching staff" (Aalborg University, 2015, p. 17).

Thus, it seems as if the role of securing a widespread use and continued improvement and development of PBL skills at AAU is now driven from the top of the university, where it once used to be driven from the bottom. This might also revive an increased collaboration among discipline-based facilitators, which was once a prominent feature of the period when students were organized in large nondisciplinary main groups, especially if an intensified continued education of supervisors with no prior experience in PBL is put in place. There might, however, also be a risk if the change is driven only from the top that this will jeopardize the robust anchoring of a more sophisticated PBL learning philosophy and might only lead to more instrumentalism.

Another mark that might distinguish the future development of the PBL course and the entire PBL model of the university is the integration of ICT into the curricula of PBL. As touched upon earlier, younger generations communicate and collaborate in new ways where the internet, social media, and other such technologies play a vital role. The PBL skills course and the supervisors have still not embraced this ICT era regarding how to integrate it into the PBL philosophy. ICT touches upon all vital PBL subjects, like knowledge gathering and knowledge sharing, communication and collaboration, and planning and production of reports, right down to how single members of a project group cultivate their identity and support and recognize each other (Rongbutsri et al., 2012). In the coming years, more research will be conducted within this field as both the PBL community and the top management of the university have realized this need (Aalborg University, 2015).

Conclusion: Lessons Learned

PBL is implemented all over the world—although it is most often at the course level. Implementation of PBL at this level might very often mean that there is no PBL coordination at the institutional level and that students do not reflect on their learning of PBL skills, such as collaboration, project management, problem identification, problem analysis, etc. Coordination at a system level is needed for creating learning and the progression of PBL skills, and one of the questions is how this learning of PBL skills can be facilitated.

As the case description also indicates, the development has very much been initiated by external and internal university drivers. The external drivers are (a) a decrease of economic resources, (b) an increase in the number of students, and (c) educational policy directives during a period of abandonment of the group-based project exam leading to new grading scales based on the fulfillment of specifically formulated learning objectives. The internal university drivers are primarily the disciplines pushing for more organizational power over the courses, which have resulted in a totally new school structure with centralized power and a new curriculum structure with more individual exams.

These drivers have influenced the teaching and learning of PBL skills, and three main modes have been identified: the instructional, experiential, and instrumental modes. These modes of teaching and learning have been developed during the special conditions the PBL university has had in Denmark in the period 1974–2016; however, the learning from these three modes can also be used in other places. The instructional phase was very much characterized by identifying and creating the scope of the PBL subject: what did the students need to learn in order to work efficiently and effectively in the project teams? The experiential phase was much more focused on how to learn these types of behavioral skills by structured experimentation and reflection, whereas the last instrumental phase basically represents the mass education approach with many more students for less money. But it also characterizes the move from a culturally embedded PBL approach with a smaller number of students to mass education with a large number of students and with heterogenic knowledge of PBL among academic staff.

From this development there are several lessons to be learned; however, the potential application of the lessons will differ depending on whether it is a PBL curriculum at the system/program level or it is for a single course.

Lessons Learned at a System Level

The characteristic for the system level is that the learning of PBL skills can be scaffolded in a progression throughout the program. However, there is still a choice to be made regarding whether the teaching and learning of PBL skills should have its own course/discipline or should be integrated into the existing discipline courses. The decision made at AAU by the Faculty of Engineering and Science was to build this as a discipline taught in a course, but with the obligation to integrate the learning into the project elements and with the integrated assessment. So, there is both a PBL skills discipline and integration into the project within the more technical disciplines.

A typical CDIO approach (Conceive-Design-Implement and Operate), which is a student-centered learning approach within the technical fields, applies the PBL methodology in single courses (Crawley, Malmqvist, Östlund, Brodeur, & Edström, 2014a, 2014b; Edström & Kolmos, 2014). The CDIO approach maps the entire curriculum and identifies courses in which single PBL skills can be taught. This means that oral communication skills might be integrated into one technical discipline, whereas learning of project management might be integrated into another discipline. In principle, the CDIO approach of integrating PBL skills into existing courses and delegating the responsibility of the learning to the discipline academics might look convincing; however, there are also considerable risks as the core research on PBL skills is missing.

Curriculum

The first lesson learned is, therefore, that learning of PBL skills does have to be an explicit part of the curriculum and based on explicit learning outcomes. The second lesson learned is that PBL skills might be some of the most difficult to teach. Student responses vary between two attitudes: "this is very complicated to learn" and "this is very banal and common sense." This challenges lecturers, facilitators, and students, and it is incredibly important that PBL skills are formulated as learning goals, otherwise, PBL will be used solely as a methodology for the learning of disciplines. In the teaching of a course, it is vital on one hand to challenge the students and on the other hand to bring in very concrete examples, preferably from workplaces.

Facilitation and Feedback

The third lesson learned points to the fact that students initially have insufficient knowledge and experience to be able to constructively assess their own learning of PBL skills. Facilitation and continuous feedback by experts are essential ingredients for student attainment. Acquisition and even the changing of behavior belong to an accommodative learning process, which requires students to question their own particular knowledge and skills and their preferred patterns of thinking and acting—and to reflect upon usability and appropriateness in relation to any given situation. The scaffolding of such assessment and reflection is crucial for developing students' approaches to continuous improvement in team efficiency and effectiveness.

Research, Development, and Academic Staff

The fourth lesson learned from the AAU PBL model is that the AAU PBL skills courses need drivers and research. The fact that a research group was built up during the second phase to take responsibility for the development and teaching has been quite important, not least as an institutional factor in defending the courses. It also contributes to developing the PBL learning models. Research and theoretical development within this area have crucial importance for documentation and development. Whether there is a separate PBL skills course or it is integrated into the disciplines, this is necessary.

This leads to the fifth lesson that the academic staff involved in teaching and researching PBL should ideally have two kinds of qualifications—on one hand, an engineering or science background or knowledge, and, on the other hand, research on PBL learning. The relation to the disciplines is important both in order to be able to speak the scientific language and to be able to provide relevant examples. To build such a group with doubly qualified academic staff takes time and resources.

Development of PBL Skills Teaching and Learning

Lesson six is that there needs to be a continuous development of these types of courses related to student needs and learning outcomes and the institutional approach of including the PBL integration. Student needs will change over time as schools and high schools may apply more and more PBL-like learning methodologies. The learning outcomes will depend on the curriculum; however, at many institutions, learning outcomes, such as collaboration, teamwork, project management, communication, etc., will normally be explicit. The institutional approach is important so that there is coordination at the curriculum level, and coherence among the learning outcomes from single courses is not left to the students themselves to establish.

And finally, the seventh lesson is that, without any doubt, the students' motivation for learning PBL skills is very much aligned with the autonomy and freedom they have in experimenting and creating their own learning path.

Lessons Learned for a Single Course Level

At most institutions, PBL is not a coordinated curriculum approach but does exist at a single course level. This also means that the whole question of how to develop PBL skills is very different as it is not a question of developing PBL skills but is solely a question of utilizing a PBL methodology for learning discipline knowledge and skills. However, the single teacher practicing PBL methodologies might need the teaching of PBL skills to be integrated in order to introduce the learning process to the students. To draw lessons learned for the single course level might be a bit difficult as most lessons learned concern the organizational and system level. Despite these complications, there are a few lessons learned that the single course teacher should be aware of in the classroom.

1) Identify if there are other PBL courses in the system from which the students could have learned how to analyze and solve problems or collaborate and manage the process. It would be meaningless to start from scratch each time. If only some students have previous learning in this field, then level the students' knowledge through peer learning.
2) Integrate the learning outcomes at a formal level and explain to students what is expected.
3) Reach out to others who have been running PBL courses and ask for their advice. There are many blogs, conferences, seminars, webinars, YouTube videos, etc. with plenty of available resources.
4) Focus on a few aspects of the PBL skills and make experiments with teaching these.
5) Collect data and make this a study on its own. For one thing, the data will give knowledge of what could be improved, for another, the data can also add up into smaller articles in this area over a period.
6) Assess it—ensure oral or written assessment is aligned with the intended learning outcomes.

What might be the most essential message to the single course lecturers would be to make the PBL process more explicit and to allow students to experiment and create their own learning systems. Otherwise, the utilization of PBL—no matter which PBL model—will not lead to the learning of PBL skills but might remain as tacit knowledge.

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20

PBL in Medical Education: A Case Study at the Université de Sherbrooke

Denis Bédard

Introduction

This chapter will present a problem-based learning (PBL) case study from the Université de Sherbrooke's Faculty of Medicine and Health Sciences (FMHS). It will describe a threefold view of the innovation process that took place in three phases: conception phase, implementation phase, and evaluation phase (Bédard & Béchard, 2009a). Over the past 30 years, the medical program experienced three versions of this innovation process, each version going through the three phases presented above. As the number of students and faculty increased, new health sciences programs were initiated, such as Occupational Therapy and Nursing, each adopting PBL as their principal mode of learning. The chapter will attempt to (a) shed some light on how PBL was adopted by the medical program at the Université de Sherbrooke, (b) describe which PBL model was initially adopted and how it developed over time from a curricular perspective, (c) explain how the role of the professor evolved with each version of PBL and what role the professor is expected to play in fostering students' learning, and (d) clarify what positions the students are invited to assume and what tasks they are required to perform. Based on the experiences and changes described in the Medical Education (MD) program at the Université de Sherbrooke, the last part of the chapter will show what trends in higher education should influence the development of innovations in medical and health sciences education.

The Innovation Process

Changing teaching in higher education is never an easy process since it involves questioning the knowledge, dogmas, and beliefs of the individuals involved. At the organizational level, the desired changes may affect the structure, culture,

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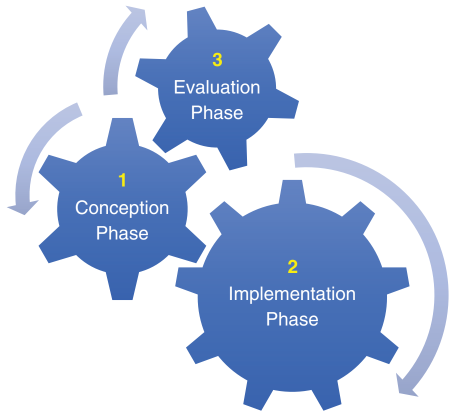


Figure 20.1 The Three Phases of the Innovation Process.

and overall orientation of a program, from upper management to the professor–student relationship in the classroom. Consequently, individuals working in these organizations have training paths that reflect their diversified fields of expertise. To describe the change, for example, the introduction of a curricular and pedagogical innovation such as PBL, particularly when it affects all or most of the activities of a training program, Bédard and Béchard (2009a) have proposed a three-phase process model: (a) conception, (b) implementation, and (c) evaluation. Figure 20.1 illustrates how embedded and interdependent these three phases are.

At the conception phase, a "legitimacy of change" problem is usually raised. Why change? What is the value of the change? Who are the leaders of change and what is their status in the institution? Feasibility issues are also considered at this phase. How quickly should a change occur? Will we have the resources (human and financial) to change? What should we do when there are conflicting ideas about the goals and methods to introduce? At the implementation phase, the question of the students' perception vis-à-vis the proposed change is very important. Will the change be beneficial in their view? What strategies should be implemented to foster their commitment to their studies? How can we actively involve the students in the change process, to help them adapt to what is new? Lastly, often we discover in the evaluation phase that no method or way of proceeding has been clearly outlined. What direction should we look in? What aspects should be prioritized and evaluated? What procedures should be adopted and how often?

As will be illustrated below, over time, a program typically goes through several versions of the innovation process. For the MD program at the Université de Sherbrooke, the first version began with the implementation of PBL in 1987. In 1995, a second version of the innovation process took place; this could then be called a "renovation." In fact, renovation evokes a process that may take place following the implementation of an innovation (Bédard & Béchard, 2009a). It involves taking a critical look at and initiating a process of reflection on the innovation. Renovation thus implies undertaking an overall review of a situation, which aims to improve it. The renovations that took place in the MD program in

1995 were made considering two main categories of factors: (a) those factors related to the evolution of the environment in which the innovation was implemented, and (b) those that stem from advances in research. The renovation process may repeat iteratively over time. Lastly, the third and last version of the process began more recently in 2011.

MD Program at Université de Sherbrooke from 1985 to 1995: PBL as an Innovation

Conception

The MD program at the Faculty of Medicine (as it was called at that time) at the Université de Sherbrooke welcomed its first 32 students in 1966. For 20 years, it prepared future physicians, primarily through lectures in their first two preclinical years prior to their two clerkship years. Even at that time, the program adopted an innovative organization of the content commonly referred to as "organ-system teaching structure" (instead of the disciplinary structure advocated by many programs). In 1985, new ideas emerged, and new objectives were set for the MD program. It was decided that the curriculum should be aimed toward the needs of society and allow future physicians to acquire a "global vision of medicine." Moreover, it should help students develop scientific reasoning and a humanistic view of providing care. Teaching methods should allow students to generate and maintain a spirit of discovery and self-learning abilities.

From an external perspective, the need to change was partly brought about by mixed reviews from the Canadian Medical Association on the quality of training in universities. These reviews were in part linked to new findings in the field of educational psychology, especially as it dealt with knowledge processing and learning: active learning, cooperative learning, motivational theories, self-awareness (e.g., Benware & Dice, 1984; Bransford, Stein, Shelton, & Owings, 1981). The reviews were also partly linked to innovation in medical education: PBL (Barrows & Tamblyn, 1980; Schmidt, Dauphinee, & Patel, 1987). From an internal perspective, a survey revealed that professors felt that the traditional curriculum used to train students was inconsistent with the methods they were being asked to use to train others.

Taking into account the trends in the field of medical training and the reports from the Canadian Medical Association, recommendations were formulated to foster students' learning.

1) Assess students' capacity to learn autonomously and give them opportunities to do so.
2) Reduce the number of activities proposed each week to encourage self-learning.
3) Reduce lecture time.
4) Offer learning experiences that help students become more autonomous and active at solving medical problems.
5) Allow "subjective assessment" from teachers to measure students' analytical abilities.

Following these recommendations and new objectives, in 1987, the MD program introduced the PBL method to its first-year students (Des Marchais, Bureau, Dumais, & Pigeon, 1992), the second to do so in Canada. The model that was developed and implemented at McMaster University in the early 1970s was adopted (Barrows, 1985). Since then, many more medical programs have adopted PBL, in full or in part, both in Canada and abroad.

Implementation

PBL focused on students' prior knowledge and beliefs (Schmidt, 1993), learning strategies, and the integration of knowledge from more than one subject area. PBL in the MD program requires students to meet twice within a 1-week period (see Figure 20.2). During the first meeting, the first tutorial session, a team of students (seven to eight people) is presented with a new problem. Students begin discussing among themselves with little intervention from the tutor (professor). The discussion is centered on the formulation of hypotheses aimed at explaining the causes of the problem. These hypotheses are generated by questions students ask to have a better understanding of the problem. At the end of the first meeting, students are asked to formulate their learning objectives (*Recommendation 1*). The tutor then provides students with references, which they use to attempt to validate the hypotheses, answer unresolved questions, and attain the set objectives (*Recommendation 4*). Two or 3 days later, the same group of students meets again (second tutorial) to go over the content of the literature received (e.g., research articles, book chapters) and exchange views on the value of the hypotheses. The students are also asked to share their answers

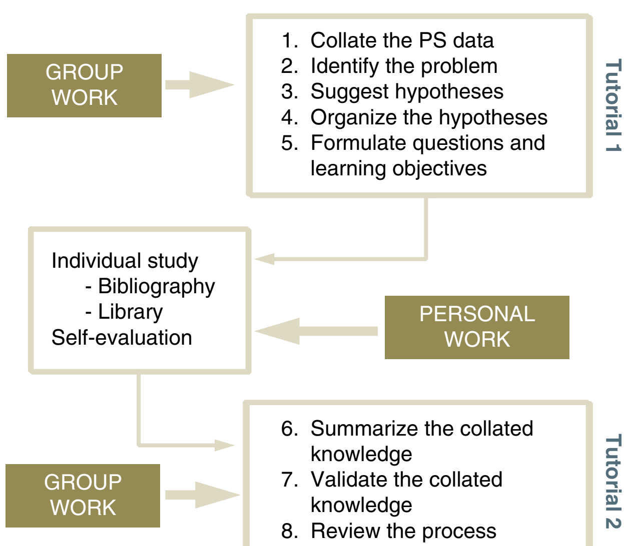


Figure 20.2 The PBL Method at the Université de Sherbrooke, 1985–1995.

to the questions formulated during the previous meeting (Tutorial 1). For the most part, the tutors are asked to assist students in their work (Barrows, 1988; Des Marchais et al., 1992). Their role as facilitator implies that they "give them space and freedom to do things their own way" (*Recommendation 4*) (Savin-Baden & Howell Major, 2004, p. 96). The tutor's role "is that of creating conditions in which students can exercise self-determination in their learning" (Savin-Baden & Howell Major, 2004, p. 96).

The undergraduate medical curriculum for the MD degree requires students to complete a 4-year program divided into three distinct phases (see Figure 20.3). Phase I is composed of units aimed at reviewing students' biomedical knowledge. Phase II of the curriculum, which lasts a year and a half, follows the first semester. During this phase, students must complete 13 system-based units that cover essential medical topics or systems, each lasting 4–5 weeks (*Recommendation 2*). Phase III requires students to engage in a 4-month multidisciplinary unit, which aims at approaching more complex medical problems. During the first module, content is generally presented in a more traditional lecture format. For Phases II and III, content is presented in a PBL format (*Recommendation 3*). For the remaining year and a half, students are asked to complete clerkship rotations in affiliated hospitals.

From an organizational point of view, it is important to mention the creation of the Pedagogy Development Office (PDO) (in French, *Bureau de développement pédagogique*). This office was set up by faculty management to train and support the faculty for the implementation of PBL in 1987. It was important to train the existing teaching staff, but also any individual who would be hired from that date on. The faculty needed specific training for their role as a tutor

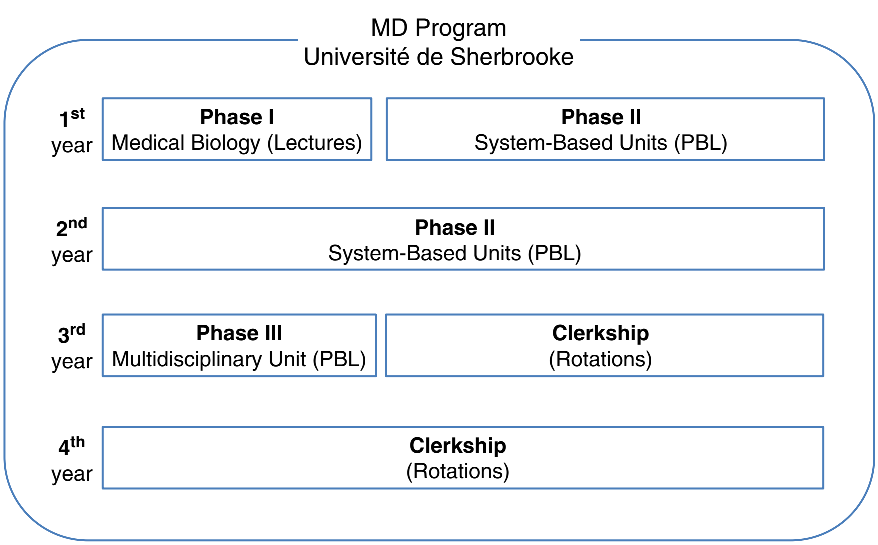


Figure 20.3 MD Program at the Université de Sherbrooke: first version.

during PBL tutorials. Part of that role was their ability to monitor students' learning by providing them with ongoing feedback based on their personal appreciation (*Recommendation 5*). Hence, the formative assessment process was used by instructors to improve their "teaching" and by students to improve their learning (Crooks, 2001; White & Frederiksen, 1998).

Evaluation

The evaluation phase is an ongoing process that usually begins the day the innovation is proposed to the stakeholders. In this perspective, three sources of data can be gathered: (a) program evaluation (Jouquan, 2009; Stufflebeam, 2003), (b) formal research endeavors, and (c) research findings in the literature.

The *first source* of data is program evaluation. In keeping with Stufflebeam's evaluation model (2003), the process is aimed primarily at improving the program. During this phase, the evaluation process is centered on decision making, which is supported by collecting information about the program. Therefore, it involves evaluating several aspects of the revised program, from curricular organization to stakeholders' perceptions, using means such as focus groups, questionnaires, surveys, and workshops. At the most macro level is the "educational ecosystem" within which the innovation is implemented. The MD program managers sought to determine the opportunities and constraints associated with the change being implemented. Was PBL implemented as planned? Was it well adapted to the reality and conditions of how future physicians should be trained in Québec? Were enough efforts and resources put into preparing everyone to negotiate the change according to plan?

The *second source* of data is conducting formal research. Two studies were carried out to measure (a) the changes in students' reasoning skills and (b) their perceptions of new Learning Clinical Reasoning (LCR) sessions. The first study had six second- and third-year students think out loud as they were asked to solve two written problems. Each unit of information (usually a sentence) regarding the patient was presented on a different page (Bédard, Tardif, & Meilleur, 1996). For each page, they were asked to think out loud to evoke the hypotheses they were considering. This procedure was used (a) to follow the evolution of the diagnostic process more accurately, and (b) to better assess the impact of each unit of information on the diagnostic process. The second study asked students to anonymously fill out a questionnaire regarding the LCR sessions at the end of each of the five major clerkship rotations (Chamberland, Bédard, Tardif, & Hivon, 1996). A total of 259 questionnaires were analyzed. The questionnaire considered variables like "motivation," "knowledge organization," and "knowledge transfer."

The *third source* of data is research findings through a literature review. In addition to the two previous sources of data, the program used research findings to propose new changes to the program. Hence, this work was carried out by drawing upon education and psychology of education research (e.g., Perkins & Salomon, 1989; Stepien & Gallagher, 1993) and medical pedagogy (e.g., Regnier, Welsh, & Quarton, 1994; Schmidt, Norman, & Boshuizen, 1990).

The results gathered from those three sources were rich and informative, and helped stakeholders in their assessment of the implementation of PBL. Among the most important outputs of the program evaluation, was that the implementation of PBL was a success. The stakeholders and faculty had succeeded in restructuring the entire curriculum to make it student-centered and problem-based. Data showed that it had almost completely replaced the more traditional lecture format as the sole instructional method for the preclinical years. Despite the 180° pedagogical turnaround, teachers appeared to be engaged in the innovative change put in place. It is also important to note that following the implementation of PBL, little focus was placed on the learning process itself or the nature of the tutor's interventions. Therefore, some educational aspects were not yet at the heart of the evaluative phase of the innovation (see version 2 of the MD program below: "PBL Under Review—Improvements").

Research results from the first of two studies conducted showed that, as was anticipated with the PBL preclinical curriculum (Bédard et al., 1996), hypotheses were generated early on for the two problems tested on students. This result demonstrated students' ability to transfer the hypothetico-deductive model of reasoning (Elstein, 1994) learned during the preclinical years to a problem-solving context, which explicitly asks them to produce a clinical diagnosis from reading a written case. From the results obtained for the differential diagnosis, the students' performance was excellent for the second-year case and good for the third-year case. Results from the second study showed a high level of satisfaction from students with the introduction of LCR in the clinical portion of the curriculum. The LCR sessions favored knowledge organization in relation to clinical problems, as well as knowledge acquisition in relation to investigation and therapeutics (Chamberland et al., 1996).

In spite of these positive results on the impact of using PBL as the main pedagogical tool, the literature review also showed that more efforts were needed to help medical students develop cognitive and problem-solving skills. In this perspective, one of the orientations that influenced the educational recommendations was making the transition from a humanistic vision of the program to a professional vision. The scientific literature, as well as reports from health associations in Canada and abroad (e.g., AACP, 1992; Curry & Wergin, 1993; McGaghe, 1991), recommended training doctors to improve their decision-making skills, responsibly apply ethical values, and develop their reflective capacities. Moreover, teachers' capacities to foster the development of such skills would need to be enhanced. It raised some questions about the role played by the PDO: Had teachers' training needs been taken into account since PBL was implemented in 1987? Had the PDO succeeded in combining training and evidence from research to follow the evolution of knowledge in medical pedagogy and psychology of learning? What role could the PDO play to foster educational changes in the predoctoral and postdoctoral programs, as well as research activities to document these changes?

Noting these difficulties and challenges, it was decided to replace the PDO with the Medical Pedagogy Centre in 1992 (MPC—in French, *Centre de pédagogie médicale*). By creating the MPC, the Office became more than a faculty education center; it also became a medical education development and research center.

Dr. Jacques Desmarchais, Assistant Dean of Studies, entrusted a new mandate to the MPC in 1992. In addition to improving the educational training of the faculty, creating a research program, and enhancing the scope of the MD program inside of and outside of the faculty, the first two objectives of the MPC were to: (a) introduce education sciences in the reform consolidation activities, and (b) facilitate the adoption of innovation within postdoctoral programs. The new mandate paved the way for innovations that were made over the next 10 years.

With the advent of this MPC, one full professor from the Faculty of Education was recruited to support the doctors involved in the activities of the new center. In fact, from the start, Professor René Hivon served as Director of the MPC until 1995. He then played a role as a scientific advisor until June 2006. This expertise in education was added to a core of clinical educator professors and a motivated, committed, and experienced faculty. After Professor Hivon's departure, the new Director of the center came from the ranks of professor doctors from the Faculty of Medicine. The following year, in 1996, the MPC became the Health Sciences Pedagogy Centre (HSPC) (In French, *Centre de pédagogie des sciences de la santé—CPSS*). The ability to unite and coordinate the actions of faculty under the stewardship of the MPC, then the HSPC, and its Director has represented an important condition for supporting innovation. Furthermore, this condition has also allowed the program to evolve based on research evidence on the one hand and knowledge from practical experience on the other. The changes that followed involved hundreds of professors.

MD Program at Université de Sherbrooke from 1996 to 2005: PBL Under Review—Improvements

Conception

Following the results and recommendations of the first cycle of the innovation process, this second cycle began at the conception phase again (now also called renovation). As anticipated, the changes brought about were not as drastic as in the first cycle. Fundamentally, the main goal was to improve how PBL was being used to better prepare students to become physicians. Also, it should be noted that the observations and modification proposals made for the MD program at the Université de Sherbrooke echoed what was also happening in other faculties of medicine, such as at Maastricht University (Moust, van Berkel, & Schmidt, 2005).

This conception phase was marked by a number of observations made during the evaluation phase, but also by a systematic analysis of the curriculum based on all the internal and external evaluation data available stemming from the visit from an accredited Canadian medical education organization in 1995. Different observations were made vis-à-vis the active personnel within the MD program:

- the presence of experienced professors who had learned to work with the new PBL method tools, but who were questioning the educational activities;
- dissatisfied professors faced with what was perceived as a certain passivity during PBL sessions;
- faculty training that was discontinued 3 years ago;

- a new predoctoral management team that was questioning the state of innovation;
- the addition of new resources at the HSPC.

At the MD program level, certain "curricular malaises" were detected. It was observed that the PBL process applied in class varied from one tutor to the next: some steps were skirted around and others did not offer systematic feedback after the study session. However, the most problematic was called "coveritis" (*couverturite* in French) (i.e., excessive coverage—from cover to cover—and multiplication of knowledge in teaching units). While the learning objectives should have been inferred from the problems presented at the PBL sessions, they were increasingly derived from the learning objectives set by tutors responsible for the training units. This phenomenon reflected the observation that there was a progressive compartmentalization of disciplinary units, resulting in curricular segmentation. At the same time, students were having difficulty integrating their acquired knowledge and were losing sight of the objectives of the overall MD program. Moreover, their motivation was on the decline and they began questioning the efficacy of the program.

To formulate plausible explanatory hypotheses and, ultimately, to offset these difficulties, it was decided to turn to the evolution of knowledge in the psychology of education (e.g., Gilhooly, 1990; Norris, 1989) and the latest knowledge concerning PBL in medical education (e.g., Norman & Schmidt, 1992). A "new" definition of learning was adopted: learning is an individual, active, constructive, cumulative process that occurs when the student actively processes the new information, thereby modifying his or her cognitive structure. In this perspective, it was decided to adopt a professional expertise development model that highlighted the importance of clinical reasoning and skill development.

Following the new orientations taken, it was decided that each curricular phase should take into consideration the type and level of knowledge to be acquired, as well as the competencies and skills targeted. At that time, an important decision was made regarding Phase I. It was decided to use PBL for acquiring biomedical knowledge. This choice was consistent with the spirit of the innovation implemented in 1987. Until then, PBL was "reserved" for acquiring medical knowledge related to body systems (e.g., nervous system, respiratory system, etc.). This change implied reviewing the teaching material, writing new problems, and training new tutors—many of whom were not doctors—in the PBL method. Furthermore, as illustrated in Figure 20.4, all three phases of the program would involve clinical skill development training and training activities dedicated to the development and understanding of the MD profession until the end of the clerkships. In addition to fostering the development of new skills, these two common threads should foster a better integration of knowledge during the 4 years of the program.

In the end, this renovation represented a changeover from the use of a "teaching technique," the PBL method, to the implementation of a "learning and teaching philosophy." The conceptual framework that evolved from this is hinged around three recognized theories in the literature on medical pedagogy and education: (a) The development of expertise (e.g., Benner, 2004), (b) information processing (e.g., Glaser, 2000), and (c) contextualized learning (e.g., Lave & Wenger, 1991).

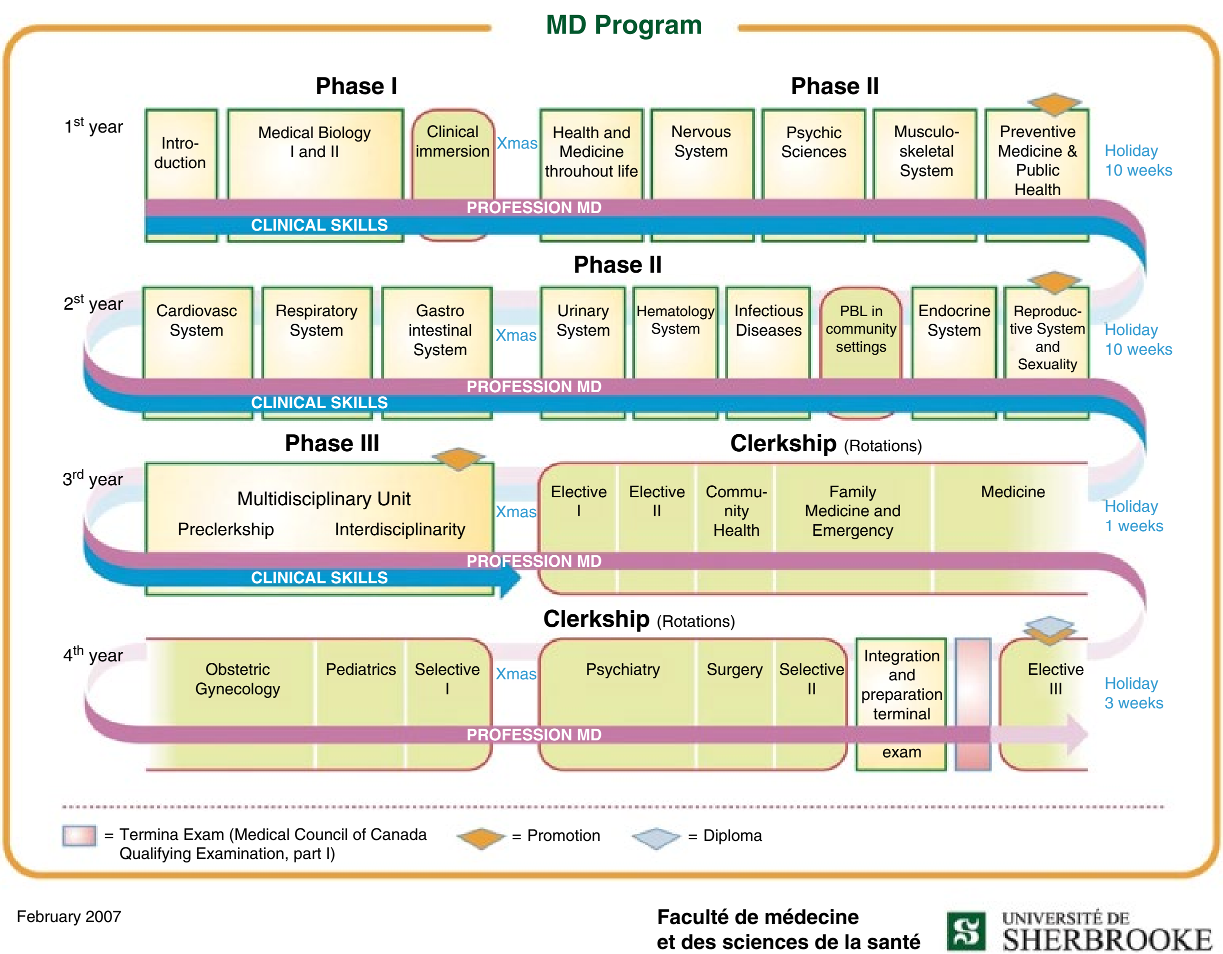


Figure 20.4 MD Program at the Université de Sherbrooke: Second Version.

Implementation

To promote its acceptance, the implementation plan (analysis of the curriculum and proposed actions) was shared with the faculty and staff at a retreat in the spring of 1997. Following discussions and debates, modifications and adaptations, at the end of the retreat, all present approved it. Implementing major changes to an existing innovation was very demanding for all players and at all levels of the organization. Therefore, it was important to not only adequately inform them of the proposed changes, but also provide them with the opportunity to express their opinion about these changes and share any concerns. Adequate communication of the proposed changes with the view of actively engaging the players in the change represents an important condition for implementing innovation. Another important condition is adequate funding to have access to the human resources and materials required. Around the year 2000, the Faculty of Medicine received funding from a university support program for "major pedagogical innovations" from the Université de Sherbrooke. The Faculty received an amount of $200,000 for the revision of the MD program by the University for a 3-year period. This funding was specifically targeted at developing, implementing, and assessing an effective model for teaching and coaching students during clinical training (clerkship).

Beyond the curricular changes proposed in the second cycle of the program (see Figure 20.4), some aspects of PBL tutorials were changed. Thereby, the problems illustrated a relevant and significant learning context from a professional point of view (Lave & Wenger, 1991). During the first tutorial and initial problem analysis, particular insistence was placed on the activation of students' prior knowledge, while highlighting the development and organization of knowledge during discussions between students. During the study period between two tutorials, the students were invited to pay particular attention to the knowledge acquisition and reorganization process. To help them, for each problem they had to produce a concept map of acquired knowledge. These maps should have represented the key concepts stemming from the problem, as well as the links uniting them. The objective of these productions was to promote the organization of knowledge in memory and, in doing so, promote its transfer in future professional situations. Lastly, during the second tutorial, the tutors fostered the integration and application of knowledge in students by providing them with feedback on the learning strategies they had engaged during the problem analysis as well as on the concept maps that the students had produced.

Seeking to support students outside of PBL periods, it was decided to implement a specific program to help medical students develop their learning strategies (Côté, Bellavance, Chamberland, & Graillon, 2004). Research in the psychology of learning had in fact shown that learning strategies that engaged students, such as ability to self-regulate their learning, played a key role in academic achievement (e.g., Zimmerman, 1990).

Implementation of the revised curriculum required proposing more supportive training for the faculty. This training needed to meet the new program orientations, but also attempt to reduce significant variations in tutor practices. In addition, the objective of this training was to empower tutors to place greater emphasis on clinical reasoning during problem analysis. This emphasis on clinical reasoning was consistent with the progressive development and implementation of the clinical skills program (Chamberland, Des Marchais, & Charlin, 1992).

The choice of having adopted a more professional rather than a humanistic vision of the program had consequences, from enrollment to clerkship. An operational definition of professionalism was adopted: medical professionalism consists of practicing medicine with competency and responsibility toward one's patient, society, colleagues, and oneself. One of these consequences was to define the training objectives in the form of competencies. This choice somewhat modified the wording of the fifth step of the PBL tutorial, which now invited students to associate the problem and hypotheses formulated with *competencies and learning objectives* (in italics in Figure 20.5). Nine competencies were then identified: (a) diagnosing, (b) investigating, (c) treating and caring, (d) educating and preventing, (e) communicating, (f) collaborating, (g) managing resources, (h) promoting health, and (i) lifelong learning. The knowledge and knowhow that underlie each of these competencies are made explicit to students. They differ, therefore, from the study objectives (see Figure 20.2), which are specific to each student. It must be acknowledged that, very often, the students transposed the learning objectives proposed by the program into study objectives.

The other changes in the wording of the steps resulting from the new orientations of the second version of the MD program at the Université de Sherbrooke also appear in italics in Figure 20.5. Overall, it is possible to observe that the student is being invited to identify the problem indicators, as well as the wording of the problem, more actively, even proactively. Lastly, stemming from research in cognitive psychology, an emphasis is placed on the integration of knowledge. At this step, the students are explicitly invited by the tutor to discuss the

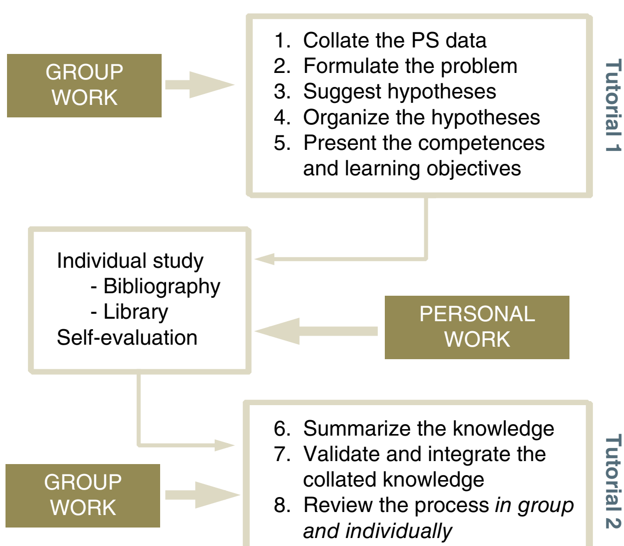


Figure 20.5 The PBL Method at the Université de Sherbrooke, 1995–2005.

connections they perceive between the new concepts and those of past problems or of knowledge acquired in other contexts (e.g., clinical skills and conferences).

In addition to the more traditional exams with multiple-choice questions (MCQ) and essay questions, the program introduced structured objective clinical exams (SOCE). The objective of these exams was to better measure one of the expected benefits of PBL, i.e., the development of students' diagnostic competence. It involved using simulated patients placed in a series of stations. The students were instructed to go from one station to the next to perform a medical examination of the simulated patient: Medical history and physical examination. Each station lasted about 10 min and, at the end, the student was invited to produce a differential diagnosis.

The addition of this evaluation method is consistent with the evolution of the medical training from the first version to the second version of the MD program at the Université de Sherbrooke. In the beginning, the program was focused on the professor and the learning content. The implementation of PBL in 1987 represented a shift toward a concentration of the program on student learning. This second version of the curriculum was further concentrated on the development of the professional expertise of the doctors in training.

Interim Period from 2006 to 2010: Satellite Campuses

Between 2006 and 2010, the Faculty of Medicine grew rapidly and structurally. In 2006, the MD program of the Université de Sherbrooke was offered at two satellite campuses in Saguenay (Province of Québec) and Moncton (Province of New Brunswick). Consequently, the training had to be adapted to take into consideration the fact that certain courses would be offered at the three campuses simultaneously. Through distance education, these courses could be offered at the same time to 35 students from Saguenay, 25 students from Moncton, and at least 100 students at the Sherbrooke campus.

Furnishing the distance education rooms required a major investment on the part of the Faculty of Medicine. To a certain point, the technological aspects took precedence over the pedagogical ones. Among these considerations, the interactions between the teacher and distance education students had to be "made transparent." Therefore, the equipment selected had to allow the teachers to do everything that they were already able to do in the classroom with the students in Saguenay and Moncton. To lighten and ease this task, certain lecture courses were proposed, called "complimentary PBL pedagogical activities," in addition to the PBL tutorials.

To meet the students' needs at each of the two remote campuses, major recruiting of teaching staff was needed. This required considerable efforts to train professors to familiarize them with the particularities of the MD program at Université de Sherbrooke and its pedagogical methods. Of course, training in the use of new technologies in the classroom was also proposed, including how to lead a group of distance education students.

These developments left little room to concentrate on a proper evaluation of the existing MD program, even though it was changing and the "pedagogical derivatives" were taking shape, as observed by Moust et al. (2005). It is important to mention that during the same period, the HSPC played an important support role in the quality of the MD program and pedagogical training of its professors in a context of a significant increase in the number of medical students and the addition of two satellite campuses. Nevertheless, what were the effects of all these changes? What evaluation could be made of the MD program 15 years after the start of the revision in 1995?

Evaluation

At the end of 2009, Faculty authorities organized a day of reflection about the MD program, following the observation that different people involved in the predoctoral training were feeling a certain "curricular malaise." A number of observations emerged from the discussions that took place that day. Among the aspects to retain, it was mentioned that:

- The program should continue to target the development of the nine existing competencies.
- The concept map asked of students represented a useful and relevant knowledge construction tool.
- Continuous pedagogical training of teaching staff is important and should continue.

Among the elements to review, it was mentioned that:

- The Faculty and its professors were faced with a paradox in the application of PBL: the obligation to cover the content vs. maximization of the self-learning process. The tension between the two goals should be reduced.
- Despite the implementation of SOCE, making it possible to better evaluate the achievement of goals targeted by the program, the evaluation methods should be reconsidered; they should be consistent with the program orientations.
- The development of student autonomy, as well as the development of students as self-learners, should be further encouraged.
- The potential of pedagogical innovation associated with the introduction of new technologies in training should be explored.

Following this day of reflection and the principal messages that it delivered, the administrators decided to set up a Curricular Reflection Committee for the MD program. The members were given two objectives: (a) review the coherence of the MD program regarding the expected competencies to be developed and the type of doctors that the program wants to train based on societal needs, and (b) make continuous improvements to optimize the use of learning objectives of the program, the PBL method, and the support and development of autonomous learning.

MD Program at Université de Sherbrooke from 2010 to 2016: More than PBL

In 2016, the 4-year MD program offered at three campuses hosted close to 800 undergraduate students, welcoming 200 admissions each year. This is a significant increase since 1998.

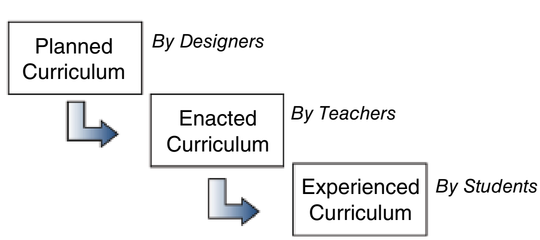
Conception

This third and most recent conception phase of the innovation process of the MD program at Université de Sherbrooke was initiated in 2010 by the new management team of the FMHS. It was built on the results of an analysis of the strengths and weaknesses, as well as opportunities and threats observed in the preceding evaluation phase. As was the case for the second version of the MD program, the recommendations suggested here involve both continuity and change (renovation). Fundamentally, this double reality represents a guarantee of quality for an innovative program and for the innovation process itself (Bédard, 2015). This does not rule out the pitfalls that may come with an innovation after it is implemented, but the perspective of building an innovation on past achievements and considering tomorrow's challenges is one of the conditions that makes it possible to avoid its rise and fall (e.g., Patterson Jr., 2007).

The conception process that was carried out to recommend changes to the MD program was as significant as for the implementation of the first major innovation in 1987. PBL as the backbone of the predoctoral training system was questioned, particularly with respect to its limitations as structuring elements of the curriculum. A conceptual framework helped answer some of these issues (Bordage & Harris, 2011). Moreover, it was recognized that the curriculum is perceived in different ways by different people engaged in the innovation process (Bédard & Béchard, 2009b; Parker, 2003). As shown in Figure 20.6, first, there is the "planned curriculum," for example, as the people in charge of designing it present it. Typically, the designers will present the planned curriculum to teachers and expect them to carry out the plan. But, as the teachers attempt to understand the new curriculum and act on it accordingly, they also interpret its meaning and plan their actions and approach taking into account the circumstances in which they find themselves. This is what is called the "enacted curriculum." Finally, students come into play as they come into the classrooms and experience the enacted curriculum presented by the teachers' words and actions. The students' encounter with the curriculum is called the "experienced curriculum," which generates its own perceptions of the curriculum.

At the conception phase it is important to be aware of the possible gaps that can appear between these three perceived curricula; not only in the early stages of the implementation phase but throughout that phase. A gradual widening of the gaps will create distortions in the curricular alignment, the common thread that should be running from the governing values and principles of the planned curriculum to the learning tasks of the experienced curriculum. Therefore, the alignment between the basic program orientations, teaching activities and evaluation procedures was reviewed.

Figure 20.6 Three Types of Curricula.



To help avoid or reduce the size of these gaps, six guiding orientations were proposed at the conception phase: (a) competency-driven curriculum, (b) generalism, (c) opening of disciplinary boundaries, (d) intra/interprofessional collaboration, (e) flexible learning paths, and (f) comprehensive and coherent administration and organization (Xhignesse et al., 2016). To meet the requirements of the first guiding orientation, an *integrated MD curriculum* was needed to structure the *active learning* activities, which in turn, were required to propose *authentic competency-based evaluations*. To promote the philosophy of generalism for the undergraduate medical curriculum, a *longitudinal approach* over the 4 years of the program had to be adopted where learning was to take place in *authentic situations* and *integrated activities* presented. To help open disciplinary boundaries, *professionally oriented learning paths* were needed, taking into account integrated and longitudinal activities, as well as *interdisciplinary collaboration*. To facilitate intra/interprofessional collaboration, *collaborative competencies* had to be added to the learning objectives of the curriculum, as well as *interprofessional modalities*, that could be enacted throughout the program. To allow for more flexible learning paths, students had to be able put forth their *personal learning objectives* during the MD program, therefore allowing the possibility of integrating *optional credits* according to their interest. Finally, the sixth guiding orientation focuses on the administrative level. This level was not explicitly taken into consideration in the two prior conception phases. In this third iteration of the innovation process, it was felt that the *commitment and mobilization* of all players had to be part of this phase, including administrators. *Efficient management* of change with a *global vision* was needed to support the new evolving and dynamic curriculum.

The greatest change introduced in this conception phase is an approach founded on the conceptual model called "Act Competently" (*Agir avec compétence*). The model Act Competently essentially proposes considering learning in an integrated perspective on the training path. Thereby, the program must propose a clear trajectory, not only of the expectations regarding resources to acquire (knowledge/understanding and knowhow) but also of skills to develop. Act Competently implies that the training expectations or goals clearly highlight the relationships that exist among the knowledge to acquire (internal and external resources), the contexts in which the tasks will be carried out, and the specific requirements associated with each task (conditions for achievement). Competency, therefore, is expressed in the student's ability to act (i.e., to mobilize the internal and external resources available to them, based on the requirements of the professional task). The learning evaluation process may then be focused on either aspect (knowledge, knowing how to mobilize), but also on an appreciation of this Acting Competently approach.

The new curriculum will allow the future doctors to learn in real or simulated situations, representative of their future practice. Students will be invited to develop the ability to act in different patient clinical care situations, but they will also be required to meet the increasing requirements of the population by developing skills that have become essential in disease prevention and health promotion, training, management, and research.

Other significant changes will be made to the MD program:

- Practical training is increased and learning is focused on real clinical situations, called "professional situations," with a global approach.
- Skills are progressively developed while encouraging student autonomy.
- New pedagogical formats will be added to PBL, such as team learning and Case Method (e.g., Hammond, 2002).
- The program will propose longitudinal mentoring to support the student in his or her learning and development of his or her professional identity throughout a semester.
- Teaching activities will no longer be organized by organ systems: the necessary knowledge and understanding of the functioning and complexity of the human body are now integrated in clinical situations that call upon all medical disciplines, as with a real medical practice.
- The pedagogical material will be completely digitalized.

Overall, the MD program will promote active learning methods, in small groups, adapted to different types of learning goals. This means that there will be different types of pedagogical activities to support the development of internal and external resources. PBL will continue to represent an important component of the program because it is a powerful pedagogical tool, but other active methods will be used when they are shown to be more suitable for the desired type of learning. It is important to remember that a problem used during PBL tutorials is not equivalent to a professional situation: the latter being a more global representation of the reality of the future practices. Lectures may also take place but always while ensuring that they correspond to best teaching–learning practices and help attain an objective that is very specific and complementary to the other activities. Lastly, there will be activities allowing students to train in the implementation of professional practices and mobilization of internal and external resources in the most realistic situations possible (e.g., simulation laboratory, simulated patients, clinical clerkship, etc.).

During the first 2 years, the new curriculum will offer preclinical training involving mandatory preclinical immersion, community clerkships, and experiential learning activities in the community. This training will be followed by an 18-month clinical training (clerkship) and a pivotal period with a flexible path at the beginning of the third year (4 months).

The preclerkship professional path will be guided by increasingly complex professional situations, each lasting 4 weeks and grouped by thematic semesters. The first weeks will be mainly devoted to learning specific content related to the professional situation. The last weeks will be devoted to putting into practice, integrating, and learning in situations that are as realistic as possible. A predetermined typical schedule will be set up to facilitate program management. This typical schedule must respect a certain number of characteristics:

- presentation of the professional situation;
- standardized weekly schedule (45 hr) respecting a set number of hours in attendance and personal study hours;

- diversified pedagogical activities chosen based on learning goals (e.g., PBL, lectures, laboratories, meeting with simulated patients);
- integration activities by students in small groups (PBL type);
- scheduled time for teamwork (community experiential learning project or other projects);
- scheduled time for preclinical exposure and community clerkship;
- training evaluation activities will be frequent with immediate feedback;
- reflective practice activity for each professional situation;
- Targeted overall evaluation activity.

Implementation

Beginning in the fall of 2017, the Université de Sherbrooke will be offering a completely revised medical program to first-year students. The 4-year program offered at Sherbrooke, Saguenay, and Moncton, will be particularly well adapted to professional practice. Students will complete it better prepared to undertake their postdoctoral training. In view of creating stronger links between the pedagogical activities and learning philosophy retained, program management has decided to make changes to the program structure. While benefiting from the great strengths of the current form of the curriculum, program management wanted to increase the coherence between the learning activities of the curriculum and the evolution of medical practice.

To encourage the introduction of the most recent changes resulting from the latest version of the MD program, faculty authorities are aware of how important it is for the staff to negotiate the change well. For this purpose, the principal strategy that will be implemented is staff training. The HSPC will contribute by providing training to the teaching staff. In addition, various actions will be proposed at the implementation phase:

- Consult and involve professors at each change deployment phase over the next 3 years.
- Regularly inform professors of all decisions made regarding the MD program clearly showing that these decisions result from consultations with staff.
- Make the support of the management of the FMHS explicit and visible.
- Regularly evaluate every change implemented throughout the implementation phase both with professors and students.

To realize the conception leading to this third version of the MD program, those in charge, as well as those involved in the various curriculum revision committees, adopted a more systemic vision of medical education at the Université de Sherbrooke. This vision made it possible to develop an ecological perspective of the training provided, for example, where the program is studied in relationship with the individuals working in it. Furthermore, it was important to study the relationships that were established among the actors (professors, medical students, and students in other branches of health sciences education, decision makers, professionals, technicians).

Consequently, in addition to PBL, team-based learning (TBL) has been added, underlying the importance of educating students in team and collaborative work.

The modified program is based on Université de Sherbrooke's "Professionalization path" model. Its principal goal is to educate resident physicians so that they are ready to continue their education in any postdoctoral program. To accomplish this, the program is structured around five professional situations reflecting the different roles of a physician: care, health promotion, education, management, and research. For each of these situations, the program targets the integration of basic sciences, clinical sciences, and social sciences in the educational activities to foster disciplinary decompartmentalization.

Moreover, in this digital age where information is readily accessible at our fingertips, it is essential to take this new reality into account. This access to information requires the development of informational competencies in students. They not only need to have a solid knowledge base and essential skills in the clinical reasoning process, but they also must be able to identify and optimally process information from multiple sources that allows them to make the best decisions for their future patients.

Conclusion and Future Directions for PBL in the Health Science Programs

This chapter has presented a case study of PBL at the Université de Sherbrooke's FMHS using a threefold view of the innovation process that took place. Over the past 30 years, the medical program has experienced three versions of this innovation process, each time going through the three phases (conception, implementation, and evaluation). Before attempting to show what impacts new trends in medical and health sciences education have had on the latest version of the medical curriculum, we will summarize the major changes that have taken place since 1985 (see Table 20.1).

At the beginning of this chapter, we stated that "changing teaching in higher education is never an easy process since it involves questioning the knowledge, dogmas, and beliefs of the individuals involved." The three versions of the MD program at Université de Sherbrooke that have been described in this chapter illustrate this phenomenon while demonstrating that implementation of major innovation is a complex process.

Medical practice is undergoing a profound change, related both to emerging health and prevention issues (aging population, chronic diseases, multimorbidity) and the transformation of the health system itself (accessibility, costs, increase in stakeholders, transformation of health professional roles, network automation). These factors, combined with an increase in scientific knowledge in the field and an increase in medical education requirements, place great pressure on medical education programs and those responsible for them. Faced with excessive content, it is important to make strategic choices in terms of relevancy and only keep what is essential (Kern, Thomas, & Hughes, 2009). For the direction of the program, it is essential to target learning that will help equip students for their future practice, while developing their critical thinking and reflexive learning capacity throughout their professional life. But how can this be translated into educational terms, throughout a curriculum?

Table 20.1 Major Changes to the MD Program at the Université de Sherbrooke

Timeline	Major changes to the medical program
1985–1995	**PBL as an innovation** • PBL becomes the main learning method for the preclinical years (Phases II and III) • Humanistic vision of the curriculum • Focus on students' prior knowledge for the role it plays in learning • Support students' integration of knowledge by using problems • Give students means by which to learn autonomously and be more engaged • Teachers' roles change from being "sage on the stage to being guide on the side" (King, 1993) • Creation of the Pedagogy Development Office (PDO)
1996–2005	**PBL under review—improvements** • PBL becomes the learning method used during Phase I • Improve students' decision-making and communication skills • Support students' development of use of ethical principles • Focus on students' reflective capacities as practitioners (professional vision) • Reduction of tutors' focus on "content learning" and standardization of their role during PBL meetings • Replace the PDO with the Medical Pedagogy Centre (MPC), then the Health Sciences Pedagogy Centre (HSPC) • Extend pedagogical innovations to the postdoctoral years
2006–2010 (interim period)	***Satellite campuses*** • *Addition of two satellite campuses* • *Introduction of distant learning activities (PBL and lectures)*
2010–2016	**More than PBL** • PBL remains one of the key pedagogical features of the MD program, but team-based learning (TBL) also takes a significant place. • Demonstrate the alignment between the knowledge to acquire (internal and external resources), the contexts in which the tasks will be carried out, and the specific requirements associated with each task (conditions for achievement) • Practical training is increased and learning is focused on real clinical situations, called "professional situations," with a global approach • New pedagogical formats will be added to PBL, such as team learning and Case Method (e.g., Hammond, 2002) • The program will propose longitudinal mentoring to support the student in his or her learning and development of his or her professional identity throughout a semester • Teaching activities will no longer be organized by organ systems: the necessary knowledge and understanding of the functioning and complexity of the human body are now integrated in clinical situations that call upon all medical disciplines, as with a real medical practice • The pedagogical material will be completely digitalized • During the first 2 years, the new curriculum will offer preclinical training involving mandatory preclinical immersion, community clerkships, and experiential learning activities in the community

More than 20 years ago, Alison King (1993) published an article titled "From sage on the stage to guide on the side" in the journal *College Teaching*. This simple yet graphic way of encapsulating the idea at the base of the paradigm shift that grew over higher education (e.g., Barr & Tagg, 1995) is still hotly debated (e.g., Kirschner, Sweller, & Clark, 2006; Kuhn, 2007; Mayer, 2004). PBL represented and still represents an important teaching method for implementing the principles conveyed by the learning paradigm (Hmelo-Silver, Duncan, & Chinn, 2007; Schmidt, Loyens, van Gog, & Pass, 2007). However, most educators agree today that there is not "one" teaching method likely to meet all learning needs and objectives. Approaches falling under the learning paradigm offer a wide range of principles and methods to attain a variety of teaching and learning goals (e.g., Svinicki & McKeachie, 2014). Those guided the pedagogical innovations implemented in the third version of the MD program at the Université de Sherbrooke.

The educational choices that were made aimed to answer a series of fundamental questions following the adoption of the learning paradigm (Barr & Tagg, 1995), in particular in medical education: What knowledge, talents, and skills do university graduates need in order to live and work fully? What must they do to master such a vast array of knowledge, skills, and attitudes (being)? Are they learning these while they study? Can they act on them? During their undergraduate years, do students find a coherent body of experiences that help them become competent, capable, and open-minded professionals? Have the different learning experiences acquired by students through the program made them flexible, adaptable learners, able to function in a knowledge society?

To consider these questions, the individuals in charge of the program should pay particular attention to certain fundamental aspects of curricular change. The curriculum should be considered as an indivisible whole, and not only as a grouping of several separate parts. Consequently, the curricular choices that he or she will make must be supported by evidence-based data and recommendations from the literature on learning and development of expertise and not only on the desire to implement new "trendy" pedagogical methods (e.g., flipped classroom). Furthermore, evaluation of learning by students must be developed in keeping with the training goals (pedagogical alignment). Regarding the acquisition of basic science and clinical science content, the individuals in charge of the MD program are invited to promote integrated, longitudinal learning based on a limited number of prototypical clinical situations of increasing complexity. In this respect, the program should strategically recommend the use of different pedagogical methods while stressing the importance of providing opportunities to validate learning (formative evaluation) in order to regularly inform students of their progress (e.g., practice with immediate feedback, knowledge integration activities). Lastly, an emphasis should be placed on a coherent evaluation system supporting competency development, which involves the use of multiple evaluative methods including some in authentic situations and frequent opportunities for feedback.

By considering these different facets, pedagogical and curricular innovation in medical education can continue to make significant advances and in doing so meet the needs of student education while satisfying societal expectations.

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21

Seeing and Hearing is Believing, But Eating is Knowing: A Case Study of Implementing PBL in a Master of Educational Management Program

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Seeing and hearing is believing, but eating is knowing.[1]

This quotation highlights the educational challenge of making knowledge accessible, meaningful, and usable for learners faced by teachers at every level of schooling. Nowhere in the world is this challenge more relevant than in East Asia, where norms of teaching and learning continue to emphasize one-way communication from teachers to pupils (Kember, 2000; Watkins, 2000). Indeed, policy-driven efforts within the region to bring about change in traditional methods of teaching and learning have faced numerous obstacles and shown only limited success. Arguably, the first step to bringing about change in the practices of teachers begins in the university where schoolteachers and leaders receive their own education. Therefore, we suggest, as implied in the opening quotation, that schoolteachers who learn by experiencing new forms of instruction will be better prepared to use these methods themselves. Similarly, school leaders will be more passionate advocates and more capable of supporting the use of new forms of instruction.

Today there are thousands of school leaders and teachers working in the international schools' sector in Asia Pacific societies. Those seeking graduate degrees in education (e.g., MA, MEd, EdD, PhD) tend to find their options severely limited since local universities have traditionally only offered graduate degrees in teacher and school leader education in local languages. This demand–supply tension contrasts, for example, with "international" Master degree programs in

Portions of the chapter were adapted from material published in Hallinger, Lu, & Showanasai, 2010; Lu, Hallinger, & Showanasai, 2014; Showanasai, Lu, & Hallinger, 2013.

1 1976, Hugh Morgan Hill, aka Brother Blue, personal communication.

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business administration (MBA, MM, DBA), which are ubiquitous throughout the region. Consequently, school educators have traditionally turned to a handful of universities in the U.K., Australia, and the U.S. These universities have typically "exported" their graduate degree programs, unchanged, to Asia Pacific delivering their curricula through a combination of short-term summer residences and "fly-in faculty."

In 2009, the senior author was given the brief to develop an International Executive Master of Arts (IEMA) in educational management aimed at a target audience of English-speaking school leaders and aspiring school leaders working in the Asia Pacific region. The development team made several key design decisions when formulating the Master degree program in educational leadership and change.

- The Master degree would be designed as an "international program" with global and regional content delivered in English as the medium of instruction.
- It would be organized as an "executive Master degree program" that required participants to have prior teaching and leadership experience.
- It would be offered as an "online" web-based degree program, with just one of the eight courses comprising the curriculum offered in a residential model.
- Given the dispersion of students across different time zones, the curriculum would be delivered exclusively through an "asynchronous mode" that would enable students to complete the coursework at their convenience, 24/7.
- The curriculum would feature problem-based learning (PBL), project-based learning, online simulations, and narrated "lectures" rich in the Asia-based multimedia content stored online.

At the IEMA's launch in 2010, this was the only online Master degree in educational leadership and management offered by an institution located in the East Asia region. The heavy reliance on PBL, computer simulations, and contextualized content from East Asian schools further differentiated the curriculum from those offered by other institutions.

In this chapter, we have several goals:

1) to review the uses of PBL and computer simulations in management education;
2) to outline how PBL was integrated into the IEMA program;
3) to provide in-depth description of the design and implementation of one online course, *Leading Organizational Change* (LOC), which was organized around a problem-based computer simulation (Making Change Happen™, The Network Inc., 1997);
4) to provide descriptive and analytical data that offer insight into the learners' engagement in the course, their use of the problem-based simulation as learning tools, and achievement of course learning outcomes;
5) to reflect on this use of PBL in an online environment in East Asia.

Applications of PBL in Management Education

Our review of background literature encompasses three related domains. First, we review the use of PBL in management education, with a focus on the preparation and development of educational leaders. Next, we examine the use of simulations in management education. Finally, we provide an overview of recent developments in the use of PBL and simulations in online management education programs.

Problem-Based Management Education

PBL is an action-directed learning approach that creates an experiential basis for situated learning of content knowledge and problem-solving skills (Barrows & Tamblyn, 1980; Bransford, 1993; Copland, 2000). Proponents of using PBL in management education (Bridges & Hallinger, 1993; Hallinger & Bridges, 2007; Stinson & Milter, 1996) have followed its main precepts as originally outlined by Barrows and Tamblyn (1980) for medical education. Project-based learning may appear similar to PBL in the form of a time-limited project that students complete while working in self-directed, cooperative learning teams (Bridges & Hallinger, 1995). However, project-based learning is more often organized around a specific product, and the learning teams may encounter multiple "problems" when they work toward achieving the end product (Blumenfeld et al., 1991). PBL also incorporates several key dimensions that distinguish it from other problem-oriented learning methods such as case-based instruction (Christensen, 1987; Garvin, 2003).

- PBL presents a problem as the initial stimulus for learning; students always receive the problem scenario to be solved prior to encountering the relevant knowledge content to be learned (Barrows & Tamblyn, 1980).
- The PBL unit takes place in the form of a time-limited project that students complete while working in self-directed, cooperative learning teams (Bridges & Hallinger, 1995).
- The learning teams access a variety of knowledge resources in order to understand and develop solutions to the problem (Barrows & Tamblyn, 1980).
- To the greatest extent possible, students are expected to demonstrate or implement their "solution" to the problem, not only write about what they would do (Hallinger & Bridges, 2007).
- Assessment emphasizes formative evaluation designed to enable and extend current and future learning (Hallinger & Bridges, 2007).

The goals of a PBL curriculum include knowledge acquisition and application, formation of lifelong learning skills, enhancement of problem-solving, decision-making, and teamwork skills, and the development of affective capacities necessary for successful professional practice (Copland, 2000; Hallinger & Bridges, 2007; Sherwood, 2004; Stinson & Milter, 1996). These goals are significantly more ambitious than those of traditional graduate management education programs, which have focused primarily on knowledge acquisition (Bridges &

Hallinger, 1995; Garvin, 2003; Kloppenborg & Baucus, 2003; Murphy, 2006). Moreover, we assert that these ambitious goals address important limitations identified in published critiques of management education (e.g., Hallinger & Bridges, 2007; Martin, Chrispeels, & D'Emidio-Caston, 1998; Murphy, 2006; Romme & Putzel, 2003).

The use of PBL in management education can be traced back to the 1990s when scholars first began to adapt the "original" form of PBL pioneered in medical education (e.g., Bridges & Hallinger, 1993). This emergent trend became evident during the 1990s in graduate management education programs specializing in both educational administration (e.g., Bridges, 1992; Bridges & Hallinger, 1995; Copland, 2000; Tanner, 1997; Walker, Bridges, & Chan, 1996) and business administration (Gilbert & Foster, 1997; Kajewski, 1996; Stinson & Milter, 1996). In the ensuing decades, a rich descriptive literature has accumulated recounting how PBL has been employed in management education programs (e.g., Ford, Martin, Muth, & Steinbrecher, 1997; Kloppenborg & Baucus, 2003; Martin et al., 1998; Tanner, 1997).

This literature offers useful detail concerning methods of curriculum design (e.g., Hallinger & Bridges, 2007; Sherwood, 2004), instructional design (e.g., Anderson & Lawton, 2005, 2014; Copland, 2000), problem selection and development (Bridges & Hallinger, 1995; Copland, 2000; Hallinger & Lu, 2012), and classroom organization (Hallinger & Bridges, 2007; Hernández, Gorjup, & Cascón, 2010). Nonetheless, in contrast with medical education (e.g., Gijbels, Dochy, Van den Bossche, & Segers, 2005), the management education literature lacks empirical studies that explicitly analyze the efficacy of alternative configurations of PBL (e.g., Luck & Norton, 2004), compare its effectiveness with alternative learning methods (e.g., Hallinger & Lu, 2011; Hernández et al., 2010; Steadman et al., 2006), or assess its impact on learners (e.g., Lu et al., 2014; Pinheiro, Sarrico, & Santiago, 2012; Schell & Kaufman, 2007; Secundo, Elia, & Taurino, 2008; Showanasai et al., 2013). Thus, 25 years after the initial adoption of PBL in management education, these research limitations mean that management educators must continue to rely largely on evidence about the efficacy of PBL derived from related disciplines.

The form of PBL that the instructors chose to employ in the design of the online Master degree program started with the design principles listed above. These design principles differentiate PBL from other methods of management education including case-based instruction (Christensen, 1987; Garvin, 2003) and project-based learning (Blumenfeld et al., 1991). When considering these design principles, the instructors had to adapt their use of cooperative team learning and self-directed tutorial groups to the highly dispersed online learning environment in which our students were studying (also, see Bigelow, 2014; Luck & Norton, 2004; Schell & Kaufman, 2007; Secundo et al., 2008). We elaborate on the rationale, nature, and impact of our adaptations later in the chapter.

Simulation-Based Learning in Management Education

Proponents have argued that simulation-based learning is also aligned to important goals of management education (Adobor & Daneshfar, 2006; Mann, Reardon, Becker, Shakeshaft, & Bacon, 2011; Salas, Wildman, & Piccolo, 2009; Steadman et al., 2006). These include enhancing complex applied competencies in decision making and teamwork, fostering skills in higher-order thinking and reflection, and learning to use knowledge as a tool for problem solving (Bigelow, 2004; Gary & Wood, 2011; Salas et al., 2009; Scherpereel, 2005). Simulations have the potential to overcome the problem of "analysis paralysis" that can emerge when learning skills and perspectives on professional practice in academic settings that emphasize the acquisition of theoretical and declarative knowledge (Bransford, 1993; Bridges, 1977; Hallinger, Lu, & Showanasai, 2010).

Well-designed computer simulations create a form of "virtual reality" that allows students to learn, apply, and refine theory in the context of job-relevant knowledge and skills (Bell, Kanar, & Kozlowski, 2008; Hallinger & McCary, 1990; Mann et al., 2011; Romme & Putzel, 2003; Salas et al., 2009). The computer simulation discussed in this study engaged students in solving a set of high-fidelity, complex, dynamic management problems. Much like the use of simulated patients in problem-based medical education (Barrows, 1993), management simulations provide students with an "evolving, interactive, and dynamic problem space" in which to learn (Salas et al., 2009; Scherpereel, 2005). When playing a well-designed simulation, students seldom experience exactly the same pattern of events twice, even when they employ the same strategy. This contingent, dynamic feature of the learning environment stimulates learners to continuously reflect on cause and effect relationships with respect to their strategic decisions and rethink their "mental models" (Anderson & Lawton, 2005; Gary & Wood, 2011; Hallinger & McCary, 1990; Scherpereel, 2005; Smith, 2005). This characteristic of simulations contrasts vividly with most teaching cases in which learners "enter a problematic situation" that remains stable as the learners develop their solutions. In sum, simulations require students to "situate knowledge in a problem context" and consider the contingencies that impact the application of both formal and tacit knowledge in management practice (Alter, Oppenheimer, Epley, & Eyre, 2007; Bandara et al., 2010; Bransford, 1993; Wagner, 1993).

So what differentiates PBL from simulation-based learning? At their base, the two learning methods share two fundamental similarities. These include, for example, a problem orientation, the use of problem solving as a means of "learning through experience," and a focus on formulating and implementing practical solutions to problems (Anderson & Lawton, 2005, 2014; Hallinger et al., 2010; Hallinger & Bridges, 2007; Steadman et al., 2006). There are also differences between the learning approaches. Simulations, by their nature, provide almost continuous, interactive feedback to the learner. This type of feedback is useful in stimulating critical awareness and meta-cognitive development, which have been identified as important capacities for the development of professional expertise (Alter et al., 2007; Gary & Wood, 2011; Hallinger & Bridges, 2007; Salas et al., 2009; Schell & Kaufman, 2007; Wagner, 1993). Beyond this process difference, the degree of alignment of the two learning methods depends on the instructional design employed by the teacher. Simulations, for example, can be used to practice the application of a previously taught theory (non-PBL mode) or used to initiate learning of theory and practical perspectives (PBL mode). Simulations can be played by individuals or in a cooperative learning mode.

Thus, we tend to view PBL as a pedagogical framework for learning within which simulations can be employed. As experienced users of PBL in a traditional classroom format, we value the dynamic complexity and rich content embedded in computer simulations. In our view, these features leverage the pedagogical power of both approaches thereby enhancing learning in university courses and executive education programs.

These combined design elements of SBL and PBL cohere to create a challenging learning environment (also, see Cook & Swift, 2006; Hallinger et al., 2010; Mann et al., 2011; Schell & Kaufman, 2007; Tan, 2007). The use of the problem-based simulation engages students, directs their learning toward the solution of meaningful problems, and offers a continuous stream of feedback that stimulates reflection and higher-order thinking (Bransford, 1993; Gary & Wood, 2011; Hallinger & McCary, 1990). In this study, we sought to collect meaningful data on the knowledge acquisition and application of learners (i.e., procedural knowledge). More specifically, we used simulation software to track the sequence and types of decisions made by the learners as well as assess their success in solving the simulated problem.

PBL in on Online Master Degree Program in Educational Leadership and Change

The remainder of this chapter will focus on describing and analyzing the design and implementation of PBL in an online international executive Master degree program in Hong Kong. Launched in 2010, the program has admitted students on a rolling basis each year. With rolling admissions, this means that new students enter each time a new class is offered. The program consists of eight courses, six regular courses, a residential course, and an independent project course. Courses are offered on a sequential basis, one course at a time. Each course lasts 8 weeks, during which the students interact in an "asynchronous mode," and all course materials are stored and available to students 24/7.

Broadly, PBL was employed as a framework for learning in several courses. The PBL format differed, however, from course to course. For example, two courses used problem-based computer simulations and several others employed more traditional forms of PBL. In the chapter, we will discuss in detail how a "problem-based computer simulation" was employed in one course, *Leading Organizational Change* (LOC). The LOC course was one of the six "regular courses" offered in the program. Student learning activities consist of:

- reviewing content (e.g., narrated PowerPoint lectures) online;
- downloading materials from the website for further study at home (e.g., video cases, lectures, readings, simulations);
- downloading materials from other sources for further study;
- engaging in the online discussion forum with peers and the instructor(s);
- completing and submitting task assignments.

LOC Course

The LOC course employs a PBL design constructed around a computer simulation, *Making Change Happen*. Thus, the instructional design seeks to exploit the strengths of two related approaches to learning. We will elaborate shortly on the course structure, the design of the computer simulation, the learning process, and methods used to assess student learning.

Course structure

The intended learning outcomes of the LOC courses encompass knowledge, comprehension, application, analysis, and evaluation in the subject area of leading organizational change. The LOC course was designed in line with the principles of PBL. Learning is largely student-directed with about half of the course devoted to learning through the simulation. The learning process allows relevant conceptual frameworks to emerge out of the learners' collective experience of implementing organizational change as they play the simulation. The introduction of change theories by the instructor and through readings during the process of active problem solving enables students to view theory as a practical tool (Bransford, 1993). Thus, PBL serves as a pedagogical framework for use of the simulation in the LOC course.

The Computer simulation: Making change happen

The *Making Change Happen* (The Network Inc., 1997) computer simulation forms the core of the LOC course. It presents learners with a common, high-impact problem to solve: implementation of a new learning technology system in a school district. Although the simulation focuses on the implementation of new learning technology, lessons learned by students are broadly applicable to other types of organizational changes and innovations (e.g., reorganization, work process, teaching method, curriculum). We note also that this simulation comes in different versions for school and business managers and has been translated and culturally adapted for use in several different languages and societal contexts (e.g., Dutch, Chinese, Thai, Korean, Vietnamese, Spanish).

Traditionally, students have played the simulation in teams consisting of two to four members. However, in this online course, students played the simulation as individuals, consulting one other through an online discussion forum. Learners are informed that they are members of a "project implementation team" responsible for developing and applying a strategy for implementing the new IT system (named *IT 2020*) over a 3-year period. The project team (or in this case the individual learner) must develop and implement a change strategy that raises staff awareness of the new IT system, creates a broad base of staff interest, enables the staff to develop new skills, and generates commitment to using *IT 2020* effectively in their daily work.

Playing the simulation

After being introduced to the problem and role, learners access other factual information concerning the change context. The project team works with 24 people in two "pilot schools" as well as the head office (see Figure 21.1). The game screen displays relevant members in the pilot schools on the left-hand side. Information on each staff member can be accessed by clicking on their icons. Descriptions of the staff members have been conceived taking into account a variety of factors including job position, social networks, organizational power and politics, personality type, and change adopter types (Rogers, 2003). Successful implementation depends upon the team's ability to understand the perspectives

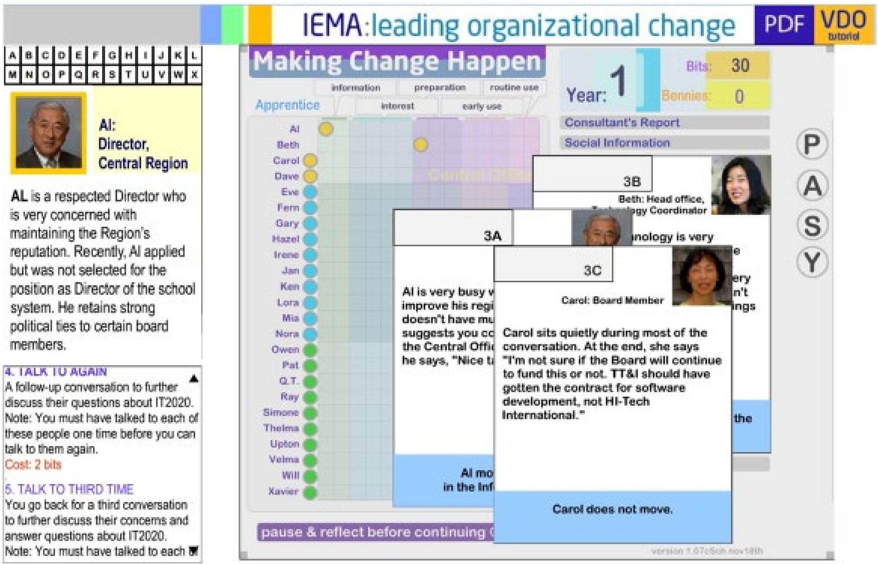

Figure 21.1 Making Change Happen Game Screen.

of these staff members toward the change (i.e., *IT 2020*) and respond with a strategy that addresses their personal concerns as well as organizational priorities, politics, and constraints (Hall & Hord, 2002; Kotter & Cohen, 2002).

Change activities are listed on the right side of the screen, again with clickable buttons providing access to information about the activity and its cost (see Figure 21.1). There are 16 change implementation activities that the teams can employ, such as gathering more information, talking with people, distributing written information, conducting a presentation for staff about IT 2020, and holding a workshop, etc. The teams spend their annual budget on these activities until they run out of time or budget for a given year of implementation.

Listed across the top of the board are five stages of the change process: *Information*, *Interest*, *Preparation*, *Early Use*, and *Routine Use*. These stages of use are derived from Hall and Hord's (2002) *Concerns Based Adoption Model*. The game pieces representing the 24 staff members (see Figure 21.1) start "off the game board" because they have yet to begin the process of change. Few staff members know anything about the *IT 2020* software system, except by rumor.

The teams have two goals in the simulation. The first is to move these 24 staff members from a state of knowing nothing about *IT 2020* to a stage of routine use of the new IT system in their work. The second is to gain productivity benefits (called Bennies) for the organization through the successful implementation of *IT 2020*. Bennies accrue during the simulation as staff members begin to use *IT 2020* in ways that increase efficiency and effectiveness.

A great advantage of the computer technology used with this simulation is that it allows seamless interactivity between the learner and the change context. The project team will "play" the simulation by considering first its strategy and then by selecting an activity to conduct with the staff members. Each time that a team "does" an activity in the simulation, several things happen:

- The cost of the activity is deducted from their budget.
- A feedback card pops up describing what happened in response to the activity.
- The game pieces representing staff members involved in the activity may (or may not) move one or more spaces across the game board.
- Bennies, if any accrue from the activity, are recorded on the screen.

For example, after an activity has been implemented, the team receives immediate feedback describing what happened and why. The first time the team "Talks to" Al, Director of the Central Region, it receives the following feedback:

> Al is very busy. He is involved in other projects to improve the region's productivity and doesn't have much time to talk with you today. He suggests that you coordinate with MIS staff at the Head Office. On your way out he says, "I don't know why they are always thinking up these new things for us to do." Al moves one space.

The first time that they "Talk to" Irene, she responds as follows:

> I just don't like computers. They're so impersonal. How can this new system help me anyway? And what will I do when the system breaks down and I have to get the credit reports out on time? Will I be blamed for the late report? Irene doesn't move at all.

Thus, unlike in a case teaching environment, the computer simulation offers learners the opportunity not only to analyze the problem, but also to "implement" their change strategy and see the results. Indeed, during the implementation process, the project team is confronted with widespread resistance to the mandated use of *IT 2020*. The nature, intensity, and forms of the resistance vary based upon a variety of personal and organizational factors. The project team must deal with emergent obstacles arising from resource constraints, politics, organizational structure, communication networks, corporate culture, and even "acts of God."

Learners usually find out that they must revise their initial strategy in order to meet the needs of the real situation. Over the course of the 3-year simulated change implementation, the learner is able to "see" the results of their change strategy both in terms of staff usage of the new IT system and productivity gains. Thus, the learners proceed through a process of planning their strategy, implementing actions, getting feedback, reflecting on the results, and adjusting their strategy. Through the simulation, the learners are able to see the *evolving results* of their strategy as the staff members begin to move through the stages of change.

Developing strategic thinking

Use of the problem-based computer simulation in the LOC module seeks to enhance student capacity for strategic thinking by requiring them to engage in goal-setting and strategy formulation at the outset of each year of simulation play (see also Gary & Wood, 2011; Hallinger & McCary, 1990). Students set annual goals that specify the desired rate of progress of staff through the stages of the change process (i.e., how many staff members they hope to have in different stages of use at the end of the year) as well as the number of Bennies they hope to achieve by the end of that year. To achieve the goal, learners need to carefully analyze the problematic situation, and develop a strategic plan that addresses key features of the problem context. Through this process, learners begin to more explicitly link goals to strategies and results, strengthening their capacity to anticipate what could unfold in future and fostering deeper thinking about cause and effect relationships. The practice on the simulation provides learners with immediate opportunities to test their strategic plan, and learners are able to see whether their goals and strategies are feasible. The gap between their intended goals and actual results drives learners to reflect on the validity of linkage between prior strategies and results. It creates a moment that prerecorded debriefing lessons containing related concepts, theories, and information become meaningful support resources for learners and that the intended knowledge are actively acquired and incorporated into the modification and improvement of their strategies.

The underlying theoretical orientation of the simulation reinforces the point that each organizational context is different, and no single sequence of steps will bring about effective change in all situations. Therefore, memorizing or seeking to identify one best sequence is useless. As students play the simulation numerous times during the course, in the classroom and at home, patterns of action that characterize successful change begin to emerge. With the aid of instructor debriefings and structured intergroup sharing, these patterns gradually cohere into *principles* that underpin effective change strategies (see Hallinger et al., 2010; Hallinger & McCary, 1990).

Effective learning in educational programs often takes place when there is a culture of learning from each other (Barbour, 2006; Bridges & Hallinger, 1995; Cook & Swift, 2006; Kimber, 1996). In the context of working on a challenging, complex task, learners seek to support each other in order to solve the problem. Therefore, in designing the learning environment, we sought to enhance cooperative interdependence among the learners (Hallinger & Bridges, 2007; Kimber, 1996) through the use of a discussion forum.

Assessment of learning

At the conclusion of the 3-year simulation, team success is assessed in terms of the number of staff in the *Routine Use* stage of change and Bennies gained. Using these criteria, the project team's results are evaluated and assigned to one of six levels of expertise: Novice, Apprentice, Manager, Leader, Expert, Master. For each level, the simulation provides differentiated feedback on how the team could improve their strategy. The learning process used with the simulation seeks to link the principles that underlie effective change strategies to the results. By playing the simulation numerous times, the learners can "try out" different change strategies and evaluate them in light of results.

Problem-based learning emphasizes assessment that fosters learning (Hallinger & Bridges, 2007). In accordance with the intended learning outcomes, the LOC course employed methods of assessment that targeted affective and skill competencies, knowledge application as well as acquisition. Assessments included performance-based assessments as well as analytical papers and a test of knowledge acquisition.

First, the students must submit a copy of the final screen showing their highest level achieved (i.e., from Novice to Master). As noted above the "level" attained by the student represents their ability to formulate and implement a successful change strategy. Higher levels of attainment reflect the student's ability to foster change in staff behavior and increase learning outcomes for the school.

Students were told that they could play the simulation as many times as they wished. By including this "result" in the course assessment it both stimulated students to play the simulation multiple times, while rewarding them for their effort and success. We consider playing the simulation between five and 15 times as desirable, in order for students to gain the full benefits of "learning through experience."

Second, each student writes a "strategy analysis" paper in which implementation goals, strategies, and results are described and analyzed. The assignment requires the student to analyze their implementation effort by linking their intended goals and strategy to results. Students also reflect on their implementation in light of key theoretical content learned in the course (e.g., Hall & Hord, 2002; Rogers, 2003). Without this assignment, it is possible that students could master the simulation as a "game" without learning to apply the underlying principles of organizational change.

In addition to the change strategy paper, each student must also write a personal case study that analyzes specific changes being implemented in their own organizations. Students again draw upon theories of change, but in this assignment, they must link lessons from the problem-based simulation to their real-life experience. This fosters the transfer of learning and allows assessment of individual students' depth of understanding at higher levels of thinking (Baldwin & Ford, 1988; Bransford, 1993; Bridges & Hallinger, 1995; Wagner, 1993).

Research Method

The research reported in the following section of the chapter was based on a field study. We gathered data during one course offering of the LOC course. More specifically, we focused on student learning with the web-based version of the problem-based simulation, Making Change Happen.

Participants

Students in this Master degree program were department heads, curriculum coordinators, vice-principals, and principals working in both government and international schools located in Asia Pacific. Thus, this field test was conducted with a common audience for the use of the simulation in exactly the type of setting that was anticipated as a target for the new online simulation (i.e., graduate management programs).

Twenty-four students taking the LOC online course were assigned to learn with the simulation during the 8-week course. For personal reasons, one student quit the program 2 weeks after the course started, so the actual class size was 23 students. Students have continuous access to the simulation as well as to a set of narrated multimedia-enriched PowerPoint presentations. The narrated presentations introduced the students to “how to play” the simulation, framed key questions used to stimulate online discussion, and offered input on relevant management theories that could be applied during the course of solving the simulated problem. These materials had been redesigned from those used in face-to-face learning environments in order to support students in online learning.

Data sources

An online discussion forum was conceived as a key learning resource for students. Discussion requirements and questions were posted at the outset of the course and online interaction was monitored by the instructors during the course. Students were, for example, “required” to post responses to at least two out of four discussion questions posted by the instructors (see Appendix A). They could, of course, respond to the posts of other learners, as well as the posts other learners made to their own online comments. Surprisingly, forum activity was intense, continuous, and widespread among the learners. Students offered shared problems and obstacles, strategic hints and strategies, shared frustrations and celebrated successes with each other.

The online forum, therefore, represented a useful source of data on how students thought about the conceptual problems they encountered, and also on their learning process. Student responses were analyzed and summarized to assess learning in this PBL environment. As such it became a most valuable source of information on the learning process experienced by the students.

In addition to the online forum data, this research also tracked data collected from the students’ efforts at playing the simulation over a 5-week period of the course. Students played the simulation as individuals. Each time a student played the simulation, the process and results were recorded and saved to a file on the central server. Data reported in this chapter include:

- frequency of student efforts playing the simulation;
- student trajectories in improving their results with the simulation over time;
- summary of final student attainment levels of the learners on the simulation.

In addition, for assessment purposes, students were asked to complete an online questionnaire providing a formative evaluation of learning with the online simulation. The online survey sought feedback on a variety of different issues ranging from the online interface, ease of use, capacity of the simulation to engage their interest, comparison to other modes of learning, and suggestions for improvement. We report relevant data obtained from the questionnaire in this report.

Finally, we provide an overall evaluation of the students’ strategy analysis papers (see Appendix B). These were assessed using a rubric (see Appendix C), which was applied by two instructors for each paper. We draw upon the results of the evaluation of student strategy analyses to assess student achievement of the learning objectives stated for the PBL project.

Results

Analysis of online discussion forum

It is important to note that the course was well prepared in terms of the sequence, documentations, and assignments. Thus, the students were properly directed and guided to learn and experiment with the simulation, which might be an important factor for its success. Based on the content analysis, the students showed their interests in the contents of the simulation and got engaged in the simulation intensively.

After the first week of using the simulation, the students started to comment on the simulation positively. All comments acknowledged the complexity of the simulation, related theories, and the simulated situations that they had encountered when they played the game. For example:

> The people in the simulation were very cleverly picked and the simulation really does help tackle and decide on strategies to implement change. It's an excellent learning tool. Kudos to Phil and team. I feel far more confident in leading change now—and am really interested in the transition material to complement change. A very valuable course for me so far!
>
> I'm loving this simulation—and have spoken about it at school … especially the floods!! In fact, I had something happen today and a thought that flashed across my mind was—'that's like the flood!!!!

There was no negative comment on the use of simulation. In fact, the students were excited by the use of simulation in the course as the positive comments were posted throughout the period of time. This implies that the use of simulation was acceptable to students and they perceived this simulation as an engaging learning tool.

Strategy Record and Performance Results

A summary of descriptive analyses of the process and results data saved on the server is presented in Table 21.1. It should be noted that, from our experience, it takes a learner about 90 min to play the 3 years of the simulation the first time. Subsequently, the duration is gradually reduced so that by the time a learner is playing for the fifth time, it only takes about 30–45 min per 3-year session, depending on how much time they devote to deeper analysis. The reason for this is that there is a lot of up-front learning about "how to play" the simulation, as well as basic information that does not change from one session to the next (e.g., descriptions of the people, nature, and cost of the activities). It should also be noted that learners need not play all 3 years every time they start a session.

Table 21.1 Summary of Simulation Playing Process and Results (N = 23)

Variables	Min.	Max.	Sum	Mean	SD
All attempts	6	119	697	30.30	28.33
Completed attempts	3	32	282	12.26	6.94
No. of actions[a]	16	43	8,821	31.28	3.207
Highest Bennies	7,070	11,620	217,650	9463.04	1046.13
Highest level	Expert (2; 8.7%)[b]	Master (21; 91.3%)			

[a] Number of actions for each completed attempt.
[b] Frequency and percentage of students.

In terms of our initial analysis, we were interested in assessing the extent of learner engagement with the PBL simulation. More specifically, we sought to understand the extent to which students employed the simulation as a learning tool, and how that varied across individual learners.

The results revealed that the 23 students played the simulation a total of 697 times. On average, each student played the simulation about 30 times, ranging from 6 to 119 times! Among the 697 recorded attempts, 282 sessions involved the learner playing the full 3-year simulation to completion. In terms of 3-year sessions, on average, students played the simulation about 12 times, ranging from the fewest, which was 3, to 32 times. Even so, their engagement in the simulation well surpassed the instructors' recommendation to students to try and play the simulation at least five times.

As noted earlier, success in the simulation is assessed in two forms: the number of staff reaching the *Routine Use* stage of change and by the number of Bennies (student benefits). The simulation tracks these for every session and combines them into a series of "attainment levels": Apprentice, Novice, Manager, Leader, Expert, Master. Within this class, 21students (91.3%) reached the Master level by the end of the course, and two students (8.7%) reached the second highest Expert level. It should be noted that achievement of Master level is very challenging.

The results concerning actual number of attempts on the simulation and the performance outcomes drove us to further test whether there is any correlation between these variables. As shown in Table 21.2, the success on the simulation (highest bennies) is more closely related to the number of completed attempts on the simulation (r = 0.60, $p < .01$) than to the overall number of attempts (including incomplete attempts) (r = 0.46, $p < .05$). This finding affirms the beneficial effect of experiencing and reflecting on the problem-solving process.

The data saved on the host server also enabled us to understand the students' longitudinal development in learning. Here we were interested not only in how frequently students played the simulation, but also how their learning unfolded

Table 21.2 Correlation Results Between Attempts and Performance Results (N = 23)

Variables	1	2
1) All attempts		
2) Completed attempts	.72**	
3) Highest Bennies	.46*	.60**

** $p < .01$; * $p < .05$.

over time. That is, we conceived of the simulation as a form of "learning from experience," which is why we encouraged them to play multiple times. Moreover, during the month-long period when the students were playing the simulation, the course also provided learning resources drawn from theory, practice, and experience (e.g., via the discussion forum). We assumed learning from these sources would be integrated with their experience of learning through the simulation.

Figure 21.2 depicts the learning trajectories of students' performance in terms of Bennies attained on the simulation per full session. The data represented in this figure suggest conclusions. First, students were trying out different strategies in successive sessions; they were using the simulation to model in a sense the effects of different approaches to leading change. Second, in doing so they were, in effect, learning from their experience. Third, despite fluctuations in the learning curves of individual learners, there was a general pattern of growth for all the students. Moreover, over time, most of the fluctuations occurred within a higher range of Bennie attainment. This suggests that following a period of learning the "basics" of effective strategies, students were trying to "tweak" the strategies, by trying different approaches, which was interpreted as a positive trend. Finally, as noted earlier, a certain amount of "random consequences" (e.g., flooding on the day of a workshop) built into the simulation make the highest levels of Bennie attainment impossible for every session.

Results of students' feedback to the online questionnaire are summarized in Table 21.3. Students' feedback on the functionality of the online simulation was rather positive. The average score for the design question was 2; meaning minor improvement needed. The average score for the interface question was 3.1; meaning students rated the design items as being between "Average" and "Better than many programs." The average scores for the Ease of Use domain were around 2, meaning students' rating were around "easy," and some students rated as "very easy," and on average, students need play the simulation 1.86 times before they understand "how to play" the simulation.

Students' feedback to open questions concerning learning experiences through the simulation revealed very satisfactory results. Students reported that they felt "excited," "interested," and "curious" about the course when they first read that the course would involve the use of a computer simulation. After the students had completed the simulation module, they felt learning through an online simulation

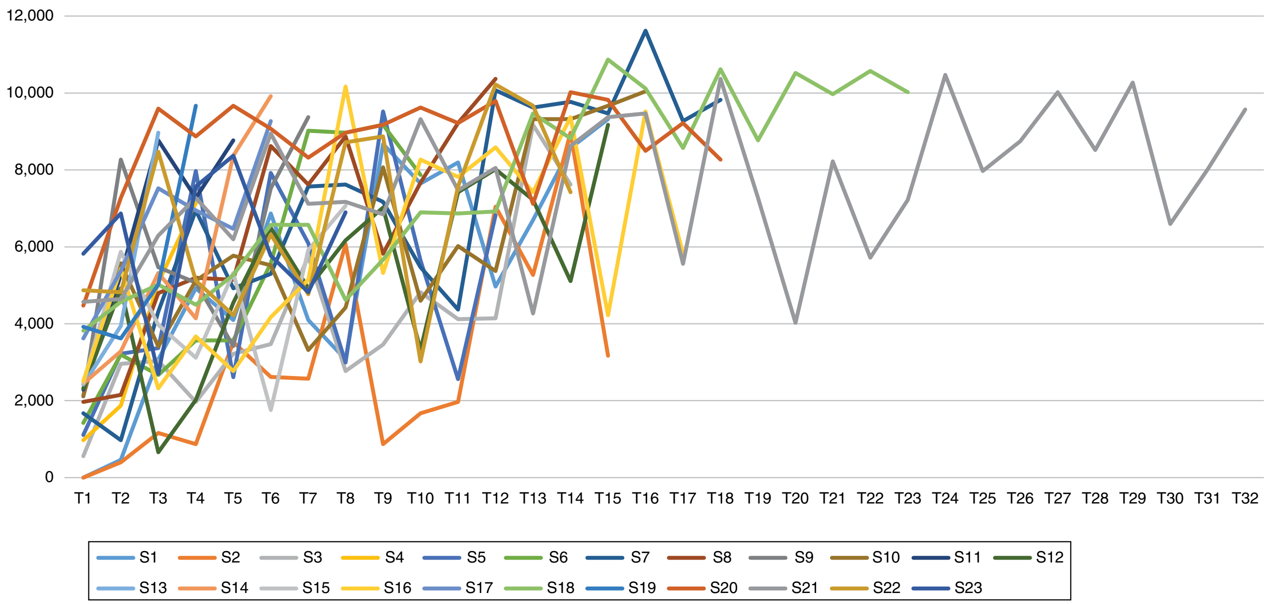

Figure 21.2 Learning Trajectories over the Stimulation.

Table 21.3 Results of Main Field Usability Testing: Functionality (N = 14)

Assessment domains and items	Mean
Design	
1. How do you like the design? (Graphics, its layout, color, pictures)	2
2. How do you like the interface? (Color changes when mouse moves, etc.)	3.1
Ease of use	
3. How easy was it to understand to use the simulation on your own?	2.36
4. How many times did you play the simulation before you understood "how to play" (i.e., not achieve a high score, but the way of playing it)?	1.86
5. How easy was it to understand the meaning of the buttons and labels?	2
6. How easy was it to find the information you needed to play?	2
7. How easy was it to read the information you need in the simulation?	1.79
Usefulness of content	
8. Did you find information on response cards useful for learning?	4.07
9. Did you find information on strategy records useful for learning?	3.21
10. Did you find information in summary at the end of the simulation that describes your level of mastery useful for learning?	3.36

as being "very positive," "enjoying," "really engaging," "relevant to what is being learnt," "helps to drill certain concepts having fun," "a great forum to build understanding," "excellent experiences," and "teaching me how to think strategically in every situation." When students were asked about three adjectives that best describe how they feel about the experience of learning through simulation, they gave very positive adjectives such as "beneficial," "enthusiastic," "challenged," "memorable," "empowered," "rewarding," and "thought-provoking" although one student expressed "frustrated," he added this was only at the very beginning.

The weaknesses they concluded about learning through simulation were mostly technical aspects, including "really good, wouldn't change anything," "can't think of any," "some spelling mistakes," "colors," "I'd like to see a record of people's responses," and "there were times when I wanted to send a mix of primary and secondary teachers to things, but this wasn't always an option." The strengths students concluded about learning through simulation corroborated their very positive responses to the prior questions. For example:

> It allowed you to use virtual people in a real life context to see if your management strategies would achieve success.
>
> You could go back to play the game as many times as you liked and try you different strategies.
>
> I think getting to test theory and practice helped to build deeper understanding.… I could read or listen about leading change but actually getting to do it makes a world of difference.
>
> This was really engaging and it was hard to stop thinking about what strategies you'd try next time (that's a good thing!). I really enjoyed it.

Conclusion

This study showcased the feasibility and effectiveness of PBL in the context of an online executive Master degree program in East Asia. It responded to one important proposition in literature that traditional PBL has great potential to be integrated with learning technologies. In this chapter, we offered a detailed description of the design and delivery of an online course that was organized around an adapted PBL-based computer simulation. We further analyzed student use of the computer simulation and student interaction during the course in an online forum, as well as their learning results and responses to the course. The results revealed that students were able to attain the course intended learning outcomes. It can also be observed that student efforts were positively associated with their performance, and there was a healthy learning trajectory over time. More importantly, students in general perceived the PBL-based computer simulation as an exciting and engaging learning tool. This finding is particularly valuable given that promoting and sustaining student engagement has been a constant challenge for course designers and instructors of online learning programs.

The findings reported in this chapter have implications for our understanding of how PBL and computer simulation can be employed productively in an online learning environment. The findings also contribute useful findings to the relatively thin "empirical" literature on the use of PBL in the domains of educational leadership (Bridges & Hallinger, 1995; Hallinger & Bridges, 2007), computer simulation (Anderson & Lawton, 2005, 2014; Hallinger et al., 2010; Steadman et al., 2006), and web-based online learning (Cook & Swift, 2006; Hernández et al., 2010; Mann et al., 2011; Schell & Kaufman, 2007; Slotte & Herbert, 2007).

Appendix A: Connection Activities

1) Initial simulation preparation and strategy. Complete the case briefing and play first simulation session with the Making Change Happen simulation. Reflect on key points and problem in initial change simulation session. To be posted in the Online Forum on by the end of the second week of the course.
   a) What was the most important insight you gained the first time you played the simulation?
   b) What two pieces of advice would you like to share with others?
   c) What one problem would you like advice on from others?
2) Change strategy refinement. This activity asks you to reflect on key strategies and one problem after playing the simulation multiple times. To be posted in the Online Forum by the end of the fourth week of the course.
   a) Having played the simulation multiple times, what two pieces of advice would you like to share with others?
   b) What one problem would you like advice on from others?

3) Change simulation final reflection: Please post any time before the sixth week.
    a) If someone asked you "What are three key ways of thinking to keep in mind when setting out on a new change effort?," what would you answer?
    b) What issue or feature of leading change remains unclear in your mind? Why?

Appendix B: Strategy Analysis Assignment Guidelines

1) ***Describe the various ways in which people reacted to this change in terms of their change adopter types.***
    a) In a maximum of two single-spaced pages, describe the various ways in which people reacted to this change in terms of their adopter types (Rogers, 2003).
    b) Define the main change adopter types and identify people by their adopter types?
    c) For each adopter type, give examples of how people within this type reacted to the change.
    d) For each adopter type, explain your strategy and the types of activities you used to move those people through change. Give specific examples elaborating on staff responses and your success in enabling them to change.
2) ***Describe your strategy for implementing change in the simulation.***
    a) In a maximum of five single-spaced pages describe your change strategy for any one full 3-year simulation session.
    b) Identify your goals for each year in terms of people and Bennies. Show your annual progress (also attach strategy record for the 3-year implementation session).
    c) For each year, list and discuss the strategies that you used to achieve your goals and whether or not you were successful. Note that strategy refers to using the organizing concepts you used to select the sequence of activities such as in Kotter and Cohen's (2002) model (i.e., Creating a Sense of Urgency, Forming a Guiding Team). When you discuss your strategic actions, please refer to specific activities you used to implement the strategy (e.g., how you created a sense of urgency, etc.).
    d) Evaluate your success and briefly discuss the strengths and weaknesses of your strategy.

Appendix C: Rubric for Assessment of Strategy Analysis Assignment

Criterion	Wgt	Poor (0/1 point)	Fair (2 points)	Proficient (3 points)	Expert (4 points)
Adopter type	**6**	Application of concepts and strategies to adopter types is either unclear or largely incorrect. Student fails to apply the concepts	Fails to include some requirements (define, strategy, activity, rationale for results). With fewer examples as well, this results in less complete understanding adopter types	Adopter types are clearly defined. Strategies are provided for each as well as activities. Either one or two of the answers do not address all aspects (cause, strategy, activity, and result) or the four aspects lack integration	Adopter types are clearly defined as well as strategies. Examples are provided as well as results. Answer provides integrated explanation of adopter types in the change process
Change analysis	**9**	Only a list or outline of what they did. Limited or largely incorrect explanation of rationale or linkage to goas and strategies	Focus primarily on "what" they did but not enough on "how" and "why" in reference to strategy and results. In reference to concepts significant errors or insufficient examples	Goals and strategies are identified and in most cases applied with a clear explanation on "what," "how," and "why." May be gaps in understanding or incomplete information to support analysis	Goals and strategies are identified with examples explaining how and why strategy was put into action with evidence. References from reading are incorporated to provide deeper understanding
Evaluation	**5**	No clear assessment of success if provided	Evaluation of success is not consistent with results presented above. Assessment of strengths and weaknesses lacks specificity	Evaluation of success is consistent with results. Assessment of strengths and weaknesses may lack specificity or linkage to prior analysis	Evaluation of success is consistent with results. Clear sensible assessment of strengths and weaknesses is offered
Communication	**5**	Spelling, grammar, and organization interfere with communication. Reader cannot determine intended meaning	Spelling and grammatical errors force reader to struggle to determine meaning. Organizational tools and references used inconsistently if at all	Some spelling and grammar errors, but reader does not struggle. Could benefit from organizational tools (paragraphs, headings) and references	Largely free of grammar. Usage and spelling errors. Format is clear and consistent. References used correctly throughout and where appropriate

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22

PBL Capstone Experience in Conservation Biology: A Self-Regulated Learning Approach

Mary English and Anastasia Kitsantas

PBL is an acronym that is used to refer to problem-based learning and project-based learning, both of which are learner-centered, inquiry-based pedagogical approaches designed to foster deep, engaged learning. In PBL, real-world problems serve as the vehicle for curriculum delivery, encouraging student motivation, providing context for content and concepts, and supporting higher-order thinking skills. Problem-based learning is defined by Barrows (1996) as a student-centered, small-group learning approach where teachers guide students through real-world problems as they develop problem-solving and self-directed learning skills. Project-based learning, as defined by the Buck Institute for Education (BIE), is similar, with the addition of student products as part of the process: "A systematic teaching method that engages students in learning knowledge and skills through an extended inquiry process structured around complex, authentic (real-life) questions and carefully designed products and tasks" (2003, p. 4). While PBL promises many potential benefits for students, without an environment carefully designed to foster the skills needed to carry out PBL tasks, such benefits may not be realized (English & Kitsantas, 2013). The purpose of this case study is to describe an undergraduate capstone course in conservation biology that employed a PBL approach deliberately designed to foster students' self-regulated learning (SRL) and to determine whether the course was effective in promoting SRL and student performance.

Because learning in PBL engages students in highly complex activities, such as identifying their own questions, constructing their own knowledge through inquiry, developing and testing hypotheses, and evaluating evidence and synthesizing information, SRL is essential for effective learning. Specific SRL skills include goal setting, planning a course of action, selecting appropriate strategies, self-monitoring, and self-evaluating. Self-regulated learners are intrinsically motivated and report high self-efficacy for learning and performance

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(Zimmerman & Kitsantas, 2005). Further, research has shown that students' self-regulation is highly predictive of their academic performance. While developing any one of these skills could enhance a learner's learning performance, self-regulated learners are metacognitively (strategically), motivationally (affectively), *and* behaviorally (physically) active participants in their own learning process (Zimmerman, 1986).

Traditionally, SRL has been measured through self-report inventories such as the Learning and Study Strategies Inventory (LASSI) and the Motivated Strategies for Learning Questionnaire (MSLQ), as well as an interview scale called the Self-Regulated Learning Interview Scale (SRLIS). Contemporary research approaches include analysis of trace logs in computer-assisted environments, think-aloud protocols, structured diaries, direct observations, and microanalytic measures (Zimmerman, 2008). Such instruments are designed to measure metacognitive, motivational, and behavioral processes. Formative and summative assessment of outcomes in PBL is frequently conducted with rubrics that reflect the specific learning objectives, products, and product standards established by the educator. In addition to disciplinary content and skills, outcomes that are commonly assessed include collaboration and teamwork, oral communication, written communication, argumentation, and critical thinking, for example.

The present study is grounded in the English and Kitsantas (2013) model, which postulates that PBL can invoke student SRL and that SRL supports student engagement and learning in PBL. According to this model (see Figure 22.1), there is a dynamic interaction between the classroom environment (e.g., teachers' support, activity structures) and the student's internal processes (e.g., prior knowledge, interests, motivation, etc.).

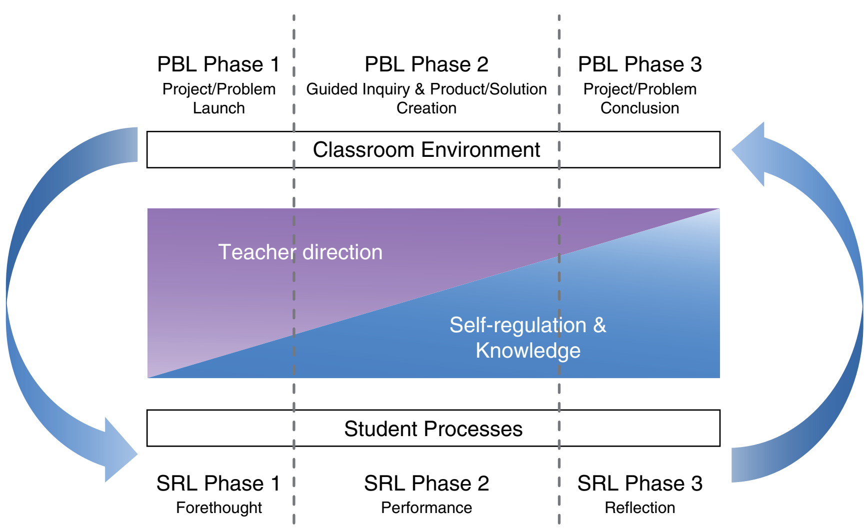

Figure 22.1 Reciprocal Relationship Between PBL and SRL.

Capstone projects have long been used in educational settings as multifaceted culminating experiences where students have an opportunity to apply their theoretical knowledge toward real-life, practical work. Used in a variety of settings, (such as nursing, engineering, education, business, and medicine) capstone projects provide a platform for open-ended investigative assignments where theory and practice come together in the pursuit of a final product, often in collaboration with professionals in the field (Denton & Spangler, 2001; Gill & Ritzhaupt, 2013).

Although variability exists in how academic programs structure their capstone projects, most capstone experiences share a number of features. In general, capstone projects across fields seek to provide a culminating academic experience where students are expected to demonstrate synthesis and integration of knowledge that was acquired in previous learning experiences (Denton & Spangler, 2001).

In the current study, the capstone engaged students in project-based learning with community collaborators focused on complex wildlife conservation problems. Overall, researchers argue that authentic, complex, open-ended problems and projects, such as these, promote critical thinking, problem-solving skills, self-directed learning, planning, goal setting, self-monitoring, and time management skills (English & Kitsantas, 2013). Further, it is believed that working with members of the communities contributes to student motivation and facilitates the development of critical domain-specific skills that students need to be effective in their future professions. The PBL methodology provides a framework for design and implementation of robust and rigorous projects that facilitate not just doing, but "doing with understanding" (Barron et al., 1998).

An SRL Approach to PBL

The PBL capstone in the current study was designed to support student SRL. The basis for the design was a model of PBL–SRL developed by English and Kitsantas (2013). According to this model, a dynamic, reciprocal relationship exists between PBL and SRL (Figure 22.1). As shown in Figure 22.1, the model indicates that the interactions between the classroom environment and student processes take place throughout three coinciding phases of PBL and SRL. The model illustrates a recommended approach for effectively supporting SRL and knowledge construction in PBL, with a greater level of teacher direction at the beginning of the project, and a gradual transition of student responsibility for learning over the course of the project.

During Phase 1, *Project Launch*, students gain an understanding of the driving question, the learning goals, and the process goals. These tasks are closely related to the *Forethought Phase* of SRL, which includes goal setting, strategic planning, and engaging self-motivational beliefs. These SRL processes enable learners to complete necessary PBL Project Launch tasks, such as developing goals and devising a plan on how to accomplish these goals.

Phase 2, *Guided Inquiry and Product Creation*, involves iterative cycles of gathering information, making meaning, reflecting, testing findings, and revising as needed (Mergendoller, Maxwell, & Bellisimo, 2006). The teacher supports incremental learning in this phase by providing scaffolds, feedback, guidance on learning content and processes, and with purposefully designed activity structures. This phase of learning corresponds to the *Performance* phase of SRL, which includes self-control and self-observation processes (e.g., attention focusing, self-monitoring, etc.) that are necessary to support knowledge construction and task management.

Finally, Phase 3, *Project Conclusion*, relates to the *Reflection* phase of SRL. While reflection is a necessary activity throughout the entire PBL process, the formal reflection phase at the conclusion of the project is an opportunity for students to consider the overall learning outcomes and process outcomes, as they relate to the project goals and expectations (Mergendoller et al., 2006). This includes self-reacting on new knowledge and conceptual understanding, comparing one's own performance to a standard, making attributions about why they succeeded or failed at tasks throughout the project, assessing whether they are satisfied with their performance, and identifying adjustments that need to be made in the next cycle of learning.

This dynamic interaction between the learning environment and the individual's SRL processes points to the importance of supporting SRL through specific PBL design and enactment strategies. The model suggests that when students are new to PBL and have lower levels of SRL abilities, teachers should provide more direct instruction initially, and gradually fade the support over time. As teacher direction fades, in an environment that supports SRL, there is a coinciding increase of SRL and student conceptual understanding. Because SRL is an intervening variable in student performance in PBL, there is an emphasis on the importance of supporting SRL. This is done through specific PBL design and enactment strategies.

Research on Capstone Projects

In general, studies that have sought to measure the effects of capstone projects on desirable student outcomes have found that the level of perceived authenticity (of the project) to be positively associated with perceived learning (Olorunnisola, Ramasubramanian, Russill, & Dumas, 2003); these projects enhance students' skills and learning to function independently (Brockopp, Hardin-Pierce, & Welsh, 2006); they serve as a socialization agent in terms of students feeling a greater sense of connection to their communities (Collier, 2000); they are an effective means to integrate theoretical knowledge and applied methods (Weis, 2004); and they increase students' critical thinking skills (Kiener, Ahuna, & Tinnesz, 2014).

While research on the SRL construct in PBL capstone experiences was not found in this review, some studies examining individual SRL processes report highly positive results. For example, Dunlap (2005) examined changes in student self-efficacy (beliefs that impact motivation and behavior) during a PBL-based senior capstone software engineering course. The software engineering course was collaboratively designed by the instructor and an education expert to help students apply what they had learned in previous courses (primarily didactically oriented) to professional problems of practice. In coordination with a community partner, students worked to solve an authentic problem. Data were collected with 31 students and included pre- and post-measures on a self-efficacy scale and guided journal entries. Findings revealed a significant gain on posttest scores of the General Self-Efficacy Scale (Dunlap, 2005). Additionally, the guided journal entries of almost all of the students showed a lack of self-efficacy regarding their ability to be software professionals at the beginning of the semester, compared with higher levels of self-efficacy at the end of the semester. The improved self-efficacy was attributed specifically to the use of authentic problems of practice, collaboration, and reflection.

Similarly, in another study, Lawanto, Cromwell, and Febrian (2015) found that 14 engineering students in a PBL capstone course reported that the team management approach ensured a "fair share" division of task that thereby promoted the use of self-monitoring strategies (related to metacognition). It was concluded that more research is needed to determine the effects of PBL on students' self-regulation.

In another engineering PBL capstone course, the effects of PBL projects were assessed in terms of the intersection between motivation and PBL environments (Temel, 2013). Through mixed-methods analysis, it was found that PBL-based courses succeeded at motivating students. Further, interviews with 14 participants revealed that PBL fostered students' motivation by supporting their perceptions of empowerment and usefulness, and perceptions that they could be successful. These opportunities were interpreted in terms of opportunities for students to become engaged as students felt empowered and perceived purpose while engaging in the task.

Overall, these studies found PBL capstone experiences to positively impact the behavioral, metacognitive, and affective self-regulation processes of self-efficacy, self-monitoring, and motivation. The aspects of the learning environment found to support these SRL outcomes include the structure of student teams, the use of authentic problems of practice, collaboration, and reflection. While these studies shed some light on aspects of PBL that can positively affect aspects of SRL, the conclusions do not provide sufficient guidance for educators on how to support SRL in PBL capstones. The present study fills this void by providing a detailed account of how an undergraduate PBL capstone experience in conservation biology was designed intentionally to promote and support SRL using the English and Kitsantas (2013) model. It was expected that this approach would effectively support SRL as evidenced by students' self-reported perceptions of SRL support, their positive ratings of the course, and community partners' perceptions of the quality of student products.

Method

Participants

Participants included 34 students enrolled in an undergraduate capstone course and six participating community collaborators. All students were seniors, with a mean age of 21.5. Eighteen were female, and 16 were male. Most of the students (29, 85.3%) were white, while three (8.8%) were Hispanic and two (3.8%) were either black or more than one race. Prior to this course, the average cumulative GPA of the students was 3.09.

PBL Capstone Course Description

An undergraduate senior capstone course in conservation biology, held at a large land-grant university in the mid-Atlantic region, was redesigned to employ a PBL approach. The four-credit course is a requirement for all university seniors majoring in wildlife conservation. The course redesign effort was prompted by historically poor student course evaluations and faculty recognition that the lecture-driven course served primarily as a repeat of content already covered. Further, an internal university survey showed that an abysmal 74% of past program graduates reported they did not learn the job search skills they needed. PBL was identified as a means of moving beyond a repeat of prior learning to an *application* of prior learning, with the goals of improving students' career readiness, level of engagement, and satisfaction with the course. The redesign was carried out through a collaborative partnership between the faculty member who taught the course and a faculty development leader with expertise in PBL. This study was conducted during the design and initial running of the revised course.

The Design Process

The design of the course took place over a 3-month period that included frequent meetings and multiple design iterations. Early discussions were focused on the vision for the course—particularly examining the weaknesses of the previous capstone and detailing ideas for the new one. One of the instructor's primary goals was to prepare students for careers in conservation biology. She wanted them to experience realistic consulting roles and to establish clear career goals. Based on this, the decision was made to focus the PBL on authentic problems in conservation biology and to provide supplemental learning opportunities outside of the project to further support career readiness. Through the supplemental activities, students explored current job openings and identified opportunities of interest, met with a career advisor, researched current events, and participated in mock interviews.

While the course instructor had experience with student group work and active learning, she was not experienced with PBL. The lead designer of the PBL experience, in conjunction with the instructor, established the overall course framework and developed the driving question, the course goals, and the objectives. In addition, the lead designer provided support to the instructor about how to effectively facilitate PBL to support both knowledge construction and SRL throughout the project. The instructor's role in the design included establishing partnerships with community organizations and developing the weekly schedule of activities, assignment instructions, and the grading system. The community collaborators—each of which was within a 1-hr drive from the university—were a private landowner restoring wildlife habitat in collaboration the federal government, two state conservation organizations, a local zoo, and a federal conservation organization.

The Design

The overall PBL approach was based on BIE's definition of PBL (2003) and Savery's essential PBL features (2006). Further design decisions related to supporting learning and student responsibility for projects were guided by the SRL in PBL model (English & Kitsantas, 2013).

The driving question for the PBL was, “What conservation action can be taken or designed to further biodiversity conservation in the face of significant threats from climate change, invasive species, and/or habitat fragmentation and loss?” The question was formulated to drive students to demonstrate key program learning outcomes. The primary project-related deliverables developed by students were: (a) a proposal describing an original solution to one of the locally relevant biodiversity conservation issue identified by a community partner, and (b) a product that would be implemented by the community partner to address the issue. Scaffolds and formative assessments for each of these assignments were included to facilitate iterative development, with multiple opportunities for feedback from peers and the instructor. The proposal assignment was structured to elicit from students a specific problem to address, and a proposed solution, including a detailed rationale and thorough discussion of relevant biological concepts and consideration of ecological, social, legal, political and economic frameworks, and constraints. The proposal was the vehicle for facilitating students’ application of prior learning. The products, which were unique to each student group, were manifestations of the proposed solutions.

Through the recommended solutions, students were to demonstrate their understanding of key concepts of the discipline. The products were to be developed in conjunction with the community collaborators, at professional standards of quality so that they could be implemented by the community partners.

Course Implementation

Fidelity of PBL implementation

The PBL approach includes both a problem to be solved and a project to be developed. The PBL environment was implemented with fidelity to Savery’s Essential Features of PBL (2006). Table 22.1 describes how each feature was addressed.

PBL–SRL design and implementation

The capstone course was implemented with fidelity not only to the PBL model, but also to the English and Kitsantas (2013) PBL–SRL model. This section describes how the PBL–SRL model guided the implementation of the course over the three phases of PBL.

Phase I: Problem/Project Launch

During Phase I of PBL (Project/Problem Launch), SRL and learning involve presenting the driving question in a meaningful context, giving explicit instructions, setting expectations for learner responsibility, activating prior knowledge, and providing project milestones and any relevant templates or guidelines. The conservation biology capstone was designed with each of these facilitation responsibilities in the forefront (summarized in Table 22.2).

The instructor created a meaningful context by situating the students as consultants working for a firm that would be producing products to solve problems related to the work of clients at partner field sites. She explained that they would be responsible for completing professional, usable products and providing a detailed rationale for their solutions. The instructor explained that they would be graded as

Table 22.1 Fidelity of PBL Implementation in Conservation Biology Capstone Experience

Essential PBL features (Savery, 2006)	Conservation biology capstone experience
• Student responsibility for learning—Students are responsible for their own learning	Each student group had agency in defining the problem, the solution, and the final deliverables. These products were informed by the goals and interests of the six community partner organizations. The instructor acted as a facilitator of the process by guiding students to resources, responding to questions with questions, and providing feedback
• Scope/complexity—problems must be ill-structured and allow for free inquiry	Complex problems in the field of conservation biology with no clear-cut answers were addressed, including the decline of tree frogs, a specific bird species, and other wildlife. Students applied their disciplinary knowledge while conducting an inquiry into the problems. Draft solutions took approximately 4 weeks to develop, while final solutions and products took approximately 8 weeks to develop
• Interdisciplinary approach—learning should be integrated from a wide range of disciplines or subjects	The driving question focused on a single discipline; however, development and presentation of projects required students to learn skills in the domains of communication and education
• Student collaboration—student collaboration is essential	Students were grouped according to the field site they were most interested in. The two major deliverables (proposal and project) were group-based. Individuals were held accountable for contributions by four separate self- and peer evaluations over the course of the project
• Group synthesis—what students learn during their self-directed learning must be applied back to the problem with reanalysis and resolution	Each group decided the roles and contributions of its members, and groups were self-managed. During the proposal stage, groups were expected to work in an integrative manner, with all students contributing to the development of the proposed solution. During project development, students used more of a divide and conquer approach, with each individual playing to his or her strengths
• Sharing, closing reflection, analysis, and discussion—a closing analysis of processes and content learned through working with the problem	After presenting their projects to the class and community partners in attendance, peers, partners, and the instructor asked questions. Final presentations were required to include a reflection on lessons learned and next steps. Students asked presenting groups critical questions, and the instructor facilitated discussions
• Self- and peer assessment—self- and peer assessment are provided at the completion of each problem and unit	Self- and peer assessment were required at four points during proposal and project development. These assessments were included in the final grade

Table 22.1 (Continued)

Essential PBL features (Savery, 2006)	**Conservation biology capstone experience**
• Authenticity—PBL activities are valued in the real world	Students worked on actual real-world problems framed by community partners. Work processes followed authentic structures in the discipline. The instructor framed the course as working in a consulting firm, with the assignment being to produce high-quality, usable products for partner organizations
• Formative feedback—student examinations must measure student progress toward the goals of PBL. Ongoing feedback is provided on process and content	Formative feedback (peers, instructors, and community partners) was provided four times (prescheduled) on each of the two major deliverables. Further, as students developed plans and deliverables during in-class sessions, the instructor provided feedback and guidance and answered questions or suggested resources
• Pedagogical base of the curriculum—PBL must be the pedagogical base of the curriculum and not part of a didactic curriculum	PBL was the delivery mechanism for the curriculum during the entire curriculum for the whole semester, with both a problem and a project as part of the experience. Some additional, smaller assignments were completed outside of the PBL to support student career readiness.

PBL, problem-based learning.

a group, but would be held accountable for individual contributions through peer evaluations, including a grade and comments. She reviewed the course policy that groups would have the right to recommend that any group member who is not contributing at a satisfactory level be “fired.” Any fired group members would then work on a project independently. The instructor explained her role as the owner of the consulting firm, available to respond to questions and provide support along the way and to make the final decision on any firing recommendations. She displayed a graphic of the PBL–SRL model (English & Kitsantas, 2013) to illustrate that, while she would provide detailed and direct instruction in the beginning, students would be expected to gradually become responsible for their projects. She explained that they should conduct research, seek help, and ask questions of her as well as each other when they were unsure or needed guidance.

The instructor emphasized the importance of narrowing their career interests during the course and developing their career skills, as well as their job search skills. To stimulate their motivation on this topic, she displayed the data from the survey of past program graduates that showed the far majority felt they did not have the job search skills they needed. To further generate motivation and interest, a representative from the career services office gave a brief talk about the services they offer and how students could benefit from proactively utilizing their services.

Prior to beginning the PBL work, students activated their prior knowledge by reviewing syllabi of previous courses in the program and creating concept maps to illustrate what they had learned in each course, and identifying their knowledge gaps.

Table 22.2 Supporting SRL in Phase I

SRL-supportive activities (English & Kitsantas, 2013)	Instructor actions in conservation biology capstone
• Present the driving question in a meaningful context	The driving question was situated in the context of the students as consultants in a firm, with the instructor as the manager
• Give explicit instructions	Reviewed the syllabus, which contained detailed descriptions of deliverables and learning processes, grading criteria, and measures for individual accountability within teams
• Set expectations for learning responsibility	Explained student and instructor roles using the English and Kitsantas (2013) PBL–SRL model as a framework. Students were informed that lack of contribution to group tasks could lead to them being “fired” by other members
• Generate interest and motivation	Emphasized career readiness as a goal, showed data from past students indicating a lack of career readiness, brought in career services guest speaker. Students selected which community partner they would work with and decided which problem they would address. Students were placed into groups with others who selected the same community partner
• Activate prior knowledge	Had students create concept maps to illustrate connections among concepts learned in previous courses and to identify knowledge gaps
• Provide project milestones and relevant templates or guidelines	Reviewed project milestones, which were included in the syllabus

SRL, self-regulated learning; PBL, problem-based learning.

Phase 2: Inquiry and Project/Solution Development

As described previously, in Phase 2 of the PBL process, students iteratively gather information, formulate and test their ideas, see how other students are approaching the problem or project, receive feedback, and revise. In order to effectively support both knowledge construction and SRL in this phase, the instructor must make students’ thinking visible and respond with the appropriate level of guidance. The conservation biology capstone course achieved these goals in several ways (summarized in Table 22.3).

Class time offered substantial opportunity for student–professor interaction. During the first half of the semester, class time was spent visiting field sites (during the 4-hr meetings) and completing pre- and postfield site visit assignments and discussions. These assignments and discussions were designed to help students prepare questions for community collaborators before visits and to reflect on the issues and interests of the community partners after visits. All students visited all field sites to learn about the work of each community partner. Each group then selected a field site and a specific issue to address.

During the second half of the semester, students utilized class time to work on their proposals and projects. The professor reported, anecdotally, that most student questions during this phase were related to field methodologies and

Table 22.3 Support of SRL in Phase 2

SRL-supportive activities (English & Kitsantas, 2013)	**SRL-supportive activities in conservation biology capstone**
• Make students' thinking visible	Interim deliverables—to scaffold the final deliverables—were graded at multiple points in the project (problem identification and action plan for next steps, proposed solution, products, and presentation). Multiple peer, instructor, and community partner reviews in class during the development of each deliverable
• Prompt self-reflection	Assignment required presite investigation into the community partner's work and how their work advances biodiversity and preparation of questions for the visit. After each field site visit, students were prompted to compare pre- and postsite visit understanding of the community partner's work, identification of potential class projects to support the partner's work, and described the level of personal interest. Reflection was also facilitated through self- and peer assessment throughout the project. Further, a final reflection about the learning was required during product presentations
• Expose students to each other's perspectives	Combined student responses to each pre- and postsite visit question into a single document that was shared with the students. Facilitated discussions in class. Group interim and final deliverables were shared in class. Students worked in groups
• Monitor performance	Collected and provided feedback on multiple iterations of the primary project deliverables Collected peer assessments four times during the project Provided input and feedback on project work during class
• Providing the appropriate level of guidance	Used class time for project work. Visited each group to check progress and provide guidance. Avoided giving direct answers to questions or explicit corrections to inaccurate information; instead, directed students to the literature or prompted them to think more deeply or reconsider how they reached conclusions. Facilitated discussion between groups. Provided feedback on draft deliverables. Praise emphasized effort rather than abilities.

SRL, self-regulated learning.

job-related tasks. She noted that she stayed in facilitator mode, often referring students to the literature for answers, and openly admitting when she did not have the answer. In retrospect, she felt this likely contributed to students' sense of trust in her and the learning process, and their willingness to ask questions and seek help. Individual contributions to group tasks were monitored through peer assessment data, which was collected four times during Phase 2. They assigned themselves and each other a letter grade for each assessment period. Space for comments was also available on the assessment form.

During the last three class meetings, groups presented their projects to the class, and in several cases, also to their community collaborator. The final product was scaffolded through deliverables that required students to articulate a problem and a proposed solution to the problem. The proposal and final products were developed iteratively, with multiple reviews from peers, the professor, and the teaching assistant, along with limited feedback from some of the community partners. Proposals addressed such issues as (a) combating invasive species, (b) educating the public about threats to local species, (c) assessing the impact of controlled forest burns, (d) monitoring and restoring the sparrow population, and (e) restoring habitats. Products included monitoring and management plans, educational exhibits, grant proposals (including budgets), and site assessments. In the proposals, students were required to provide a rationale for their proposed solutions and to explicitly address the key frameworks in conservation biology. During the presentation of final products, students were required to share reflections on lessons learned and what they gained from the project.

Phase 3: Project/Problem Conclusion

To support SRL in Phase 3 of the PBL process, the instructor should facilitate sharing of final products, rationale, as well as reflections on the learning process. As students share, the instructor should continually relate student findings back to the learning goals and objectives, and highlight key points. Further, students should be encouraged to ask the presenting group questions about their decisions, their process, and their products. The conclusion phase of the conservation biology capstone course is described below and summarized in Table 22.4.

Final presentations were given during the last two class meetings of the semester. Each group shared a PowerPoint presentation that explained what they did, along with an explanation of the reasoning behind their approach and lessons learned throughout the process. Additionally, a gallery walk session was conducted, through which students viewed each other's artifacts displayed on

Table 22.4 Supporting SRL in Phase 3

SRL-supportive activities (English & Kitsantas, 2013)	SRL-supportive activities in conservation biology capstone
• Students share products and solutions along with rationale and processes	Each group presented their work through a PowerPoint presentation and a gallery walk. The PowerPoint presentation included a rationale. Presentations were followed by Q&A, during which time students responded to questions from community collaborators, the instructor, and other students about project design choices and rationale
• Students share reflections on learning outcomes and process outcomes as they relate to project goals and expectations	Reflections were required as part of final product presentations
• Students ask questions of each other	Nonpresenting students asked questions of the presenting group about their products and their processes
• Present in an authentic context	Community partners were invited to attend presentations on campus. Some of them attended

SRL, self-regulated learning; PBL, problem-based learning.

classroom computer monitors. Community partners were invited to attend. Two of them did attend and participated in asking questions of the presenting group.

Data Collection Instruments and Procedures

PBL Effectiveness in Supporting SRL Survey (adapted from Yuan, 2007)

The PBL Effectiveness in Supporting SRL Survey is a modified version of Yuan's (2007) PBL Evaluation Questionnaire. The survey, which was administered online at the end of the final class meeting, was designed to assess how effective students felt the course was in relation to expected outcomes of PBL. The instrument contains 20 Likert-scale items on five subscales (four items on each subscale). The following subscales were selected for inclusion in the current study, as indicators of SRL: (a) development of problem-solving skills, (b) development of self-directed learning, and (c) improvement of motivation. For each item, respondents entered a number from 1 ("barely or not effective at all") to 5 ("highly effective"). Additionally, the survey contained eight optional open-ended questions designed to gain additional insights into student perceptions about the course and recommendations for improvement. Examples of open-ended questions include, "What aspects of the course (if any) contributed most significantly to your learning and success?" and "What suggestions do you have for improving this course for the future?" In a previous study conducted by Yuan (2007), 51 (N = 51) fourth-year nursing students in Shanghai completed this survey. The content validity index (CVI) was calculated as one. The internal consistency established using Cronbach's alpha was .80, and the test–retest reliability with a 2-week interval was .89. In the current study, the Cronbach's alpha was calculated at .95.

Student course evaluations

This is a standard university-developed survey that is distributed to students across courses and disciplines as a mechanism for providing course feedback. The online survey contains 17 multiple-choice items on a 6-point Likert scale, from 1 (strongly disagree) to 6 (strongly agree). Example items include: "The instructor presented the subject matter clearly" and "I have a deeper understanding of the subject matter as a result of this course." Additionally, the survey included four open-ended questions. Two questions of particular relevance to the current study were selected for inclusion: "What could you have done to be a better learner?" and "What did the instructor do that most helped your learning?"

Community Collaborator Survey

The Community Collaborator Survey was designed to gather data about community collaborator perceptions of the effectiveness of the overall partnership and level of satisfaction with student products. The online survey contains eight open-ended questions, including "How would you describe the quality of the student products?" and "How could the overall approach to this partnership be changed to increase the value to your organization?" A link to the online survey was emailed to community partners after the course concluded.

Data were collected at the end of the course. Time was allotted at the end of the final class meeting for students to complete the PBL Effectiveness in Supporting SRL Survey.

Results

To evaluate the level of SRL demonstrated by students in the course, data were analyzed using descriptive statistics and qualitative analyses. Overall, it was expected that students enrolled in this course would exhibit high levels of SRL, as evidenced by their own perceptions of SRL support gained through the PBL process, by student evaluations of the course, and by community partners' perceptions of the quality of student products. Below is a detailed description of findings on each of these data collection instruments.

Student Perceptions of PBL Effectiveness

Data from the PBL Effectiveness in Supporting SRL Survey revealed positive student perceptions regarding support for self-regulatory skills and knowledge construction (Table 22.5). Of the 34 students enrolled in the course, 25 (74%) completed the online survey. Means for the subscales ranged from 4.43 to 4.65 on the 5-point scale.

Table 22.5 Student Perceptions of Effectiveness of the PBL Approach

Subscale	Mean	SD
Construction of professional knowledge ● Applying previous relevant knowledge and experience ● Interpreting, analyzing, and applying key concepts ● Furthering your in-depth understanding of conservation biology ● Acquiring knowledge that is useful for your future professional work	4.65	.43
Development of problem-solving skills ● Facilitating discussion about challenging problems and issues ● Increasing your ability to solve real-world problems ● Provoking you to consider alternative solutions to problems ● Improving your ability to draw reasonable conclusions based on evidence	4.43	.69
Development of self-directed learning ● Encouraging you to continue to pursue knowledge on your own ● Helping you to identify gaps in your knowledge ● Helping you improve your ability to identify learning resources ● Helping you to think independently	4.58	.51
Improvement of motivation ● Encouraging you to take an active role in your learning ● Motivating you to learn more ● Stimulating your interest in learning ● Encouraging your participation in the discussion of issues or problems	4.52	.69

PBL, problem-based learning.

The descriptive statistics show that construction of professional knowledge was the highest scoring subscale, followed by the development of self-directed learning, improvement of motivation, and development of problem-solving skills.

In addition to the Likert-scale questions, the survey included several open-ended questions—two of which were particularly helpful in gaining insights into students' perceptions of the course. Twenty-three of the 25 students who responded to the survey answered the optional question "What aspects of the course (if any) contributed most significantly to your learning and success?" All of the responses were positive about the course experience. More specifically, four themes emerged from students: (a) appreciation for the authentic, real-world project experience, (b) the career preparation that was gained, (c) the value of working effectively as part of a team, and (d) the application of prior knowledge gained throughout the program. Specific quotes that are representative of those given in response to this question include: "The fact that we were making a final project that was actually for someone outside the university. It made it much more realistic and drove me to do the best job I could," and "There were a couple [of] things—going to the site visits was very interesting and opened my eyes on all the possibilities of future work, and our group project was like nothing I've done at school before; this class had me apply the things that I've learned in other classes, and I thought it was awesome!"

The other question that elicited pertinent comments was "Would you recommend this class be conducted as a project-based class again in the future? Why or why not?" Twenty of the 21 students who responded to the question affirmed that the course should be conducted as a project-based course again in the future. Comments indicated that the course offered an in-depth learning experience and the opportunity to do hands-on work directly relevant to their careers. Several comments referenced the value of gaining real-world skills such as management and teamwork and working with community collaborators. Further, some students reported that they enjoyed the project work and they found it to be intellectually stimulating and rewarding. Table 22.6 contains all responses to these two open-ended questions.

Course Evaluation Data

Of the 34 students enrolled in the course, 17 of them (50%) completed the course evaluation. To determine student perceptions of support for SRL, mean responses were calculated for each relevant question (Table 22.7).

As depicted in the table, student perceptions about the course support for SRL were highly positive, as the mean for relevant items was 5.7 (on a scale from 1 to 6). Students found the course to be particularly helpful in terms of gaining a deeper understanding of the subject matter (M = 5.71), increasing their interest in the subject matter (M = 5.71), and improving their knowledge of theories related this course (M = 5.71). Students also valued the out-of-class assignments (which included field site visits and project development) (M = 5.70).

The course evaluation also included several open-ended questions. Responses to the question "What did the instructor do that most helped your learning"

Table 22.6 All Responses to Relevant Open-Ended Questions on PBL Effectiveness Survey

Questions
1) What aspects of the course, if any, contributed most significantly to your learning and success?
• More realistic, group work, working with our teams
• Getting us ready for future jobs, future possibilities
• Opportunity to "walk in their shoes," realism, "real world," "real problems"
• Site visits, learning from site managers, working with employers
• Easy to take seriously, real-life project
• Use what we've learned, not just theoretical
2) Would you recommend this class be conducted as a project-based class again in the future?
• Best aspect of class, very useful, enjoyable
• Real-world experience, no tests in real life—projects
• Hands on experience, very helpful
• I have an idea of what I am going to do, have confidence that I can do it
• Makes you feel like you are making a real-world difference

PBL, problem-based learning.

Table 22.7 Student Course Evaluation Items Relevant to SRL

Item	**Mean**	**SD**
SRL-supportive learning environment		
1) The instructor provided feedback intended to improve my course performance	5.76	.44
2) The out-of-class assignments were educationally valuable	5.70	.59
3) The instructor clearly defined students' responsibilities related to the course	5.59	.62
Student learning and motivation		
4) My interest in the subject matter was stimulated by this course	5.71	.47
5) I have a deeper understanding of the subject matter as a result of this course	5.71	.47
6) I improved my knowledge of principles, theories, techniques related to the course material	5.71	.47

SRL, self-regulated learning

provided insight into students' perceptions of what the instructor did to support their learning. An analysis of the responses revealed relationships to the SRL-supportive activities prescribed by the PBL–SRL model (English & Kitsantas, 2013). Table 22.8 contains a sample of the comments, mapped to corresponding SRL-supportive activities.

The SRL-supportive activities most frequently referenced by the students were in Phase 2, when the bulk of the work was conducted. These comments reveal that the level of support and guidance provided to students was perceived as critical to learning.

Table 22.8 Student Course Evaluation Responses Mapped to SRL-Supportive Activities

What the instructor did that most helped students learn	SRL-supportive activities (English & Kitsantas, 2013)
• She gave us feedback on everything and had great ideas and really made us feel like we were doing something worthwhile	Monitor performance (Phase 2) Provide appropriate level of guidance (Phase 2)
• Engaged students in teamwork	Expose students to each other's perspectives (Phase 2)
• I think allowing us to work on a project that could make a real difference was the best thing about this course	Generate interest and motivation (Phase 1)
• She was sure to meet with every student and group as we worked on our final projects throughout the course. We always received plenty of feedback before continuing to the next step	Monitor performance (Phase 2) Provide appropriate level of guidance (Phase 2)
• The instructor gave many helpful materials and provided great feedback and out-of-class help	Monitor performance (Phase 2) Provide appropriate level of guidance (Phase 2)

SRL, self-regulated learning.

Community Collaborator Survey

Three of the six community collaborators responded to the Community Collaborator Survey. Overall, their feedback was positive about the process and the quality of student products. In response to the question "To what extent did the students meet the goals, objectives, or requirements of the project, as you understood them?" two of the three respondents reported that they were completely satisfied that goals and objectives of the project were met. Regarding the quality of the student products, two of the three respondents expressed that the student products exceeded their expectations and that they were impressed with the quality. Two of the three respondents reported that student products were ready to use and immediately applicable, while the third respondent felt the products were good overall but needed additional editing and proofing.

The third respondent noted that while students generally met his expectations, he wished they had generated more original ideas and had done a more in-depth exploration of some of the issues. He also found some of the student recommendations to be economically infeasible. Additionally, he suggested that the project could have benefited from more time and closer collaboration between him and the students.

Discussion

While other studies of PBL capstone courses have reported positive outcomes related to SRL (Dunlap, 2005; Lawanto et al., 2015; Temel, 2013), there is a lack of information about the design and enactment features that resulted in SRL. The current study was conducted to develop an understanding of how to foster

SRL in PBL capstone experiences through the three phases of PBL. As such, a PBL capstone course in conservation biology was designed with fidelity to the PBL model (Savery, 2006) and the English and Kitsantas PBL–SRL model (2013). It was expected that this approach would effectively support SRL as evidenced by students' self-reported perceptions of SRL support, their positive ratings of the course, and community partners' perceptions of the quality of student products. All three data collection instruments indicate that the approach was effective in supporting both knowledge construction and SRL—including metacognitive, motivational, and behavioral processes.

Student responses to the PBL Effectiveness in Supporting SRL Survey and the course evaluation were highly positive on all items related to perceived support of knowledge construction and SRL, indicating that students found that the course supported the development of their learning, motivation, self-directed learning skills, problem-solving skills, and professional knowledge. Responses to open-ended questions regarding what contributed to learning were aligned with findings in other studies of PBL capstones—revealing the value students placed on teamwork, real-world projects, and working with professionals in the field (Temel, 2013). Some students stated that the "real-world" aspect of the course made it easier to "take the project seriously" and allowed students to apply what they learned. In consideration of the role of the instructor in facilitating learning in a PBL course, students mostly responded that feedback was key in supporting their learning.

Further, students in the current study frequently expressed the importance of instructor feedback and guidance in their learning. Students reported that the instructor met with them individually and in groups, with one student reporting that they received "plenty of feedback before continuing to the next step"—which indicates appropriate scaffolds and formative feedback. Feedback, in this case, was given by the instructor as well as the other students.

The third set of data—community collaborators' perceptions of the quality of student products—is another indicator of student SRL. Those community collaborators who responded, overall, reported that the quality of student products either met or exceeded expectations. While one collaborator felt more in-depth exploration of some of the issues was needed to generate more original ideas, along with additional copy-editing, the other respondents were impressed with the quality and were able to implement the products immediately.

Because the other PBL capstone courses reviewed here each focused on one specific SRL skill, rather than all SRL skills over the three phases, comparing them with the course in the current study is challenging. However, a common theme throughout the current study and those reviewed (e.g., Dunlap, 2005; Temel, 2013) is that students are motivated by real-world projects in their field of study that allow them to apply knowledge, learn important skills, work with professionals in the field, and gain career-related experience.

Implications for Designing PBL Capstone Courses

Given that capstone projects are often complex, and carry a high workload for students because they are designed to integrate several years of learning, it is important to intentionally support SRL through design and enactment. To promote and support student SRL, students should engage in authentic projects and choose their projects based on career interests. As described earlier in this chapter, the present study was grounded in a model by English and Kitsantas (2013) that elucidates a dynamic, reciprocal relationship of PBL and SRL over three phases of PBL. This model places particular emphasis on the learning environment that must be designed to foster SRL. Below, we present specific guidelines on how an instructor can design capstone courses.

In Phase 1, the teacher should set clear expectations for performance. This is critically important for students who do not have PBL experience. In the current study, the instructor accomplished this by emphasizing the importance of students taking responsibility for their learning and illustrated how the process would work by showing them the PBL–SRL model diagram. Establishing an authentic context is also important in Phase 1, as this plays a key role in motivation. In this study, students were cast as professionals working for a consulting firm, which proved to be realistic and valuable to students.

In Phase 2, SRL-supporting activities include scaffolding the learning and making thinking visible so that appropriate support can be provided. In the course under study, this was accomplished by having students work on projects during class time, assigning multiple interim deliverables, and ensuring students received multiple rounds of formative feedback from peers, instructor, the teaching assistant, and community collaborators throughout the project. Student comments indicated that these activities were highly important in supporting their learning.

In Phase 3, students should be prompted to reflect on both knowledge and learning processes. In the current study, students we asked to reflect throughout the process through peer- and self-evaluations, through journal entries, and through reflections embedded in final presentations. Engaging in these types of activities can help students become more independent, strategic, and motivated in their learning (Bembenutty, Cleary, & Kitsantas, 2013).

In summary, student comments on the PBL Effectiveness Survey pointed to design features and SRL-supportive activities that reinforced their learning. Important design features were authentic, real-world project experience, the career preparation gained, working effectively in a team, and applying prior program-specific knowledge. These features relate to the SRL-supportive activity of providing a realistic context, which is critical to evoking student motivation. Important facilitation activities noted were primarily related to monitoring performance and providing feedback. These activities take place in Phase 2 of PBL. The frequent student recognition of feedback as an important factor in their learning reinforces the importance of this aspect of PBL capstone facilitation. To ensure a high level of SRL and knowledge construction, PBL should be designed with fidelity to both the PBL model and the PBL–SRL model. Doing so requires an in-depth understanding of both PBL and SRL processes and how they relate to each other.

Limitations and Future Directions

There are several limitations associated with this study. First, the study tested the intervention with only 25 participants, which limits the generalizability of the findings. Furthermore, this study relied on self-reported perceptions of SRL behaviors and facilitation practices. Observation data would have strengthened the findings of this study. Future research should use microanalysis, a hybrid methodological approach, to further investigate how students engage in SRL while exposed to PBL in capstone courses. In addition, video analyses could reveal additional insights into this process.

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23

Promoting Ambitious Teaching and Learning through Implementing Mathematical Modeling in a PBL Environment: A Case Study

Jennifer M. Suh and Padmanabhan Seshaiyer

Introduction

There is a growing body of literature on ambitious teaching in mathematics, which refers to reform teaching practices that develop "mathematics proficiency" in all learners, including conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and productive disposition (Anthony et al., 2015; Kilpatrick, Swafford, & Findell, 2001). Ambitious mathematics teaching (Anthony & Walshaw, 2007; Lampert, Beasley, Ghousseini, Kazemi, & Franke, 2010) requires a responsive teacher who can engage diverse learners in rigorous mathematics while being skillful at helping students view themselves as competent problem solvers and mathematicians. Part of this ambitious goal is facilitating students as they make sense of and solve authentic problems through inquiry-based learning (Anthony et al., 2015). Problem-based learning (PBL) and teaching through mathematical modeling are two complementary approaches that are ambitious student-centered pedagogy in which students learn through the experience of solving an open-ended problem. This chapter presents a case study of two elementary lesson study teams implementing mathematical modeling units within a PBL environment. The case study documented how teachers co-designed and introduced the mathematical modeling task through an engaging ill-structured problem context, where students had to formulate a mathematical problem based on a real-world situation.

PBL is defined as "an inquiry process that resolves questions, curiosities, doubts, and uncertainties about complex phenomena in life" (Barell, 2007, p. 3). The role of the teacher in a PBL environment is quite different from the traditional direct instruction environment because the teacher becomes the expert facilitator who helps support students to organize their own understanding of the problem. In fact, Barell (2007) states that in PBL, students actively ask good questions, conduct purposeful investigations, think critically, draw conclusions,

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and reflect until they arrive at a meaningful solution, thereby preparing students for the complexity of the twenty-first century. This chapter begins by describing how the PBL environment offers an ideal setting to introduce mathematical modeling in the earlier grades. Mathematical modeling according to the Common Core State Standards in Mathematics (NGACBP & CCSSO, 2010),

> links classroom mathematics and statistics to everyday life, work, and decision-making. Modeling is the process of choosing and using appropriate mathematics and statistics to analyze empirical situations, to understand them better, and to improve decisions. (http://www.corestandards.org/Math/Content/HSM)

With the current demands of developing twenty-first-century learners who can communicate, collaborate, think critically and creatively (Partnership for 21st Century Skills, 2011), PBL environments and mathematical modeling lessons offer elementary students the opportunity to demonstrate these twenty-first-century skills as young mathematicians. In this case study, researchers examined classroom episodes to examine how teachers designed mathematical modeling tasks in the elementary grades and some of the important pedagogical practices and mathematical norms that are needed for students to fully engage in this process as mathematicians.

Several characteristics of a PBL environment make it an ideal setting and process to integrate mathematical modeling. Marra, Jonassen, Palmer, and Luft (2014) summarized the primary characteristics of a PBL learning environment as being:

1) problem-focused, where learners begin by addressing an authentic, ill-structured problem and knowledge building is stimulated by the problem and applied back to the problem;
2) student-centered, where the instructors do not dictate the learning activities, but rather serve in a supportive role;
3) self-directed, where students individually and collaboratively assume responsibility for generating learning issues and processes through self-assessment and peer assessment and access their own experiential knowledge and learning materials;
4) self-reflective, where learners monitor their understanding and learn to adjust strategies for learning;
5) facilitative, where instructors are facilitators (not lecturers) who support and model reasoning processes, facilitate group processes and interpersonal dynamics, and probe students' knowledge deeply. (pp. 223–224)

The problem-focused nature of addressing an authentic, ill-structured problem supports one of the essential requirements for a mathematical modeling task. In a mathematical modeling task, students are presented with an actual problem (which at the onset does not look like a textbook mathematics problem) that relates to a real-world phenomenon in the natural world, their community, or even to their personal lives. The open-ended problem presented offers an opportunity for the students to go through a *mathematical modeling* process that not only produces a potential answer but a tangible solution that can be continuously connected back to the real-world. These real-world problems tend to be messy and require multiple math concepts, a creative approach to math, and involve a cyclical process of revising and analyzing the model. Mathematical modeling involves translating between the real world and mathematics in both directions where the real world is defined as everything that has to do with nature, society, or culture, including everyday life as well as school and university subjects or scientific and scholarly disciplines different from mathematics (Blum, 2002).

This mathematical modeling process allows students to engage in a PBL type experience where they create models that give mathematical meanings as students interpret, analyze, and iterate their solution methodology. This means that students are expected to identify the quantities of interest, define what they think are the appropriate variables that describe these quantities, and establish meaningful relationships between these quantities mathematically and solve the associated problem. At each of these steps, students have the opportunity to learn to make *assumptions* and also learn to work under given *constraints*. As students work within these assumptions and constraints, they work to simplify the messy real-world problem, to start mathematizing, and to build a solution incorporating important mathematical tools. For example, when students work with a mathematical modeling task that elicits them to rank data for making important decisions, they may use tables, graphs, organized lists, or even a decision matrix for making suitable comparisons that can help them to refine their solution process.

The PBL process would expect the students to also bring in their personal knowledge and experiences to make suitable assumptions. For students to be able to make meaningful assumptions that justify their mathematical reasoning to solve the problem makes the PBL process a rich mathematical modeling experience that helps them to develop problem-solving habits of mind that are valued in the mathematics curriculum. Having the students define, test, iterate, and revise their design to refine their models enhances their metacognitive abilities. Therefore, mathematical modeling is a necessary process within the PBL framework that provides a useful foundation for developing students' mathematical understanding. While the type of tasks a teacher employs in a PBL setting reflects reality, the design of the mathematical modeling task is rich enough to be guided by mathematical principles making the mathematical modeling process unique.

The Process of Mathematical Modeling, an Ideal PBL Activity

The process of mathematical modeling requires the modeler to be creative and make choices, assumptions, and decisions; it is iterative, with multiple paths open to the mathematical modeler and no one clear, unique approach or answer (Cirillo, Pelesko, Felton-Koestler, & Rubel, 2016). Implementing mathematical modeling in a PBL environment is ideal because of its problem focused, student-centered, collaborative nature (see Figure 23.1) that starts by letting the students "wonder and notice" or identify and observe a situation in the real world from multiple perspectives. After this identification process, students as modelers think creatively and critically to ask questions, make reasonable assumptions,

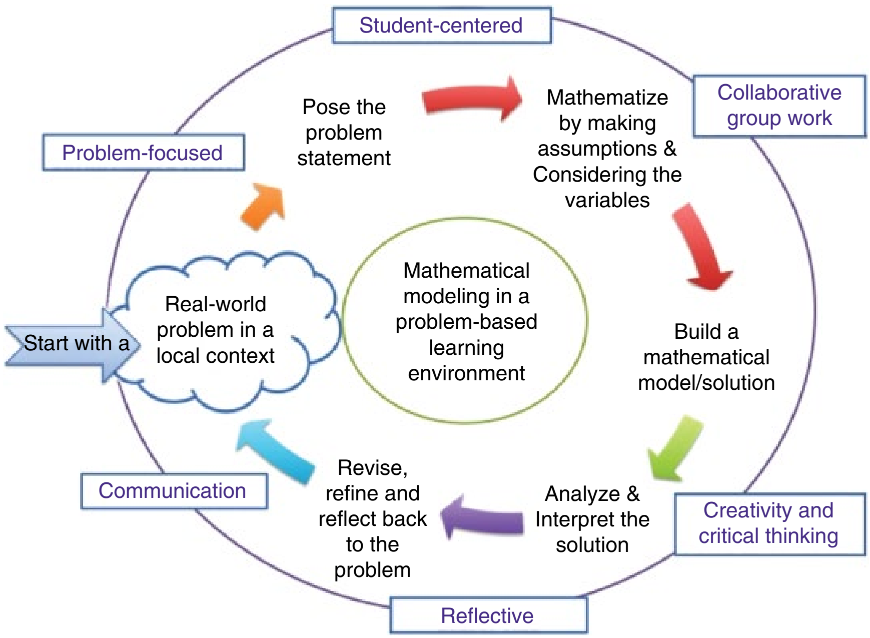

Figure 23.1 Mathematical modeling, an ideal problem-based learning activity.

eliminate unwanted information, identify variables (either quantitatively or qualitatively), and understand constraints they have to work with. The next step is to consider the important variables so that the modelers building a solution can propose a suitable representation that illustrates the relationships between the quantities of interest in the problem through mathematical symbols, relations, and operations. Once a solution is reached, modelers describe and analyze to make sense of the model or representation they have created as a group and how those representations help them communicate their ideas. The results are then translated back to the real-world model and are interpreted and at times revised and refined in relation to the original situation. For a robust and reliable solution, however, one must repeat the process, which helps the students to understand the difference between precision and accuracy. Finally, modeling can help students to learn how to validate their work and use the models created to predict by suitable extrapolations (Blum, 2002). This process of making assumptions, identifying variables, formulating the model, interpreting the result, and validating the model is iterative in nature and is modified or changed and repeated until a satisfactory solution has been obtained and communicated. Once students become familiar with this process, they are self-directed, and the teacher's role is facilitative.

While mathematical modeling is a process, *models* may be considered to be a system of rules, sets, operations, and relationships that can be employed to represent, explain, or even predict the behavior of other related systems (Doerr & English, 2003). Mathematical modeling includes activities that bring about social experiences and engage the students to collaborate in small teams, to use their creativity and critical thinking skills for solving problems and then communicate their results to a broader audience. Doerr and English (2003) describe the mathematization process as including multiple cycles of interpretation, descriptions, conjectures, explanations, and justifications that are iteratively redefined and reconstructed as learners interact with others. For elementary students, this process provides a perfect venue to rehearse an important mathematical practice of critiquing the reasoning of their own and others by pressing for justification and evidence of student thinking. Mathematical modeling also allows for students to engage in meaningful ways with a given real-world problem, especially if they are given the freedom to create, use, and change quantities in ways that make the most sense to them and so their ideas can be shared and perhaps even generalized to other similar real-world situations. This not only helps to develop their quantitative reasoning and problem-solving skills in elementary grades, but also helps to develop lifelong learning and twenty-first-century skills that are essential for solving real-world problems. In the past decade, there have been several studies that indicate that younger students can make important contributions if they are given an opportunity to engage in authentic modeling tasks (Doerr & English, 2003; English, 2010, 2013). While the National Council of Teachers for Mathematics (NCTM) standards specify that instructional practices enable students to "use representations to model and interpret physical, social, and mathematical phenomena" (NCTM, 2000, p. 7), studies have shown that modeling practices do not play an important role in pedagogical practices in most schools (Zawojewski, 2010). More specifically, most elementary teachers in the United States do not use mathematical modeling tasks in their classrooms although CCSSM addresses mathematical modeling as an essential mathematical practice across grade levels. It is important to note that the role of the teacher is crucial in mathematical modeling. The teacher must be able to: (a) provide opportunities for students to acquire mathematical competencies and make connections between the real world and mathematics; (b) maintain the high cognitive demand of the mathematical modeling process, and (c) provide classroom management that can help students in the mathematical modeling process.

Lesh and Zawojewski (2007) compared problem solving and mathematical modeling and noted several attributes, which connect to the twenty-first-century skills. For example, mathematical modeling requires students to create mathematical descriptions of meaningful situations encouraging them to *think critically* as they experience the stages of developing, reviewing, and revising important mathematical ideas and structures during the modeling process and *think creatively* as they consider, more than one solution approach or solution model.

In recent years, there have been a lot of calls to integrate mathematical modeling into precollege curricula internationally (OECD, 2013). There have also been several discussions on the definitions of the words *model and modeling*, which has led to different interpretations of how teachers understand mathematical modeling. Previous research on how elementary teachers and students engage in mathematical modeling has demonstrated that it is feasible to develop a disposition toward realistic mathematical modeling in students (Lieven & De Corte, 1997). However, mathematical modeling can be difficult for teachers to implement as they must be able to merge mathematical content and real-world applications while teaching in a more open-ended and less predictable way (Blum & Ferri, 2009). It can be a challenge for students because each step of the modeling process presents a possible cognitive barrier (Blum & Ferri, 2009) and may be messy. As stated in the Common Core Standards for Mathematical Modeling (NGACBP & CCSSO, 2010),

> Real-world situations are not organized and labeled for analysis; formulating tractable models, representing such models, and analyzing them is appropriately a creative process. (http://www.corestandards.org/Math/Content/HSM)

These real-world problems tend to be messy and require multiple math concepts, a creative approach to math, and involves a cyclical process of revising and analyzing the model. The PBL environment and the mathematical modeling process require students to collaborate and communicate. Research in mathematics education has contributed to the understanding of how specific norms need to be established to ensure participation in these ways. The term “socio-mathematical norms” coined by Yackel, Cobb, and Wood (1991) defines how students participate in mathematics. Yackel et al. (1991) investigated the classroom norms set up in a second-grade classroom that focused on small-group problem solving, followed by whole-class discussion in a second-grade classroom they studied for an entire school year. Norms were mutually established within the context of working on math activities. Similar to this study, the researchers examined what socio-mathematical norms would need to be established to ensure successful mathematical modeling in the elementary grades and support the facilitation of learning. The developed framework included the notion of openness that is explicit in mathematical modeling and the natural student cycle in this process that includes observing a real-world problem; posing the problem statement; making assumptions; simplifying constraints; considering variables; building a mathematical model/solution; analyzing and interpreting the solution; and validating the results against the real-world problem. This process also allows the students to verify if their solution is the “best” under a suitable measure they come up with. The process also allowed twenty-first-century skill development including creativity, critical thinking, collaboration, and communication to be an integral part of the student learning.

The Purpose of the Study

For this study, researchers examined how teachers designed, implemented, and assessed mathematical modeling in their elementary classrooms. More specifically, two cases of classroom mathematical modeling lessons were analyzed to better define what mathematical modeling looked like in the elementary grades. These two questions guided the research:

1) What design decisions do teachers attend to as they plan, implement, and assess mathematical modeling in a PBL unit in the elementary grades?
2) What pedagogical practices and socio-mathematical norms are necessary to enact mathematical modeling in the elementary grades?

Methods

Participants

Twenty-four elementary teachers originally participated in a larger professional development research project where they first experienced mathematical modeling as learners and then formed school-based lesson study teams to design and implement mathematical modeling through a follow-up research lesson in their own classrooms. This study will report on two out of the five teams that implemented mathematical modeling. The participants in the lesson called *Food for Thought* consisted of five female teachers teaching fifth and sixth grade, whose teaching experiences ranged from 2 to 28 years. The participants in the lesson called *Butterfly Garden* consisted of four female teachers, two male teachers, and one coach, who taught the range of second grade to fourth grade and had 3–12 years of teaching experience.

Research Context and Procedures

This study took place in the eastern part of the United States in a large school district in the metropolitan area that had diversity in ethnicity and socioeconomic levels. The case study reports on the part of a larger 3-year exploratory research project that sought to research and evaluate the effects of professional development in mathematical modeling for elementary mathematics teachers. This portion of the study took place over 16 weeks and had two parts. The first part was a week-long summer professional development institute entitled *Mathematical Modeling in the Elementary Grades*. This institute covered modeling as a phenomenon from the real world via a cyclical mathematical modeling process and focused on improving teachers' content-specific knowledge. The second part included collaborative coaching and lesson study (Lewis, 2002) to support teachers' needs as they implemented materials and strategies in their classrooms. The professional development—both the week-long summer institute and the follow-up lesson study—was designed to help teachers support their students' learning progression in modeling and build mathematical understanding. Teachers presented their experiences at a local symposium following the completion of the lesson study.

The researchers used design-based research (Kelly & Lesh, 2000) as a method of inquiry in order to examine how elementary teachers planned, implemented, and assessed mathematics modeling and study the complex dynamic system and the responsive nature between the teacher and the students during the mathematical modeling process. By examining teacher-designed educational tools such as lesson plans, questioning techniques, and interpretation of students' work, the researchers wanted to capture the features teachers attended to as they co-designed, planned, implemented, and assessed students' learning through a mathematical modeling task. In addition, the researchers identified some areas of challenges and ways the team of teachers supported one another. They were particularly interested in the ways teachers were challenged by the merging of mathematical content and the real-world applications while teaching in a more open-ended and unpredictable way. As elementary classroom teachers assumed the roles of co-designers of the mathematical modeling tasks, the researchers documented ways teachers enacted the mathematical modeling process with their elementary students and investigated their design decisions and the ways they set up socio-mathematical norms in their classrooms that encouraged students engaged in mathematical modeling.

Data Sources

The data for this study included the artifacts collected from the lesson study cycle included the planning agendas, actual lesson plans, student work samples, the analysis of student work, and teachers' PowerPoint summarizing their lesson study. These artifacts allowed the researchers to examine the design features of the lesson, the enactment, and how students interacted with the mathematical modeling task and technology to contribute to the student learning outcomes. Lesson study preplanning, classroom observation, debrief sessions, and the individual teacher reflections were also included as a way to triangulate to reveal aspects of teachers' own thinking (i.e., interpretive systems). This lesson study process conducted with all of the teachers focused on developing their strategic competence and strategies for modeling mathematical ideas (Suh & Seshaiyer, 2017).

Data Analysis

To begin analyzing the themes, the researchers employed the document analysis technique using teachers' individual reflections and lesson plan, and the transcripts of the lesson study debriefs. They systematically analyzed the data by developing initial codes and used the method of axial coding to find categories in such a way that drew emerging themes (Miles & Huberman, 1994). To verify and compare recurring themes and categories, the research team worked individually on coding the documents before comparing preliminary codes in order to agree upon recurring themes from the reflections. *Dedoose*, an internet-based data management tool for qualitative research (Dedoose Version 6.2.7, n.d.) was used to code and analyze the data. These themes were confirmed by a qualitative research analysis of the code applications produced by Dedoose.

Results

The analysis of the data from the planning process revealed important design choices made by the teachers based on their students' background knowledge, the concern for aligning grade-level mathematics objectives guided by their state curriculum and considerations made for an authentic launch, engaging exploration, and meaningful summary of the learning.

Key Design Decisions Made by Teachers in Mathematical Modeling Lessons

To answer the first research question, what design decisions do teachers make as they plan, implement and assess mathematical modeling in a PBL unit in the elementary grades, the researchers analyzed the data from two of the research lessons, including lesson artifacts, memos, and teacher reflections. The major themes emerged into three categories: (a) In the planning phase, teachers carefully selected context that was motivating, relevant, and rich with the connection to content skills and process skills and used a backward design model (where the goals are set before choosing the instructional method and forms of assessment) to map the learning opportunities. To make the real-world phenomenon of interest to students, teachers chose local contexts that had personal relevance and one where students had an "emotional tie," such as reviving their school garden and helping their community to fight hunger. (b) In the enactment phase, teachers explored mathematics through intentionally planned and spontaneous teachable moments for math modeling, and used the "catch and release" strategy to help revise and facilitate the learning process. (c) In the assessment phase, teachers used formative assessment strategies to assess students' content and process skills, which were aligned to several of their mathematics teaching objectives.

Attending to the curricular connections by mapping the essential learning goals

Teachers voiced the need to focus on the mathematics concepts that they had to teach based on their districts' standard-based objectives. To help meet this need, teachers used the backward design model of planning (Wiggins, McTighe, Kiernan, Frost, & ASCD, 1998) to plan for their mathematical modeling lessons. Using that approach, they started with the result desired: What should the students know, understand, and be able to do? Consider the goals and curriculum expectations, and focus on the "big ideas" (principles, theories, concepts, points of views, or themes). This backward design approach helped them consider some viable mathematical modeling contexts that had rich mathematical learning opportunities. By examining the elementary mathematics curriculum, teachers planned for opportunities for different types of mathematical models that aligned with the mathematics strand. These included five that were appropriate for early mathematical modeling: (a) descriptive models allow students to describe a phenomenon using mathematics (i.e., describing how many mulch bags are needed for the edible garden by using computation); (b) optimizing models allow the student to use mathematics to maximize or at times minimize (i.e., optimizing the area of the garden with a given length of fencing using area and perimeter); (c) predictive models allow students to use mathematics to observe a pattern and predict the outcome (i.e., predicting the amount of space a vegetable will need as it grows by using information about growth patterns); (d) probability models allow students to use mathematics to determine the extent to which an event is likely to occur, measured by the ratio of the favorable cases to the whole number of cases possible (i.e., knowing the germination rate of these particular green beans is 95% helps you determine how many beans will actually grow into a plant); and (e) rating and ranking models allow students to use mathematics to make decisions (i.e., with a limited space in the garden, students can use rating and ranking tables to determine the best option).

As teachers planned, they attended to these following questions focused on the context, concepts, and the curricular alignment. In addition, they focused on the criteria for evaluation of learning assessing content standards and the 4Cs: critical thinking, creativity, collaboration, and communication (see Table 23.1).

Table 23.1 Map of the Essential Planning Elements

	Food for Thought **project**	***Butterfly Garden*** **project**
1. Contextualized problem: How does the context relate to the mathematical concepts embedded in the problem, and how does the context support students in using mathematical modeling to solve the problem?	*How can we help fight hunger in our community?* One in five children go hungry. How can we find ways to help families that, at some point in time, struggle to find their next meal?	Our school is looking to make the best use of our outdoor space. How might we take an environmentally friendly/conscious approach to improve our space?
2. Core concepts and twenty-first-century themes: Are connections made between and among multiple disciplines?	*Twenty-first-century themes: Global and community awareness & health literacy* (service learning, empathy, community activism)	*Twenty-first-century themes: Environmental literacy* (service learning, plant & animal life, design thinking)
3. Cross-curricular connections & content standards: Curriculum: Content standards: How do students discuss the important quantities and the relationship between quantities? How do the problem and context elicit the modeling process to describe, optimize, predict, and make decisions using mathematics?	Math: Using statistics, computation and estimation, proportional reasoning Language arts: Persuasive writing Science: Health & nutrition *Focus on mathematical modeling: Descriptive & predictive modeling.* Investigate and describe the hunger problem using ratios, statistics, and fractions, decimals, and percentages to determine how many are affected in their community. Given a problem situation, construct graphs, draw conclusions, and make predictions	Math: Designing a garden using geometry and measurement & budgeting expenses Language arts: Persuasive writing Science: Plant and animal life cycle *Focus on mathematical modeling: Optimization and rating and ranking models for decision making.* Estimate and measure the length and to find the perimeter and area of their garden, in standard units of measure Given a budget for the school garden, students designed an optimal garden for butterflies
4. Criteria for evaluation of learning: (content standards & 4Cs critical thinking, creativity, collaboration, communication): How did students actually engage with mathematical ideas in this lesson? How did this lesson support students in using tools and reasoning to answer questions about a contextual situation? In what ways, did mathematical modeling promote the twenty-first-century skills?		

To focus on the mathematics elicited by the tasks, the researchers asked these reflective questions during the debriefs with the lesson study groups. During the preobservation, they asked, "What important mathematical ideas and competencies will the task and context afford you as you engage your students in this mathematical modeling process?" After the lesson, they asked teachers to reflect on how students actually engaged with mathematical ideas in this lesson. "How did mathematical modeling support students use of mathematical ideas, tools, and reasoning to answer questions about a contextual situation?" And in thinking about next steps, they asked teachers to consider how they would capitalize on students' mathematical ideas, misconceptions, and mathematical opportunities that were revealed in this lesson to build on future lessons.

In addition to focusing on the mathematics for both the *Food for Thought* project and the *Butterfly Garden* project, teachers also enhanced their lessons through interdisciplinary, inclusive, innovative, and inquiry-based active learning approaches (see Table 23.1). The mathematical modeling process helped to serve as a connection between the mathematics that helped to make sense of the real-world problem and the connections they made to other disciplines both within and across grade levels. This not only helped them to become proficient students, but gave them an opportunity to apply the mathematics they learned to solve problems arising in everyday life, society, and the workplace (CCSSM, 2010).

Despite initial concerns about the time it would take to use mathematical modeling in the classroom, the teachers were pleasantly surprised that the modeling process paid off in the long run. One of the biggest "payoffs" was the content that was covered in the classroom during mathematical modeling. In fact, content was brought about without the direct instruction of the teachers; for instance, students first experienced working with proportional reasoning without prior direct instruction. They began the lesson with the statistic "1 out of 5 children don't know where their next meal will come from" and having kids figure out what that means regarding their class, their grade level, their school, their community. By having the students work with proportional reasoning during the mathematical modeling task before direct instruction, it helped the teachers move through the proportional unit faster since the students could relate the content to the prior mathematical modeling lesson. Teachers also found that students were motivated to learn new content and actually asked to be taught the necessary mathematics that they needed for the modeling task. One teacher commented that her students asked, "Teach us the math to do this!" Another stated that "We hadn't covered estimating yet but, the students needed to use it." Yet another teacher presented her students with a pretest at the beginning of a mathematics unit and found that her students already knew the upcoming content as a result of the mathematical modeling process. The mathematical modeling process prompted students to see the need for the mathematics. Teachers were able to use mathematical modeling across disciplines, for example, making connections to science in the *Butterfly Garden* mathematical modeling project or to economics and reading and interpreting tables.

The twenty-first-century themes played a role in helping teachers consider meaningful real-world contexts (Partnership for 21st Century Skills, 2011). The twenty-first-century skills endorsed by the school district are called the 4Cs, and include developing creativity, critical thinking, communication, and collaboration. In addition to these twenty-first-century skills, the Partnership for 21st Century Skills has identified twenty-first-century themes as global awareness, financial, economic, business and entrepreneurial literacy, civic literacy, health literacy, and environmental literacy. The teacher–designers embraced these themes. The *Food for Thought* project was inspired by the teachers wanting to instill service learning and community awareness, while the *Butterfly Garden* project was focused on the theme of environmental stewardship. Both projects helped students to develop their creativity and critical thinking skills that helped them to ask the right questions and make informed decisions, which is what mathematical modeling affords. For the *Butterfly Garden*, students had to optimize their budget to find the "best" purchasing plan to buy plants to attract butterflies. For the *Food for Thought* project, students used their creativity to generate different ideas to run a food drive. In the process, students developed their abilities to create models that can help interpret and explain real-world problems, to develop quantitative and representational fluency, to reason using mathematical arguments, to develop a collaborative experience with explicitly shareable products, to impact classroom discourse in a healthy positive way, and to develop technology-enhanced solutions. Such mathematical modeling tasks helped to build both the procedural and conceptual understanding while engaging students in complex real-world problems through creativity, collaboration, critical thinking, and communication (Suh, Matson, & Seshaiyer, 2017).

Enacting the Mathematical Modeling Process

To help name and identify the stages that the mathematical modelers were engaged in, the researchers used the three-phase lesson planning process, more specifically, the launch, explore, and summarize phases to help teachers go through the mathematical modeling cycle.

Launching through an authentic motivating context that elicit mathematics content standards and process goals

In the case study of the math modeling tasks called *Food for Thought* and the *Butterfly Garden* projects, teachers carefully selected context that was motivating, relevant, and rich with a connection to content skills and process skills. In the *Butterfly Garden* project, teachers launched the mathematical modeling task within the PBL unit by collaboratively planning a lesson in posing an authentic scenario to contextualize their mathematical modeling task.

> I told my students that our school's principal was looking for landscape ideas for our school's future courtyard. I provided the students with only the dimensions of the courtyard, centimeter grid paper, and access to technology. (Fourth-grade teacher, Tony)

To help students define the problem, the teacher provided them time to develop a "What I Know" and a "What Do I Need to Find Out" T-chart. Due to their prior experience with mathematical modeling, the students were able to develop an extensive list of what they would need to find out. One student mentioned during this process, "Creating this list will help us become more organized in our thinking, as well as seeing the importance of most important versus least important which will save us time."

In the *Food for Thought* project, teachers posed and defined the problem through a real-time documentary video. One of the first steps to mathematical modeling is defining the problem and identifying the variables important in the mathematical problem. The teachers used multimedia to first appeal to student empathy by watching a documentary about hunger that also provided the important statistics and data on the current state of hunger in our country and the world.

> But then we went into the whole, you know, "Food for Thought," like how are we going to help our community and solve this hunger problem, and where's the math in it? So we had the statistic from the video, one out of five children don't know where their next meal will come from, so that was the launching statistic numbers. And, so, how can we use math as we work together to solve this problem? (Sixth-grade teacher, Anne)

The documentary multimedia video not only brought out the statistics of hunger but also created a sense of empathy in their students for the children who go without meals. The students remembered "the one out of five children go hungry every day" statistics and started to think about what that would mean in their own class of 25 students. That would mean five would not get to eat. Then they thought about their school of 600 students, which would be 120 students who would starve. The teacher commented, "And, so, they really had some great ideas about proportional reasoning, working with decimals and fractions and percents. And, so, they did a super good job with that." By watching a documentary of real people interviewed about their hardships, the video pulled at the students' heartstrings, as mentioned by the teacher,

> And I was listening to some of the things, even one boy who never pays attention too much, said to me, "Wow, this is really making me sad. Like this is …" You know, it really hit home for him, and he's like, "I think we really need to do something about this." So they were looking at solutions that could actually happen, that we could actually do. (Sixth-grade teacher, Anne)

Exploring math through intentionally planned and spontaneous teachable moments for math modeling

The authentic mathematical modeling tasks involved students engaging in unique stages of the mathematical modeling process. Not only were the elementary teachers new to mathematical modeling but the students had not had prior experience with such an open-ended, student-centered approach in learning mathematics. While the teachers struggled with the balance of facilitating an open-ended task, they also planned for specific model eliciting prompts. For example, for the *Butterfly Garden* project, the fourth-grade teachers saw a great opportunity to pose a problem about maximizing the garden plot with a limited amount of fencing. Students explored all the dimensions possible for a given perimeter and calculated the area allowing mathematical modeling to take place with an optimization task.

Another scenario where the teacher facilitated the mathematical modeling process was noted in the *Food for Thought* project. Once students in the class defined the problem of helping with the fight against hunger, they had to simplify the problem by making the problem smaller scale so that they could actually think of a realistic solution. In the mathematical modeling process, the teacher referred to this as "Making Assumptions to Define, and Simplify the Real-World

Problem" and asked questions like, "What assumptions do you need to make? What are the constraints that help you define and simplify the problem?" This was a necessary scaffold as this approach was novel to the students. They had not encountered such an open-ended problem as finding a solution to fight hunger in their community. In order to respond to this question, the team of students set off to do their research.

Once the team decided on a direction to take to build their solutions, they needed to work on the next step of *Considering the Variables*. The teacher asked questions to help move the students to mathematize the real-world problem: "What variables will you consider? What data/information is necessary to answer your question?" The teacher monitored her classroom and took notes on what each group decided to focus on. The students were on the web looking at the census data for their county trying to find the demographic and breakdown of adults and children to apply the "one in five children go hungry" statistics to their county. Other times, teachers capitalized on spontaneous moments for mathematical modeling. For example, during the *Food for Thought* project, one of the groups found the Official United States Department of Agriculture (USDA) Food Plans Cost of Food at Home at Four Levels, U.S. Average, October 2015 and started to investigate how much it would cost an average family of four. Students read and analyzed the table and created their own spreadsheet with how much they would need to support 10 families over the Thanksgiving holiday. Although the teacher had not planned for this instructional move, she felt that the new information that the student located on the USDA website provided an opportunity to have the students read a table of information, and use that data to calculate the estimated funds needed to support 10 families.

Teachers facilitated the learning while making moves and decisions with "catch and release" moves, which marked times when teachers made a pedagogical decision to stop and build collective knowledge around important mathematics. Many times, these "catch and releases" were taken up to move students' thinking forward, in particular to: (a) highlight a student's contribution to the class and pose it as a tool for thinking more deeply about a problem; (b) reveal a common misconception that needed to be addressed as a whole-class discussion; and (c) provide more information that could help students refine their assumptions or provide constraints so that the problem could be one that students could mathematize.

As the student teams built solutions they also were asked to analyze and validate their conclusions. The teacher asked questions like "Does your solutions make sense? Now, take your solution and apply it to the real-world scenario. How does it fit? What do you want to revise?" The teacher noted that this process was different from the typical math lessons, where there was a final right answer. She reflected,

> So, you know, just that messy process of inquiry learning and talking about iterations and reiterations and just moving on and on with each session that we had. The kids' thinking became more specific, their math became more crucial, I guess you could say, to help them determine how they could get to their original goal, the original food, you know, project, food solution that they had originally intended to do. So it's pretty cool stuff. (Sixth-grade teacher, Anne)

As the mathematical modeling lesson progressed, there were specific planned "catch and releases" that were at times planned scaffolds and at times spontaneous scaffolds. Teachers were very much intentional about being judicious about when to intervene and facilitate while monitoring for math opportunities.

Summarizing through formative assessment strategies to assess students' content and process skills

In the *Butterfly Garden* project, students assigned one another roles, used number sense, computation, measurement, and proportionality to develop their eco-friendly school courtyard. Independently, students used Excel to create budget expense reports after choosing appropriate structures and features from Lowe's and Home Depot. At the end of this one-and-a-half-week process, the students were provided time to share one another's landscape layouts. One of their guiding assessment questions for the *Butterfly Garden* math modeling task was "What are students' ideas about the reasonable magnitude of measurement?" Students were provided an additional day to make revisions based on observations and ideas they gained from the first proposal. On the last day, student "leaders" turned in their work to be presented to the school's principal for final review.

> "And then this [these] were their final plans. So I gave them the approximate dimensions of our school's future courtyard, and I gave them just a long sheet of grid paper. They had to use scaling, which is not a fourth- or fifth-grade standard, and they went through, and they decided how they were going to use their scaling and how they were going to use their grid paper. And then, also, two of the groups, they have been doing budget expense reports. We haven't gotten to computation yet, and this is because of the second math modeling task that they did. So again, it's just the constant cycle through of what did we learn from these processes? What can we apply to this one? (Fourth-grade teacher, Tony)

In the final stages, student teams had to present and justify the reasoning for their solutions.

To get to this point, many of the teams left Friday afternoon making plans with their team how they were going to work together on Google Docs and also to create their proposals. They cared about their project because it was embedded in a real problem and they had found ways they could solve the problem in some small way that would impact the community. This seemed to empower them and fuel them to collaborate beyond the class time and space. The joint PowerPoints were prepared together in person but also virtually as homework.

Pedagogical Practices and Norms for Student Participation in Mathematical Modeling

For the second research question—what pedagogical practices (for teachers) and socio-mathematical norms (for how students participate in mathematics) are necessary to enact mathematical modeling in the elementary grades and what support is needed as teachers implement mathematical modeling in their classrooms—the researchers analyzed data from the lesson study debriefs, lesson reflections from teachers, and focus group interviews.

Table 23.2 Five Critical Norms for Mathematical Modeling

Pedagogical practices for mathematical modeling	Student participation norms
• Provide an authentic and personally relevant context for students to see mathematics with multidisciplinary connections • Promote math discussions to elicit the use of mathematical modeling to describe, optimize, predict, and make decisions using mathematics • Plan for appropriate scaffolds to help students revise and refine math ideas in the iterative modeling process • Introduce open-ended math problem posing with multiple entry points and creative solutions • Establish socio-mathematical norms for collaboration, participation, and promoting productive struggle	• Make connections between real-world mathematics situations and the mathematics learned in school • Use mathematics they know and "new" math to solve real-world problems that may require more diverse skills of mathematics • Expect to be asked questions to revise, refine, and reflect on mathematical ideas • Embrace and be comfortable with open-ended problem posing and its complexities and being creative and critical problem solvers • Expect to be contributors in the math classroom by listening, commenting on, and questioning their classmates respectfully and persevering through complexity

To summarize the findings, the researchers identified five critical norms (see Table 23.2) needed in the classroom to ensure success in implementing mathematical modeling. These five critical norms for mathematical modeling combined the important pedagogical practices exhibited by teachers that also created a set of socio-mathematical norms that students needed to participate in the mathematical modeling process. A brief summary of each of these ambitious pedagogical practices and norms is described in Table 23.2.

Providing an authentic problem context in which students can engage in mathematics

Teachers learned about the importance of authentic tasks and "keeping the problem real." All but one of the groups presented the mathematical modeling tasks to their students with a video that connected with students' prior experience and ways that students can impact their schools and their communities. "The task pulled at their heart strings," observed one group of teachers, noting how a video on hunger in the United States and a visit by a nonprofit group galvanized their students' ownership of the problem. One teacher shared with his class, "Whenever someone asks you what math is good for in the future, you can remember this MM [mathematical modeling] project." These tasks tended not only to be authentic but interdisciplinary as teachers could target more than one subject through the mathematical modeling task. The teachers concurred that by providing local context and authentic tasks for students to grapple with through the mathematical modeling, the process helped them see the relevance of mathematics in their lives.

Promoting math discussions to elicit opportunities to use mathematical modeling to mathematize, make predictions, and decisions

One of the questions that the teachers kept front and center was "Where is the mathematics?" While they appreciated the engaging nature of the problem-based approach, they did not want the problem and project to go off on too distant a tangent from the mathematical ideas they wanted to explore. For example, teachers noted some students focused on creating an art project or drawing instead of focusing on the mathematics to help them make important decisions in designing the butterfly garden. Teachers noted that it was important to focus on the use of mathematics to help them either make a decision or make a prediction. One of the ways they kept the mathematics front and center was to promote class discussion through prompts to allow the student to refine their assumptions and constraints during the mathematical modeling process, which elicited opportunities to use mathematics to make predictions, optimize, and/or make decisions.

Planning for appropriate scaffolds to help students revise and refine mathematical ideas during the iterative modeling process

In interviewing one of the teachers, he mentioned that he often would use a "catch and release" when he saw an opportunity to intervene to either elicit a mathematical connection or bring up a mathematical opportunity. Teachers also discussed the role of scaffolding and what that looks like. It was important for the teacher to discuss the mathematical modeling process and the mathematical modeling vocabulary (i.e., assumptions, variables) when starting the task so the students could see what it looked like and felt comfortable with the process. Related to the engagement factor was the access to rigorous mathematical learning and the opportunity to learn for all learners. Special educators and English language resource teachers shared how mathematical modeling leveled the playing field for many of their struggling learners because the open-ended nature of the problem provided multiple entry points with which the learners could engage. Scaffolding at appropriate times became an area of pedagogical dilemmas for teachers. Teachers used question prompts and mini-lessons as a scaffold that was coined by the researchers and teachers as the "catch and release," a strategy to allow for teachers to briefly pause students during their independent and collaborative group work. These "catch and release" lessons allowed for the teacher to refocus students toward important mathematics; to highlight worthwhile students' math thinking to become visible and explicit for collective learning; to provide guidance, and to balance the cognitive load of working through a real-world problem.

Embracing open-ended math problem posing with multiple entry points and creative solutions

One of the challenges encountered by teachers in the mathematical modeling process was defining their role as the students worked on mathematical modeling tasks. The open-ended nature of the students' problem posing and building solutions challenged the teachers. Teachers noted their own struggle with how much direction and what type of support to provide to students during the modeling process. The open-ended nature of the mathematical modeling task was a novel approach for both the students and the teachers. Students in most of the case study classrooms were used to focused lessons with specific objectives for each day that were more directly instruction in nature. They were not used to posing mathematical problems or even being exposed to a mathematical modeling task that did not have one definitive answer. Teachers had to acknowledge the open-ended nature of problems posed in a mathematical modeling task. Teachers noted the importance of asking questions during a mathematical modeling task and how that helped students in justifying their reasoning in decisions during the mathematical modeling process. They also noted that mathematical modeling lent itself well to differentiation by offering multiple entry points and solutions. Many of the teachers discussed the importance of doing multiple mathematical modeling tasks to help the students become comfortable by way of consistency with seeing these types of tasks.

Establishing socio-mathematical norms for group work and participating in the mathematical modeling process

When asking teachers what support they needed to promote mathematical modeling in their classrooms, they cited the need to set up norms in their classroom at the beginning of the year with regard to student expectations in their mathematics classroom. Teachers voiced a need to develop several important skills and dispositions that were essential to engaging successfully in mathematical modeling. These dispositions or attitudes included students' comfort and confidence in dealing with complexity and tolerance for the productive struggle. Many students were used to having problems broken down for them into "textbook problems" and were not used the complex nature of real-world problems with the many assumptions and variables that needed to be considered. Mathematical modeling required working on a task for longer periods of time and required persistence in working with difficult problems. This also meant that teachers had to resist spoon-feeding students the information they needed or intervening too much. It required a balanced level of scaffolding that made the learning productive. The PBL environment and mathematical modeling task required students to work in groups and communicate to achieve a common goal or solution, which was challenging to some groups of students.

Discussion, Implications, and Future Directions

Teachers noted that teaching through mathematical modeling was not only new and ambitious for them, but also new for their students, and setting up norms for engaging in mathematical modeling was something they needed to establish at the beginning of the year. This included creating norms for valuing individual contributions and working collaboratively in teams. Teachers also noted that they needed to help their students break away from the notion that all math problems had one right answer. With mathematical modeling, the assumptions and constraints that they put onto a real problem could lead to various solution paths. Many students needed to be reminded that mathematical models also go through an iterative cycle of refinement much like their writing process. Such refinement comes as students think more deeply about the assumptions and constraints in the problem and, as they revise their thinking, their mathematical model becomes more accurate in finding the potential solution to the real problem scenarios. Teachers also realized that mathematical modeling is an investigative process designed to help the students understand variability and uncertainty in real-life situations. Students formulated a question (anticipating variability), collected data (acknowledging variability), analyzed data (accounting for variability), and interpreted the results (allowing for variability). The mathematical learning progression as the students go through this process in lesson study makes the mathematical modeling process more impactful for the teachers (Suh & Seshaiyer, 2015).

This exploratory research examined the nature of teachers taking up an ambitious teaching practice of introducing mathematical modeling in the elementary grades. Although we cite some of the challenges they faced, in general, we documented the design decisions teachers made that ultimately led to successful implementation. As researchers, we recognize that we need to examine contrasting cases where the implementations did not succeed and examine the obstacles. We plan to explore that more in depth in future studies and extend this study to examine how to best support teachers enacting ambitious teaching through mathematical modeling to elicit students' twenty-first-century skills such as creativity, critical thinking, communication, and collaboration. One important outcome from our case study is the formulation of the five pedagogical practices that were elicited by teachers enacting this ambitious teaching and the norms that need to be expected of students to take on this ambitious learning process. The five pedagogical practices and norms could be a starting place for defining support structures and could become a usable tool to support teachers in implementing mathematical modeling in their PBL classrooms. In addition, the researchers recognized the need to create a guide to help teachers evaluate the mathematical modeling process during the different phases and created a toolkit called "Points for Evaluation during the Mathematical Modeling Process" (Suh & Seshaiyer, 2017, see Table 23.3). This toolkit looks at the different phases of the mathematical modeling process using three important dimensions—the mathematics content, the mathematical process, and the real-world context that is unique to each modeling task—so that teachers can maximize the interaction among these three dimensions.

One important implication for educators is the need to involve and encourage teachers more in innovative curriculum design through lesson study. The teacher designers voiced their excitement about the designed mathematical modeling lessons and shared their enthusiasm for the engaged elementary students' learning through this PBL opportunity. Teachers agreed that, despite some of the challenges they faced in using a novel approach in their mathematics instruction, the PBL environment and mathematical modeling lesson created a learning environment that gave students ownership of their learning. Having a student-centered learning environment was a paradigm shift for many of the teachers. Student engagement as a result of mathematical modeling was one of the recurring themes in the data. Teachers found that, though the mathematical modeling

Table 23.3 Points for Evaluation during the Mathematical Modeling Process (Suh & Seshaiyer, 2017)

Defining a problem statement
- Content: The problem is *posed* in a way that elicits mathematical exploration
- Process: The problem statement provides opportunities to *describe, predict, optimize, and/or make decisions* on solutions to the problem
- Context: The problem is *set* in an authentic, real-world situation that is personally meaningful

Making assumption and constraints
- Content: Students *make* reasonable assumptions and identify appropriate constraints
- Process: Students *discuss and determine* the reasonableness of the assumptions and constraints
- Context: Students are able to *justify* their assumptions based on information that they gathered in the real world

Considering the variables
- Content: Students *identify* variables that define the mathematical relationships among quantities
- Process: Students *choose* the appropriate quantifiable variables to identify potential mathematical models
- Context: Students *collect* real-world data for the variables to establish a mathematical model

Building a solution
- Content: Students *apply* relevant mathematical knowledge to build their solution
- Process: Students *employ* multiple solution strategies to solve the problem efficiently
- Context: Students *explain* their thinking by using multiple representations with connections to the real-world problem

Analyzing and drawing conclusions
- Content: Students *validate* their solutions through mathematical reasoning
- Process: Students *provide* a detailed analysis of their discovery and draw conclusions
- Context: Students *connect* their solutions back to the real-world problem

Evaluating the model
- Content: Students can *support* their understanding of the model they created
- Process: Students *revise/refine* their thinking and critique their peers' solutions
- Context: Students *interpret* other models to improve their own model to better fit the real-world scenario

process was messy for them, it was engaging for the students. They found that students begged for, "Just five or ten more minutes," to work on mathematics and regularly asked when they would have class time to work on the project. This type of mathematics also impacted student disposition toward mathematics. One teacher noted that mathematical modeling is a natural process and the messiness comes from the teacher more than the student. "It's messy for us because we don't know what is going to happen, we have to do the anticipation and have to be flexible, the messy is from the teacher perspective, but the messy is engaging for students, the messy is that they have so much choice which is engaging and motivating." A participant remarked that at a recent parent–teacher conference, a parent shared that their child had gone from hating mathematics the year before to currently loving mathematics. The shift was attributed to the mathematical modeling project in this teacher's classroom. This study revealed that as teachers collected evidence of student learning and opportunities for mathematics teaching and learning during their mathematical modeling lessons, they became inspired by what their students were capable of doing as young mathematical modelers.

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24

A Case Study of Project-Based Learning of Middle School Students Exploring Water Quality

Ann M. Novak and Joseph S. Krajcik

Situating the Case

Research from learning sciences (NRC, 2007; Sawyer, 2014) supports the design of learning environments that engage students in authentic contexts where they find solutions to problems and make sense of phenomena. Though exciting, it presents challenges for teachers and curriculum designers to create such environments. This research has driven policy documents throughout the globe to promote knowledge-in-use by students (FNBE, 2015; NRC, 2012; OECD, 2014). If we want to truly promote students' understanding of science and motivate students to develop a lifelong interest in science, and if we want them to become scientifically literate citizens, then students have to "do" science in order to learn science (Krajcik, 1993). They need to take part in the same activities that scientists do: asking questions, exploring and explaining phenomena, and solving problems, all within real-world contexts. They need to be able to *use* their knowledge, just as scientists do. Project-based learning (PjBL) is an instructional approach where students engage in similar activities to scientists. In this chapter, we discuss how PjBL can engage students in learning science by doing science.

For more than two decades educators have been encouraged to move away from covering many topics at a superficial level or focusing on technical vocabulary and isolated facts. Science teachers need to move away from seeing themselves as the "conveyer of knowledge." Rather, to promote student *use* of knowledge, environments need to be created that move toward students examining a few "big ideas" of science by going in depth to assist students to learn a few major science ideas (NRC, 2012; Smith, Wiser, Anderson, & Krajcik, 2006), with a changing emphasis to "less is more" (NRC, 1996) that allows them to also understand the interdisciplinary nature of science (Czerniak, 2007). Emphasis should be placed on creating learning environments that foster students to actively, rather than passively, construct knowledge. This requires science teachers

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to support students in making sense of phenomena and designing solutions to problems. Exploring phenomena, therefore, drives instruction; exploring and explaining phenomena are at the core of what it means to do science. This perspective aligns with the Framework for K–12 Science Education (NRC, 2012) and three-dimensional learning (Krajcik, 2015a; NRC, 2012), in which students make sense of phenomena using disciplinary core ideas, scientific and engineering practices, and crosscutting concepts (CCCs).

A major goal of science education is to assist students to develop usable knowledge, also termed integrated understanding (Fortus & Krajcik, 2011; Hmelo-Silver & Pfeffer, 2004; Bransford, Brown, & Cocking, 2000; Roseman, Linn, & Koppal, 2008), which allows learners to explore and explain phenomena, to solve pressing local and global problems as part of being scientifically literate citizens (Choi, Lee, Shin, Kim, & Krajcik, 2011; OECD, 2004), learn more when needed, and to transfer their learning to new situations (Bransford & Schwartz, 2001). It is a challenge specified by the Framework for K–12 Science Education (NRC, 2012) in the United States but also countries like Finland (FNBE, 2015) and Germany (Kulgemeyer & Schecker, 2014). It is not enough to assist students to develop knowledge of science ideas separate from engaging in practice—it is not *what you know*, but rather *how you **use** what you know* (NRC, 2012). Knowledge-in-use, being able to apply understanding, is viewed as important across the globe, with various nations moving to competency and performance-based standards (FNBE, 2015; Kulgemeyer & Schecker, 2014; OECD, 2014). Experts have knowledge that is organized around core concepts or "big ideas" because they understand relationships between science ideas. These highly organized knowledge structures guide experts' thinking (Chi, Feltovich, & Glaser, 1981; Hmelo-Silver & Pfeffer, 2004; Bransford et al., 2000; NRC, 2007) allowing them to explain phenomena, solve problems, and apply their understandings to new situations.

Scientists understand more than the big ideas of their field. They also have a deep integrated understanding of CCCs and scientific and engineering practices. CCCs, such as patterns, cause and effect, scale, and systems, are ideas that occur within and across science disciplinary boundaries. CCCs bridge disciplinary boundaries, as they provide explanatory power throughout science and engineering. Patterns, for instance, occur in biological, chemical, and Earth systems phenomena. Scientists in all fields look for patterns as they make sense of phenomena and seek cause and effect relationships for observed patterns, and thus patterns and cause and effect relationships serve as important unifying concepts of science. Scientific and engineering practices are the everyday ways of knowing and doing that scientists and engineers employ to study and explore the natural and designed worlds. Both scientists and engineers engage, for example, in the practice of developing and using models. Scientists use models to understand and explain phenomena; engineers use models to develop and analyze systems as well as develop and test designs. Students also need to engage in practices in order to learn the big ideas of science. Learning content, big ideas, and CCCs depend on engaging in practice, and learning practice depends on *using* the big ideas and CCCs of science. This focus on using the three dimensions is referred to as three-dimensional learning (NRC, 2014). In order to help students develop usable knowledge, teachers need to view themselves as guides who create learning environments conducive to the "doing" of science (Krajcik, 1993). These three-dimensional learning environments integrate the practices of science, the big ideas of science, and the unifying concepts—those CCCs that cut across the various fields of science (NRC, 2012).

The Promise of PjBL

PjBL (Dewey, 1938; Krajcik & Czerniak, 2018; Krajcik & Shin, 2014) holds much promise in assisting students to construct integrated understandings of big ideas, practices, and CCCs that will foster their development toward a lifelong interest in science and becoming scientifically literate citizens. Through PjBL students explore phenomena and design solutions to problems and see the relevance of learning science because it situates learning with students "doing science"—finding answers or solutions to questions or problems that are meaningful to them. It also parallels what scientists do. PjBL shifts the responsibility of learning to the learner: students are no longer passive recipients of "knowledge" but rather active constructors of knowledge. Thus, the classroom becomes an environment where students take ownership of figuring out the phenomenon, with the teacher acting as a guide and co-constructor of understanding. These are highly engaging learning environments where students are motivated to continue to learn.

PjBL provides a unique learning environment to motivate all learners in developing usable knowledge by engaging them in three-dimensional learning (Krajcik & Shin, 2014; Schneider et al., 2016). PjBL is based upon principles of how students learn and how to engage all learners, and is grounded in four major theoretical ideas that emerged from learning sciences and educational research: (a) active construction, (b) situated learning, (c) social interactions, and (d) cognitive tools (Bransford et al., 2000; NRC, 2007). Designers of PjBL environments use six key design features based upon these theoretical ideas (Krajcik & Czerniak, 2018; Krajcik & Shin, 2014):

1) Use a driving question to explore a phenomena or problem to make sense of, which drives the learning.
2) Focus on learning goals that students need to understand the world.
3) Explore the driving question over time by participating in science and engineering practices.
4) Engage in collaborative activities with other students, the teacher, and community members to explore the driving question.
5) Scaffold students using various supports that allow students to construct an understanding of complex ideas and that help them participate in activities normally beyond their ability.
6) Create tangible artifacts that address the driving question and serve as external representations of learning to make thinking visible.

The Value of Using Water Quality

Engaging students in a project related to water quality makes an ideal context for using practices to learn important science ideas. Nicknamed the water planet, Earth's surface is covered with 75% water, essential to people and ecosystems, which comprise vast populations of plants and animals, and the relationships between them and their environment. Only a minuscule amount, some suggest about 0.1%, is freshwater usable by most organisms. The problem, though, is that people pollute half of the fresh, usable water on the planet, disrupting various ecosystems. Distribution of available freshwater across the globe is uneven. Because our students will be tomorrow's leaders, we have an opportunity and an obligation to assist them to develop an understanding of science ideas related to water and to foster a commitment in them to become global scientifically literate eco-citizens who are advocates for preserving, restoring, and enhancing water in their communities, as well as becoming stewards of the Earth. PjBL can support this mission. In addition to exploring water quality through PBL, a service learning component, discussed later in the chapter, can be incorporated to serve as a powerful opportunity that can assist students to think beyond themselves to the greater good.

Case Presentation

Instructional Context: Overview of the Case

Four classes of seventh-grade learners, a total of 60 students with 31% self-identifying as students of color, from a coeducational, independent, sixth- to twelfth-grade college-prep school engaged in a PjBL curriculum. Over the course of a semester, they examined the water quality of a nearby stream by exploring the cause–effect relationships of variables that could impact the water quality including human land-use practices. Students explored the complex water quality system through engaging in scientific practices such as asking questions, collecting and analyzing data, and constructing explanations integrated with several disciplinary core ideas, along with CCCs of cause and effect, patterns, systems, and stability and change.

The first author designed the curriculum[1] (Novak, Gleason, Mahoney, & Krajcik, 2006) and is the teacher. In addition, the first author conducted research related to the project, some of which will be discussed later in this case.

Goals of the Curriculum

The goal of this PjBL curriculum is to assist students to develop usable knowledge (Hmelo-Silver & Pfeffer, 2004; Bransford et al., 2000; Roseman et al., 2008) of a stream system by exploring and explaining this complex phenomenon in a way that is meaningful and engaging. When designing the PjBL curriculum, it was important to ask the following questions: What are the major science ideas we want students to construct understanding of and be able to use? What do we want students to be able to do with their knowledge? How can the project be contextualized to make it meaningful and accessible to students? How will we assess student learning?

Core ideas, CCCs, and practices from the project are identified in Figure 24.1. These three dimensions work together to help students explain the phenomenon—the stream system. As you can see in Figure 24.1, the curriculum integrates

1 The curriculum was developed in collaboration with colleague Chris Gleason, a former teacher from Greenhills School.

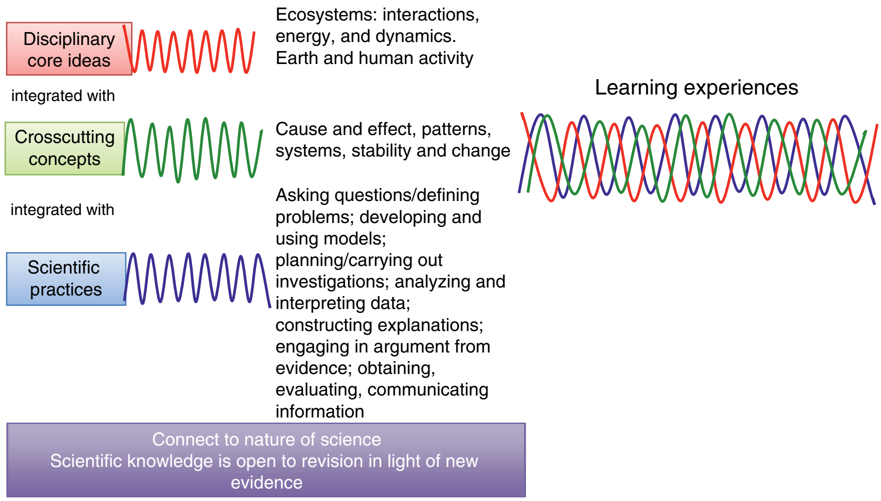

Figure 24.1 Three Dimensions of the Water Curriculum.

many practices, including students designing and carrying out investigations, analyzing and interpreting data, and constructing scientific explanations and building models, the CCCs of cause and effect and systems, and disciplinary core ideas from Earth and Human Activity, and Ecosystems: Interactions, Energy, and Dynamics related to water quality of a stream for freshwater organisms. Students learned important science ideas as they engaged in various practices with a focus on constructing an explanation of the stream's water quality over time. In addition, students experience the nature of science ideas (NGSS, Appendix H, 2013a), particularly being open-minded to the possibility of revising one's current thinking as new evidence is obtained. More comprehensive illustrations of the water project's three-dimensional learning ideas from the Framework (2012)/NGSS (2013b) and the performance expectations the water curriculum builds toward may be found in Appendix A and Appendix B, respectively.

Using PjBL as the Instructional Approach for the Water Curriculum

As mentioned above, PjBL includes several features: (a) using a driving question to explore phenomena; (b) focusing on learning goals; (c) engaging in scientific and engineering practices to make sense of phenomena; (d) collaborating with other students, the teacher, and community members to explore the driving question; (e) scaffolding students to allow them to construct an understanding of complex ideas and participate in activities normally beyond their ability; and (f) creating tangible artifacts that address the driving question. Several of these features are further discussed in the next section as we examine the water curriculum.

Making learning relevant

Perhaps the most important yet most challenging component of PjBL is creating a context for learning that is anchored in a real-world phenomenon or problem and has real-world consequences, is meaningful and important to students, and is related to what scientists really do. PjBL empowers students to take ownership of their learning because it motivates them to learn and piques their curiosity to develop a lifelong interest in science, moving them along the pathway of scientific literacy. To help students see the relevance of what they are learning, a driving question—a key feature of PjBL—is used (Krajcik & Blumenfeld, 2006; Krajcik & Czerniak, 2018; Krajcik & Shin, 2014). This is a well-designed question that is explored and answered by the students and teacher. It sets the stage for all activities and investigations. It allows the teacher to regularly connect back to it, which facilitates students "seeing the connections," resulting in students developing integrated understanding. To respond to the driving question, students need to use big ideas of science, crosscutting concepts, and scientific practices, that align with state and national standards. Throughout the project, students work to answer the driving question by engaging in a process of meaning-making to respond to the driving question and related subquestions, and simultaneously construct an understanding of important science ideas, CCCs, and scientific practices.

In the water project, students explored the driving question, "How healthy is our stream for freshwater organisms and how do our actions on land potentially impact the stream?" (Novak et al., 2006). The project began with various contextualizing activities (Krajcik & Czerniak, 2018) that helped students see the value of the project and which then led to the driving question. The first day of the project students were not *told* about the project; rather the project was introduced through a series of questions that were posed to students:

> How many of you took a shower last night or before you came to school today? Did all of you brush your teeth this morning? You're all wearing clean clothes this morning. How did they get clean? You ate breakfast with clean dishes this morning. How did they get clean? Did any of you drink water this morning or yesterday? Or have drinks that contained water? What do you know about water and all living organisms, including us? Water.… It's a pretty important part of our lives. We can't live without it! Plants and animals can't live without it either!

These questions were followed by learning experiences to introduce important science concepts and/or practices, and that set a meaningful context addressing various subquestions that further contextualized learning where students explored important related phenomena. Students explored various subquestions including: How much water is on Earth and how much is usable? How much water does my family use in an average day? Where does the water come from? How does the shape of the land determine where the water flows when it rains? What products do people use every day on land that can pollute the water? How do substances get into the water in the first place? These learning experiences focus on science ideas related to watersheds, topography, point and nonpoint source pollution, needs of organisms, and population dynamics. All of these contextualizing activities led to a final activity, a stream walk, which then led to the driving question. The driving question could be introduced like this:

> Our school and our neighbors—a condominium village and a retirement complex—comprise our school's mini watershed. Anything we do outside

> at school or people do outside at their homes can end up in our little stream. Our stream flows into a larger stream and then into a major river that provides 80% of our city's drinking water. This river flows into one of the Great Lakes. The natural questions are "How healthy is our stream for freshwater organisms and do our actions outside on the land negatively impact the stream?"

Rather than "telling" students what the class would do to investigate the stream, the following question was posed to students:

> How do *you* think we can investigate the stream? What can *we* do to find out how healthy our stream is?

Students spent time generating ideas of how they could investigate the stream and what they needed to know in order to answer the driving question. First, in small groups, they brainstormed ideas about what may impact the quality of the water and then shared ideas as a class. This process, along with dialogue during benchmark lessons, fosters student–student discourse illustrating both the PjBL features of scaffolding and collaboration. Possible questions might include "Why does what I do outside at school or home potentially impact the quality of the water? Do substances people use on land hurt fish and other organisms in the stream? How will we know if the stream is polluted or not? To begin investigating these and other questions students first explored how experts determine water quality. The teacher said to the students:

> We'll need to research to find out what tests water quality experts conduct, what tools they use, and what the various tests mean. We can talk with local groups who know about the stream and/or water quality. And we can present our findings to the local community.

Throughout the beginning stages of the unit, the contextualizing lessons of the project that led to the driving question avoided "telling" students what they would be learning about or doing in class. Rather, students were guided through learning experiences that set a context for authentic, worthwhile learning. The contextualizing activities that lead to the driving question and subquestions create a "need to know" learning environment. The goal is to develop a curriculum that puts students in an authentic experience that piques their curiosity to "find out more about" and "figure out" a phenomenon. This type of learning environment shifts the learning to students so that they take ownership of finding an answer to the driving question. Thus, a student-centered learning environment is created where the teacher becomes the guide.

Investigating phenomena

Once the driving question is introduced, students can work with each other and the teacher to design and carry out long-term investigations in order to respond to the driving question. Students take part in the same practices of scientists to investigate, in depth and detail, in order to construct deep understanding of big ideas of science and CCCs. Investigating phenomena in a collaborative environment using various practices are features of PjBL that also align well with three-dimensional learning. Scientific practices include asking questions and designing and carrying out investigations that include thoughtfully planned and sequenced activities and investigations (by the teacher and/or student) that afford students opportunities to explore components of the phenomenon. Other practices include collecting and analyzing data and constructing evidence-based explanations and developing water quality models. All of these practices take place in a collaborative environment.

PjBL is based on social constructivism (Vygotsky, 1978): students construct meaning through interactions with peers, teachers, and others. A collaborative community experience, therefore, is a fundamental aspect of the science experience: students work with each other and with the teacher to explore phenomena. Learning technologies—computers, software, probeware, modeling tools, and other peripherals—can be powerful tools to support student learning (Novak & Krajcik, 2005). They help students and teachers communicate, collaborate, carry out investigations, and develop products—tangible artifacts that help make students' understanding visible (expanded on later in the chapter)—by supporting students in the practices of doing science. Students also spend time in meaning-making: working to figure out and make sense of evidence, including discussing and analyzing evidence using science ideas and CCCs, and creating various artifacts such as constructing explanations and building models, products that make their understandings visible, both during and at the end of instruction.

In the water project, once the driving question was introduced, students conducted an internet search to determine how expert scientists determine water quality. They found that they would be able to conduct many of the same tests that experts do (an intentionally designed element of the curriculum). As part of this authentic, open-ended, nonroutine, long-term investigation (Novak et al., 2006), students were organized into teams. Each team adopted one of nine sections of the stream, where they collected four pieces of empirical data in real time, across four different episodes, over the course of 6 weeks. Students collaborated and engaged in several scientific practices. Using sensors attached to portable technology tools (Novak & Krajcik, 2005) students collected pH, thermal pollution data, and conductivity data (which measured the amount of dissolved solids like salt, nitrogen, and phosphorus). They used dissolved oxygen kits to measure the amount of dissolved oxygen in the water. These learning technologies allowed them to investigate questions like "Is our stream acidic, basic, or neutral?" "Does our stream have thermal pollution?" "Is there enough oxygen in the stream to support life?" Students also collected a variety of qualitative data that included observations of what is in the water, such as aquatic organisms, stream flow, dirt, leaves, algae, soap suds, litter, etc. They made and recorded observations around the stream banks noting loose soil, living and dead plants, trash, etc. They also recorded area observations of what was nearby including buildings, green lawns, roads, storm drains, etc.

Prior to data collection at the stream, students engaged in learning experiences that investigated the causes or sources related to each water quality test, including any actions by people on the land that could contribute to the causes, indirectly through runoff, or directly as point-source pollution. These lessons also included the possible effects of how these measures may contribute to poor water quality and the effects on freshwater organisms and the ecosystem either as a direct result of people's actions or as an indirect result of a land-use practice that could trigger a chain reaction of events impacting organisms in the stream. Students also learned how to conduct the tests, including gaining experience with using the learning technology tools. For example, students investigated the question "What is the pH of everyday products people use outside?" In class, they tested 15–20 products, such as car wash soap, fertilizer, road salt, and windshield wiper fluid. They also explored the pH ranges that are conducive for various aquatic organisms. These learning experiences took place within the four walls of the classroom. Students then went to the outdoor classroom, the stream, to collect the qualitative and quantitative data related to a particular water quality measure, in this case, pH. Next, students systematically analyzed these data to look for patterns and trends and cause and effect relationships to determine the quality of the stream for supporting life. Students shared and discussed their pH results.

Students used their real-time data as evidence to construct a scientific explanation, the major artifact of the PjBL project. Creating tangible artifacts to respond to the driving question and that illustrate student understanding of phenomena are an integral feature of PjBL. Throughout the project, students revised their explanation as more data were collected and analyzed. They justified the use of the evidence to support their claims using scientific principles discussed in class. They examined how people's actions outside in the mini-watershed can adversely affect the quality of the stream. Students' explanations are more thoroughly discussed later in the chapter.

Using modeling technology (Damelin, Krajcik, McIntyre, & Bielik, 2017) students also developed dynamic models of the stream's water quality (Novak, 2017a)—another artifact that demonstrates student learning. Modeling complex phenomena can support students in developing an integrated understanding of content as well as in building understanding of the practice. Models serve as artifacts that provide insights into students' understanding about relationships between variables to explain phenomena (Damelin et al., 2017).

The water project culminated with an interdisciplinary public speaking unit where students collaborated to develop presentation slides and formally presented their explanation in class (Novak, 2017b). Students also connected their science learning with the local community as they shared their knowledge through formal presentations at a retirement home that is a constituent group in the mini-watershed. Finally, students planned and participated in a service learning activity through an annual "Walk for Water" event where they experienced, first hand, what many adolescent girls and women do every day to provide their families with freshwater. This event further helped students see the value of the project and worked to begin to help students foster a sense of being a member of a global community.

Service learning

One goal of the seventh-grade science curriculum is to empower students to view themselves as global eco-citizens who can take positive action to contribute to the global community. As a component of the seventh-grade water project, but with sustainability and service learning at the core, an annual "Water Day" was developed, where all seventh-grade students and their teachers "Walk for Water"—a 4-mile walk from the stream near the school to a local park where the stream then flows into another stream. Each student carries 6 L of water in a backpack (three 2-L pop bottles filled with water) from the stream near the school and then pours it into the other stream. This stream eventually flows into a major river that supplies the city with 80% of its drinking water. These students experience what adolescent girls and women do every day in developing countries where freshwater is scarce. Girls in these developing countries often drop out of school so they can provide their families with water. Prior to the walk, a student water committee makes signs with facts related to water access, waterborne diseases, etc. These signs are posted along the walk. Various activities occur in science classes including student groups creating public service announcements related to a water issue. Following the walk, students collect water quality data with people from the local watershed council. Students, teachers, parents, and volunteers from the watershed council participate in the day. Ultimately, awareness of students and their families is raised, and money is also raised to support water initiatives that students choose: funds have been provided to build wells at schools in Uganda and South Sudan, money has been donated to *Raincatchers* (https://raincatchers.org), and water and money have been donated to the water crisis in Flint, Michigan in the United States. The annual water walk represents a collaboration among the school's Director of Information Technology, Diversity Director, and the primary researcher—the seventh-grade science teacher—resulting in a powerful, eye-opening experience for the students.

The vision of another seventh-grade service learning effort was to foster learning and community through promoting water quality. Each year, five classes of seventh-grade students were going to the stream 8–10 times during the semester as part of the water project. An unintended consequence of students accessing the water was that their visits were inadvertently degrading the stream banks: exploring the phenomenon contributed to negative human impact on that phenomenon. The goal of this service learning effort was to create a sustainable ecosystem around the stream. Students, teachers, parents, community partners, and sponsors built two bridges, a boardwalk, water steps, and trails into "our" stream for water quality studies, forged and chipped a trail in the schools' woods, and repaired a failed water berm. This effort exemplified a collaboration among students, teachers, parents, community partners, and sponsors that integrated community and school-based work allowing for meaningful learning experiences for students and community members. Since the original work, seventh-grade students have expanded and maintained the trails each year.

Making students' thinking visible

When students, or scientists, investigate a phenomenon they are responding to a question or problem to explore and explain the natural world. Scientists construct scientific explanations in order to explain phenomena. In the water PjBL curriculum, students constructed *one* explanation that developed over time, incorporating new evidence that included additional evidence and science ideas.

We refer to this process as an evolving explanation (Novak & Treagust, 2018). In all, students cycled through four versions of the evidence-based explanation over the course of 6 weeks that became progressively more complex as students collected additional data from the stream to address the question, "How healthy is our stream for freshwater organisms and do our actions outside on the land negatively impact the stream?" (Novak et al., 2006; Novak, McNeill, & Krajcik, 2009). The explanation structure was a framework that included a claim, evidence, reasoning, and rebuttal (McNeill & Krajcik, 2011). Creating tangible artifacts, like the evolving scientific explanation in the water curriculum, is an essential feature of PjBL. Constructing evidence-based explanations to explain complex phenomena is an important scientific practice that promotes learning and fosters integrated understanding (McNeill & Krajcik, 2011). Learning complex ideas, like those in this project takes time and often occurs when students work on a meaningful task over time that forces them to synthesize and use ideas (Bransford et al., 2000; Krajcik & Shin, 2014). The iterative process provided students with opportunities to revisit, rethink, and revise ideas, synthesizing and using those ideas to make sense of the data they collected. Since each data collection cycle explored a new water quality test with new science ideas, it also allowed students to extend their learning to new situations. In addition, some water quality measures were connected to other measures that assisted students to see the relationships between those tests. Constructing an evolving explanation allowed students to make connections among science ideas and develop more sophisticated explanations by using science ideas to think about and explain evidence over time. In each cycle of data collection and analysis, students discussed and grappled with what their data meant and if they served as evidence for their claims. These opportunities for discourse occurred both in whole-class discussions and in small groups. Discussions were supported by the teacher and students questioning students verbally in class and by the use of teacher-prepared guide sheets with prompts that student water quality groups worked on together. These facilitated student discussions related to reporting evidence and using science ideas to discuss why the evidence could support the claims students made about the health of the stream based on the evidence from the water quality tests. The teacher also provided students with feedback that they used to revise their explanation. The explanation framework, verbal prompts to promote classroom discourse, teacher-prepared scaffolded guide sheets, and teacher feedback served as synergistic scaffolds that allowed students to undertake the challenging task of constructing the evolving explanation (Quintana et al., 2004; Tabak, 2004). Supporting students through the use of multiple scaffolds is another important component of PjBL. These multiple forms of support can work synergistically to assist students to build stronger understanding (McNeill & Krajcik, 2008, 2009; Quintana et al., 2004; Tabak, 2004). The process also helped students when faced with new evidence: they incorporated science ideas more often to discuss their data in later iterations of the explanation than they did in the earlier ones (Novak & Treagust, 2014).

The evolving explanation became a living artifact that served a dual purpose—a formative and summative assessment tool, for both the student and the teacher. The first two iterations of the explanation occurred after students collected two pieces of water quality data, pH and temperature (looking for thermal pollution). Explanation #1 occurred before students were introduced to the explanation framework. This initial explanation provided insight into students' prior knowledge of how to explain a phenomenon. Explanation #2 occurred after students were introduced to the explanation framework. The third iteration (Explanation #3) occurred after students collected data about dissolved solids and included the three pieces of evidence (pH, temperature, and conductivity—the measure of dissolved solids). Explanation #4 added the percentage of dissolved oxygen, making four pieces of evidence. The teacher provided students with written and verbal feedback throughout the construction of the explanation. The final explanation, Explanation #4, included all four water quality tests and an overall conclusion about the health of the stream.

The Evolving Explanation: Measuring Integrated Understanding

In the water PjBL curriculum, students were supported to develop integrated understanding through the practice of building a more sophisticated explanation over time that would illustrate students evolving knowledge to explain a complex water system. Did the evolving explanation within a three-dimensional, PjBL learning environment provide evidence that students developed integrated understanding? What evidence do we have to support the value of this work?

Various analyses were used to track the development students made through the four iterations of the explanation. The research explored: (a) the building of science ideas across time, including students making more connections among ideas that showed the causal relationships among variables; (b) whether or not students connected science ideas to evidence (reasoning); and (c) if students' claims consistently matched the evidence, including if students adjusted their claims, if needed, when faced with new evidence. Results would provide insights as to whether constructing and revising the explanation assisted students in organizing their knowledge around core concepts to develop a more integrated understanding. The four iterations of each explanation were collected and analyzed for each student using a variety of statistical and qualitative measures (Novak, 2016; Novak & Treagust, 2018).

Results showed that the construction of an evolving scientific explanation facilitated students' development toward integrated understanding (Novak, 2016). By constructing the evolving explanation, students developed knowledge structures across time that, like experts, allowed them to apply their understandings to explain a complex phenomenon. Overall results indicated that all students' understanding of science ideas, as seen through an increase in both the number of science ideas and the relationships among those ideas (Novak & Treagust, 2014), developed from iteration to iteration. All students also increasingly connected science ideas to their evidence, a process called reasoning (Novak, 2016) that research shows is the most challenging part for students (Berland & Reiser, 2009; Gotwals & Songer, 2006; McNeill, Lizotte, Krajcik, & Marx, 2006; NRC, 2007). However, about half of the students were challenged by adjusting their claims when new, contradictory evidence was obtained (Novak & Treagust, 2018). The results, overall, illustrate that students' understanding moved from

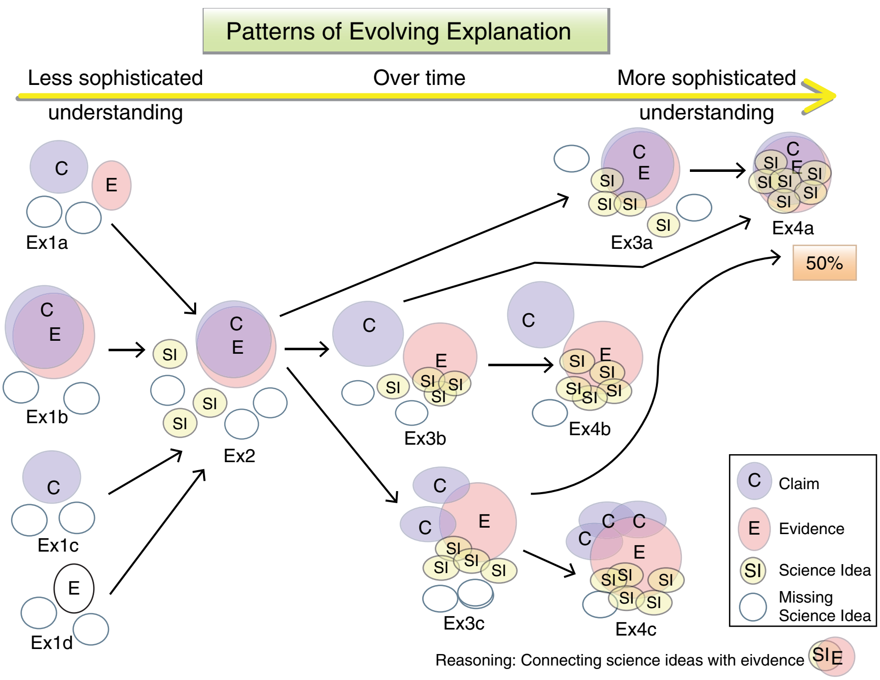

Figure 24.2 Various Patterns from the Evolving Explanations.

less sophisticated to more sophisticated. Figure 24.2 illustrates student development over the course of all four iterations of the evolving explanation.

Explanation #1, which students wrote prior to being introduced to the explanation framework, can be seen at the far left of Figure 24.2. Four representative examples of students' explanations are illustrated in Ex1a, Ex1b, Ex1c, & Ex1d. Moving from top to bottom in the diagram, and using the key at the bottom, right side, we see that some students made a claim and reported evidence without connecting the two, others connected evidence to their claim, some made a claim and reported no evidence, and finally some made no claim but reported evidence. What was consistent through all the various examples of students' initial explanations was that most students did not include any science ideas. Once the explanation framework was introduced to students, they revised their explanations. The overwhelming majority of students' explanations looked like Ex2 in Figure 24.2. Here, students aligned their claim with evidence. In this case, both pieces of evidence were positive. Looking across all four iterations students' science ideas developed as they included more ideas in their explanations and they are more connected. This is illustrated in Figure 24.2 by the circles representing science ideas and the overlap of those ideas representing more and more connections between ideas. In addition, the overlap of science ideas with evidence across time, in Figure 24.2, illustrates findings that showed students' reasoning improved over time.

Many students were challenged by the idea of adjusting their claims over time, particularly when faced with contradictory evidence. This is the case for Explanation #3. Students needed to rethink and revise their claims. This can also be seen in Figure 24.2 (Exp3a, 3b, and 3c). However, as is seen in the final iteration (Explanation #4) 50% of the students were able to use their knowledge even though they took several different pathways. All students constructed explanations that developed from less sophisticated to more sophisticated.

Discussion

Designing PjBL curricula requires a thoughtful, deliberate process with multiple considerations. The Framework for K–12 Science Education in the United States (NRC, 2012) introduces three dimensions—scientific and engineering practices, CCCs, and disciplinary core ideas—that work together to allow learners to make sense of phenomena and design solutions to problems. Developing learning experiences for classrooms should integrate these three dimensions with students exploring phenomena as the driver of instruction. A PjBL environment is a powerful and promising approach for this instruction (Krajcik, 2015b). Considerations to address when designing PjBL include: What are important science ideas and what are unifying concepts that cut across those ideas? How can these ideas and CCCs be incorporated into an authentic experience where students collaborate to ask questions, figure out, problem solve, and engage in other practices in order to investigate phenomena in a way that makes learning relevant and meaningful to all students? How can the experiences be contextualized to pique student interest and motivate students, not only in this project but to develop a lifelong interest in science and to work toward becoming scientifically literate adults? What driving question and related subquestions will sustain investigation over a period of time? Are there learning technologies that can support student learning? What artifacts can students create that are meaningful, that assist them in their learning, and that provide insight of student understanding, both to the student and to the teacher?

Another goal of PjBL is utilizing an instructional approach that fosters teachers to embrace the role of guide and co-constructor of knowledge *with* students rather than that of conveyer of knowledge *to* students. The water curriculum is a prime example of the teacher's role to assist learners to make sense of phenomena. The project illustrates what can be done and how to go about creating a community of learners engaged in exploring and explaining an important, complex phenomenon that is relevant to students' lives.

The design considerations for PjBL can, by themselves, be a tremendous challenge and daunting undertaking. Another challenge associated with PjBL is the amount of instructional time required to complete a project. If students are going to use practices to delve deeply into ideas, if they are going to explore and explain phenomena by "doing" science just as expert scientists do, then this will take time. That means fewer science ideas will be "covered." However, covering fewer topics and creating environments that focus students on using ideas to make sense of phenomena is exactly what is being called for in new standards across the globe. Nonetheless, teachers and curriculum designers find coping with time challenging.

The case study discussed addressed the considerations for designing PjBL in developing curriculum related to water. This project was a semester-long curriculum that engaged students in scientific practices and CCCs as well as a cross-section of disciplinary core ideas from different science areas. It successfully engaged students in an authentic investigation to answer a meaningful question where they explored a stream phenomenon including collecting real data in real time and then analyzing those data to construct an explanation, over time, as new evidence was obtained. For a comprehensive look at the curricular components, see Appendices A and B at the end of the chapter. An additional goal of the project was to incorporate service learning to foster students to see themselves as global eco-citizens who can take action and make positive contributions.

Over the years, students have found the water curriculum to be engaging and worthwhile as conveyed in student surveys following the project. Quotes below, from the most recent enactment of the project, are representative examples of anonymous feedback that students provided about their experiences.

> I really like the whole unit. I liked all of the different activities that we did because it was the first time I learned this in-depth on a particular subject. I especially liked the data collection, explanation, …. because it's cool to see and do what real scientists do for a living. (student feedback, February 2017)
>
> I liked being able to go outside and test the water. I felt like a real scientist, and it was very helpful for me and (throughout) my science career. Very memorable unit and made me interested, too. (student feedback, February 2017)
>
> I really liked going out to the stream and taking the tests with my partners. We learned a lot while having a great time. (student feedback, February 2017)

Research that looked at student learning in the water project indicated that students made significant learning gains across the four iterations of explanation they constructed (Novak, 2016). Over time, they actively worked toward constructing usable knowledge structures around concepts associated with the phenomenon of a stream system and human impact on water systems. One challenge that many students faced was revising their initial claims that were supported by evidence obtained from the first two water quality tests. These claims needed to be adjusted as they were later unsupported after new water quality tests were conducted that provided additional evidence of the overall water quality of the stream to support organisms (Novak & Treagust, 2018). In most classrooms, students do not have these experiences: research shows that when students' science experiences include the construction of explanations, it occurs with different phenomenon and is usually a paragraph or two (Cavagnetto, 2010). A challenge is to provide students with and support them in "nature of science" aspects of science, in this case, the idea that scientific knowledge is open to revision in light of new evidence (NGSS, 2013b).

Conclusion/Recommendations

As Bransford et al. (2000) and Krajcik and Shin (2014) suggest, learning complex ideas takes time, and students can be supported to engage in such challenging undertakings when they work on a meaningful task that forces them to synthesize and use ideas. This water quality project extends over a semester, engaging students in making sense of the water quality of a stream. Devoting time in curricula where students work on meaningful tasks, in the form of iterative experiences (Fortus & Krajcik, 2011; Bransford et al., 2000; NRC, 2012) using supportive structures like the explanation framework (McNeill & Krajcik, 2011) along with other synergistic scaffolds (Bransford et al., 2000; Quintana et al., 2004; Tabak, 2004), can assist students to think more deeply about science ideas because they are synthesizing and using those ideas (Krajcik & Shin, 2014). The multiple opportunities students received in this PjBL water curriculum allowed them to revisit important ideas and assisted them to move away from understanding science ideas as disconnected facts and to begin to organize their knowledge around core science ideas in much the same way that experts do (Chi et al., 1981; Hmelo-Silver & Pfeffer, 2004; Rottman, Gentner, & Goldwater, 2012).

Although developing and using PjBL curriculum is a challenging undertaking, it provides many benefits. Students develop sophisticated knowledge that they can use, they engage in doing science, and they are engaged in the learning process. Since the project includes collecting real data in real time, teachers also engage in the process of doing science, as the outcome of data collection is not known—students and teachers are learning together. Moreover, teachers gain ownership of the curriculum as they are the ones who design or modify materials for their own classroom use.

The water project, using a PjBL approach, serves as a springboard by which students can expand their exploration of a nearby stream in their neighborhood, to the greater local and global communities. Now more than ever, we are all members of a global community, and we recognize how various ecosystems are tied to each other and how human activities can have far-reaching impact. School experiences can assist students toward viewing themselves as global eco-citizens. If the stream the students are exploring is polluted, it will pollute the river into which it flows. That river flows into another body of water. Students need to be armed with conceptual tools that prepare them to be members of this global community as scientifically literate eco-citizens. In order to solve pressing local and global issues, students' futures will necessitate that they develop fundamental integrated understandings of science ideas, the practices of science, and the unifying concepts between various disciplines that prepare them to make sense of the various issues affecting the planet and then *use* their understandings to explain phenomena and solve problems. They will need to possess the capacity to learn more, all within a collaborative context of a community of learners and problem solvers.

The water PjBL curriculum, as well as how it is used from the teacher perspective, can serve as a model for how to design PjBL curriculum and the various considerations that need to be taken into account. It can also serve as a model for teachers of how to use PjBL as an instructional methodology. A major goal of science education is to assist students to develop usable knowledge and to help students become scientifically literate adults. PjBL shows promise to support this mission.

Appendix A: Water Unit's Three-Dimensional Learning Ideas from the Framework/NGSS

Science and engineering practices	Disciplinary core ideas	Crosscutting concepts
Practice 1: Asking questions and defining problems Practice 3: Planning and carrying out investigations Practice 4: Analyzing and interpreting data Practice 6: Constructing explanations Practice 7: Engaging in argument from evidence Practice 8: Obtaining, evaluating, and communicating information	**MS-LS2 Ecosystems: Interactions, Energy, and Dynamics** LS2.A: Interdependent Relationships in Ecosystems • Organisms, and populations of organisms, are dependent on their environmental interactions both with other living things and with nonliving factors (MS-LS2-1) • In any ecosystem, organisms and populations with similar requirement for food, water, oxygen, or other resources may compete with each other for limited resources, access to which consequently constrains their growth and reproduction (MS-LS2-1) • Growth of organisms and population increases are limited by access to resources (MS-LS2-1) • Similarly, predatory interactions may reduce the number of organisms or eliminate whole populations of organisms. Mutually beneficial interactions, in contrast, may become so interdependent that each organism requires the other for survival. Although the species involved in these competitive, predatory, and mutually beneficial interactions vary across ecosystems, the patterns of interactions of organisms with their environments, both living and nonliving, are shared (MS-LS2-2)	**1. Patterns.** Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them **2. Cause and effect: Mechanism and explanation.** Events have causes, sometimes simple, sometimes multifaceted. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts.
	LS2·B: Cycle of Matter and Energy Transfer in Ecosystems • Food webs are models that demonstrate how matter and energy are transferred among producers, consumers, and decomposers as the three groups interact within an ecosystem. Transfers of matter into and out of the physical environment occur at every level. Decomposers recycle nutrients from dead plant or animal matter back to the soil in terrestrial environments or to the water in aquatic environments. The atoms that make up the organisms in an ecosystem are cycled repeatedly between the living and nonliving parts of the ecosystem (MS-LS2-3)	**4. Systems and system models.** Defining the system under study—specifying its boundaries and making explicit a model of that system—provides tools for understanding and testing ideas that are applicable throughout science and engineering

(*Continued*)

Science and engineering practices	Disciplinary core ideas	Crosscutting concepts
	LS2·C: Ecosystem Dynamics, Functioning, and Resilience ● Ecosystems are dynamic in nature; their characteristics can vary over time. Disruptions to any physical or biological component of an ecosystem can lead to shifts in all its populations. (MS-LS2-4) ● Biodiversity describes the variety of species found in Earth's terrestrial and oceanic ecosystems. The completeness or integrity of an ecosystem's biodiversity is often used as a measure of its health (MS-LS2-5) **MS-ESS2 Earth's Systems** ESS2·C: The Roles of Water in Earth's Surface Processes ● Water continually cycles among land, ocean, and atmosphere via transpiration, evaporation, condensation and crystallization, and precipitation, as well as downhill flows on land (MS-WW2-4) MS-ESS3 Earth and Human Activity ESS3.A: Natural Resources ● Humans depend on Earth's land, ocean, atmosphere, and biosphere for many different resources. Minerals, freshwater, and biosphere resources are limited, and many are not renewable or replaceable over human lifetimes. These resources are distributed unevenly around the planet as a result of past geological processes (MS-ESS3-1) ● ESS3·C: Human Impacts on Earth Systems ● Human activities have significantly altered the biosphere, sometimes damaging or destroying natural habitats and causing the extinction of other species. But changes to Earth's environments can have different impacts (negative and positive) for different living things (MS-ESS3-3) ● Typically as human populations and per-capita consumption of natural resources increase, so do the negative impacts on Earth, unless the activities and technologies involved are engineered otherwise (MS-ESS3-3), (MS-ESS3-4)	**7. Stability and change.** For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study

Appendix B: Performance Expectations Water Curriculum Builds Toward (Framework/NGSS)

MS-LS2: Ecosystems: Interactions, energy, and dynamics	MS-ESS3: Earth and human activity
Students who demonstrate understanding can: • MS-LS2-4. Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations • MS-LS-2. Construct an explanation that predicts patterns of interactions among organisms across multiple ecosystems • MS-LS1. Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem	Students who demonstrate understanding can: MS-ESS3-4. Construct an argument supported by evidence for how increases in human population and per-capita consumption of natural resources impact Earth's systems MS-ESS3-3. Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment *MS-ESS-4. Develop a model to describe the cycling of water through Earth's systems driven by energy from the sun and the force of gravity *Performance Expectation from MS-ESS2: Earth's Systems

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Section V

New Developments and Emerging Trends in PBL

Introduction

This final section of the handbook offers insights on new advancements that will impact problem based learning (PBL) practice, such as technology innovations and emerging learning theories and models. Technology innovations, particularly networked and immersive technologies, have opened up myriad new possibilities to enhance and apply PBL more successfully. There are now abundant opportunities for research and experimentation in designing PBL for digital and e-learning environments. Furthermore, the emerging global challenges and the need for transforming pedagogy to better support acquisition of twenty-first-century skills demand new models of learning that are progressively changing from focusing on content knowledge to supporting and modeling process skills, problem-solving skills, and thinking skills. In addition, making students' thinking evident through innovative learning design that enables students' ways of thinking and knowing to be manifested in active, collaborative, and self-regulated learning is as crucial as learning design that supports the acquisition earning of core subject matter. Section V addresses these new trends and developments in PBL in five chapters.

In Chapter 25 "3D Immersive Platforms and Problem-Based Learning Projects: A Search for Quality in Education," Araújo describes how the emerging technologies of augmented reality and 3D platforms can be used to support professional development programs that use active learning pedagogies such as PBL, and how the coupling of emerging technologies and PBL is creating new ways for understanding education in the twenty-first century. Challenging the readers with the demands and needs of a democratic society brought about by the sociopolitical and economic transformations experienced in recent decades, Araújo contends that educators and students should have an active role to play in the search for a school that is accessible to all, equitable, and aims at quality. Building on his historical analysis, he further promotes that together with the implementation of

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active learning methods, technology has a key role in the search to increase the quality, the universalization, and the democratization of education.

In Chapter 26 "PBL and Networked Learning: Potentials and Challenges in the Age of Mass Collaboration and Personalization," Ryberg explores PBL from the perspective of the emerging field of networked learning that has strong roots in humanist and critical theory. He describes that networked learning is mediated by online networks, including social networking sites and other social media that support user interaction and content generation. Basing his argument and the proposed pedagogical model on the research in networked learning, Ryberg views PBL as more than an instructional strategy. He argues that PBL is a deeper-seated philosophy of engaging students with real-world, societal problems, where they become change agents and develop as critical citizens. Ryberg further outlines different ways in which digital technologies and social media can support PBL group work, and discusses the potentials and challenges to PBL when using social media to enable learners to create personal learning environments (PLEs) and personal learning networks (PLNs) that support student-driven inquiry, peer learning, and collaboration.

In Chapter 27 "Project-Based Learning and Computer-Based Modeling and Simulation," Morge, Narayan, and Tagliarini study PBL in the context of computer-based modeling and simulation activities. They demonstrate how computer-based modeling and simulation can serve as a powerful complement to PBL and foster computational thinking when applied to problems from a variety of science, technology, engineering, and mathematics (STEM) disciplines. Using three examples of generative modeling environments, Morge et al. discuss the strengths and limitations of computer-based modeling and simulation activities demonstrated by application to problems from a variety of STEM disciplines.

Savin-Baden and Bhakta, in Chapter 28 "Problem-Based Learning in Digital Spaces," focus on PBL in digital spaces. They describe implementations of PBL in both online and virtual worlds, prompting a reconsideration of what counts as effective learning within the boundaries of current curricula structures. The authors also present the findings of a study that explored the use of online PBL to examine whether students could detect a covert pedagogical agent that provides human-like interactions and use the results to make suggestions about how PBL practice might be developed and improved through digital technologies.

Finally, in Chapter 29 "An Exploration of Problem-Based Learning in a MOOC," Verstegen and colleagues explore the application of PBL for MOOCs (Massive Open Online Courses). They describe the instructional design of a MOOC that teaches participants the principles and design of PBL by exposing them to authentic problems and group collaboration in an online context. Given the implementation process of MOOCs, Verstegen et al. share important lessons learned and reflect on the MOOC design experience and potential future uses of PBL MOOCs.

25

3D Immersive Platforms and Problem-Based Learning Projects: A Search for Quality in Education

Ulisses F. Araújo

> *Some say that more difficult than acquiring new knowledge is to loosen up the old. Abandoning an idea presupposes surrender part of our thinking—that we considered true for a long time—and let yourself be fascinated by the unusual. In this fascination capacity lies the germ of progress.*
>
> (Moreno, 1999, p. 13)

To innovate in education, it is necessary to get fascinated by the unusual, by the intellectual adventure of riding paths not yet traveled, assuming principles of uncertainty and indetermination as partners of this trip. But this must be done with wisdom and safety. After all, innovation is not based upon an empty space or on fragile foundations. To preserve, transmit, and enrich the cultural and scientific heritage of humanity are the principles that justify the existence of education, both formal and informal.

The sociopolitical and economic transformations experienced in recent decades have extended formal education for almost 100% of the population in most countries, bringing with it the demands and needs of a democratic society, inclusive, permeated by the differences. Beyond that, the emergence of new realities and languages, digital and virtual, is demanding from educators, politicians, and the population in general a reinvention of the school as we know it—a model that was consolidated in the nineteenth century and is still dominant nowadays.

To continue occupying the important role that society has accorded to education over the past 300 years, the school depends, paradoxically, on its capacity to conserve its characteristics of excellence and production of knowledge, as well as the capacity to adapt to new technologies and the requirements of society, culture, and science.

To better understand contexts of innovation and why there is a need for reinventing schools is the vertebral column of this chapter. In the first part, educational revolutions throughout the history will be discussed, showing that the

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spaces for novelty are not empty. In the second part, the discussion will be around the role that active learning methods, such as problem-based learning (PBL), have in the process of school reinvention, as well as technology and new languages. Finally, some examples will be presented to demonstrate how this reinvention is being constructed in different settings, with a special focus on 3D immersive platforms, which are an emergent technology that promises to approximate different dimensions of reality in the educational field.

Educational Revolutions

> The revolutions that better resist to the test of time are the silent revolutions. It's hard to find in them a set time, a specific action that can be pointed to as the precise moment when the change of mentality that engenders revolutions came to light. The silent revolutions advance in people's minds, change gradually their values and attitudes. (Esteve, 2003, p. 23)

This epigraph reminds us that the silent revolutions are those that transform the world slowly through changes in mentality that gradually awaken people to new realities and different ways of understanding human relationships with nature, society, culture, and politics. In the field of education, such processes, historically, help to understand the development of the schools as social institutions.

The Spanish author Esteve and his book *The Third Educational Revolution—La Tercera Revolución Educativa* (2003) are the main references for this discussion of Latin American countries. He points out as the first educational revolution in human history the creation of *Houses of Instruction* in the ancient Egyptian empire, nearly 3,500 years ago—different from the family education that had taken place before. They were created and disseminated around 1,500 BCE by Pharaoh Thutmose I of the Eighteenth Dynasty, a monarch who emphasized the importance of education and encouraged culture.

Located mainly in the temples, according to Smith (2000), the Houses of Instruction had as an initial function to teach by memorizing the symbols (hieroglyphics) of Egyptian writing. Considered a divine instrument given by God Thoth to some men, writing was later taught to selected students, who used the papyrus for its realization. They were the scribes, who belonged to the priestly elite and the state administration.

Thus, during the long period of the first educational revolution, which lasted up to the Renaissance, formal education was set up as something important for society but reserved for a small portion of the population, made up of the social and religious elite. The main characteristic of this period, however, is that this model of education was characterized by a one-to-one relationship: master and disciple, preceptor and student.

According to Esteve (2003), during the Renaissance, another silent revolution took place in Europe, and he points out what can be considered the mark of the second educational revolution in human history: a decree of King Friedrich

Wilhelm II from Prussia, in 1787, making basic education compulsory in Prussia. This removed the responsibility for the management of schools from the clergy turning it over to be managed by the state.

In this historical movement, a pedagogical and architectural model of school that placed teachers at the center of the process was formed as a characteristic of the second educational revolution. Teachers were regarded as the holders and transmitters of knowledge, and a large number of students were placed under their responsibility. It is important to highlight that this model was designed to serve only about 10% of the population. In accordance, classrooms were designed based on these principles: small classrooms; teachers occupying a space next to the blackboard marking it the center of the pedagogical activity; and students' desks facing it. Following these concepts, students were positioned to receive the instruction coming from the master, which demanded homogenization in the classroom and the exclusion of differences in order to be efficient in the transmission of knowledge (Araújo & Arantes, 2014).

From the second half of the nineteenth century up to the present day, Esteve (2003) believes that a third revolution is taking place, based on the principles that now 100% of children and adolescents must attend formal education in democratic societies.

The aim of universalization linked to the democratization of modern societies brought a radical diversity to the classrooms, challenging the educational model of the second revolution, which was based on principles of homogenization and exclusion of differences.

The integration of these "new students" into the classroom, many of them with no educational background in their families—they were/are actually the first generation to attend a formal schooling process—is demanding new approaches in education.

Teachers who have trained in the best universities to transmit knowledge and control the homogeneity of their classrooms through standardized assessment tools and the exclusion of differences, legitimated by society and public policies, now have to deal with all these differences in spaces restrained by "four walls." People from different gender and social, economic, psychological, physical, cultural, religious, racial, and ideological backgrounds now share the same spaces and cannot just be excluded from school.

This is one of the origins of the educational crisis that educators are facing nowadays, in the opinion of many authors (Apple, 1992), and echoed by the academic field, families, and the press. School buildings have been designed to attend the demands of the second educational revolution, and teachers formed to work with those principles, but the classroom composition in terms of students, as a characteristic of the third revolution, is no longer homogeneous, with students possessing the same level of knowledge, development, skin color, gender, etc.

From this perspective, the third educational revolution that has led to increased access to education (accessibility) as well as the inclusion of all the differences in school spaces (equity), has led to an education quality challenge (see Figure 25.1) and a malaise in the professionals devoted to it, by requiring other forms of relationships to the teaching and learning of students.

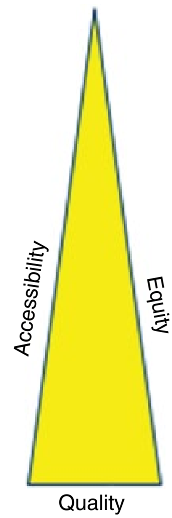

Figure 25.1 Loss of Educational Quality.

Figure 25.2 Increase in Educational Quality.

To overcome this situation is a real challenge for our generation of educators. The challenge is to adapt the process of education, so that the universalization and the democratization accomplished in the past decades, which ensure diversity in school spaces, do not adversely affect its quality (Figure 25.2).

So, the challenges of diversity and universalization imposed by the third educational revolution have led to an understanding that educators need to take an academic–scientific approach to what can be called a “reinvention” of education. The school and university model consolidated in the nineteenth century now has to consider the demands and needs of a democratic and inclusive society, permeated by differences, and guided by inter-, multi-, and transdisciplinary knowledge. Teachers are challenged nowadays to use inclusive methods that lead to respect for differences and cultures, and also to appreciate the students’ different types of skills and levels of knowledge.

The beginning of the twenty-first century has brought a real and complex challenge for all of those involved with education. It could be said that this generation of professionals (and also students) will be responsible for the reinvention of education, and there is no way out. It is something that needs to be faced, and the solution, or the construction of a new paradigm, is already underway.

Probably this generation of educators are in the middle of the same challenges that were faced in the eighteenth and nineteenth centuries when the new pedagogical and architectural model of school was developed, schools and classrooms were built, placing teachers at the center of the process, attending the needs and characteristics of the second educational revolution.

Now there is a need to understand and develop a new pedagogical architecture that fits contents, spaces, forms, and relations coherent to the democratization and universalization of the third educational revolution.

In some ways, it can be expected that an educational disruption is underway, as well as similar disruptions in many fields of the economy and social relations. As pointed out by Christensen, Aaron, and Clark (2002), the theory of disruption can provide researchers, practitioners, and policy makers with a new perspective on increasingly affordable and accessible educational opportunities in our society. They say, also, that innovators are unlocking the gates to accessibility and affordability in education through disruptive innovations.

For sure a historical distance in the future will be needed to understand and realize what has come of this period of uncertainty and distress, but believing in the constructivism perspective, it is clear that educators and students have an active role to play now in the search for a school that is accessible to all, equitable, and of good quality.

Reinventing Education

From the perspective adopted in this chapter, school, as we know it, should be reinvented. The changes needed to build a new model of education and science should consider the dimensions of *contents*, *methods*, and *relationships between teachers and students* from a complementary perspective.

From the *contents* point of view, to live with differences in the classroom and the school is essential so that pupils develop relationships based on respect and ethics, toward each other and the world in which they live. So, a school that seeks to reinvent its model should consider introducing ethics, social responsibility, and sustainability content to its curriculum, beyond the traditional content it has been working with. This is what the Association of American Colleges and Universities (AACU) recommends in its 2007 report (AACU, 2007), saying that one of the types of learning that should be expected of students is: personal and social responsibility, including knowledge and civic engagement at local and global levels, knowledge and intercultural competence, ethical thoughts and actions, and skills for learning throughout life.

To change the *form* or *methods in the classroom* it is necessary to rethink the timing, spaces, and relationships in education, incorporating the radical transformations that the technological revolution and communication practices have provoked in the democratization process. The use of digital tools and technologies that promote interaction and new forms of social relations in line with new knowledge production lead to different forms of course organization, and to the devising of different ways of managing the relationships of teaching and learning, with changes in the roles of students and teachers in the learning process, toward a collaborative and cooperative learning.

The United Nations Educational, Scientific and Cultural Organization (UNESCO), in its *World Conference on Higher Education Report* (2009), points out that the use of technological tools and perspectives in education in the coming decades could provide better conditions to expand access while promoting the quality and success of education.

In a third dimension, of *relationships between teachers and students*, authors such as Shulman (2004) and Weimer (2002) argue that teaching–learning must suffer a reversal, no longer focusing on teaching and opening perspectives for learning grounded on the leadership of the learner. That is, breaking up with the dichotomies between "the one who knows everything" and "the one who knows nothing." According to this perspective, the construction of knowledge presupposes an active individual who participates intensely and reflectively on the educational processes, building their identity and producing knowledge through dialogue with peers, teachers, and daily culture.

Active learning methodologies are the core of an approach where the emphasis on teaching is replaced by an emphasis on learning, where teachers have a new role and perspective in their profession, and this is a key issue in reinventing schools, as shall be discussed in the rest of this chapter.

PBL and Active Learning Methods

Ernest Von Glasersfeld (1984) and the Swiss epistemologist Jean Piaget (1967) are two earnest defenders of what is called radical constructivism—a conception that rejects both the empiricist thesis that knowledge results from the pressure of the social or external world on the subjects, and also rejects the aprioristic epistemology that knowledge is innate. In a radical constructivism knowledge is neither predetermined by genes nor is it brought about by simple internalizations (from outside to inside), but it is constructed through the actions of human beings toward the objective and subjective world where they live.

As has been pointed out before (Araújo, Arantes, Danza, Pinheiro, & Garbin, 2016), educational proposals consistent with these principles must create educational environments where students assume an active role, and participate in the classes in an intense and reflective manner. It presupposes students who build their intelligence, identity, and values through the dialogue established with peers, teachers, family, and culture, in the everyday reality of the world in which they live. Therefore, in this epistemological model, students are authors of the knowledge and protagonists of their own lives and not mere reproducers of what society decides they should learn. Essentially, this is an educational proposal that promotes intellectual adventure and, accordingly, the constructivist conception is the most appropriate to achieve these goals.

Constructivism as an adventure of knowledge presupposes giving voice to students, promotes dialogue, incites their curiosity, leads them to question everyday life and scientific knowledge, and, above all, provides them with the conditions to find the answers to their own questions, both from the individual and the collective point of view. Specifically, constructivism—by recognizing the active and authorial role of students in the construction and constitution of their identities, knowledge, and values—places students at the center of the educational process (Araújo et al., 2016).

In this way, active learning methods in education have as their main presupposition an active student, who assumes an active role in the apprenticeship and the search for knowledge, changing, at the same time, the teacher's role in the classroom. Authors such as Jean Piaget, Lev Vygotsky, John Dewey, Kurt Lewin, Ernest Von Glasersfeld, Paulo Freire, and Jerome Bruner are important references for those who want to go deeper in the comprehension of this perspective, which is not the focus of this article.

The PBL approach is one of the main innovative active learning methodologies being implemented at all educational levels all around the world, and the following paragraph summarizes the initial PBL conception adopted in this chapter.

According to Barrows and Tamblyn (1980), PBL is a learning method based on the principle of using problems as a starting point for learning. Mayo, Donnelly, Nash, and Schwartz (1993) say that PBL is a pedagogical strategy for posing significant, contextualized, real-world situations, and providing resources, guidance, and instruction to learners as they develop content knowledge and problem-solving skills.

Complementary PBL Approaches

There is a variant of the traditional PBL conception, also understood as an active leaning method, which is known as *project-based learning* (PrBL). Enemark and Kjersdam (1994) from the Aalborg University in Denmark, point out that *project-organized* means that the curriculum is taught through project work supported by theoretical lecture courses related to the problem at stake. The project-organized concept moves the perspective from knowledge description and analysis to knowledge synthesis and assessment. The concept is based on a dialectic interaction between the subjects taught on the lecture courses and the problems dealt with in the project work. The project work may be organized by using a "know-how" approach for training professional functions, or it may be organized by using a "know-why" approach for training in methodological skills of problem analysis and application.

Also, another approach that has been spreading out in different places and contexts throughout the world, and can be considered complementary to PBL and PrBL, is *design thinking.*

According to Meinel and Leifer (2011), design thinking is a human-centric methodology that integrates multidisciplinary collaboration and iterative improvement to produce innovative products, systems, and services with an end-user focus. The projects start with a challenge or a problem, and it is human-centered because the process of designing innovative services, as an example, begins by examining the needs, dreams, and behaviors of the targeted people to be affected by the designed solutions, listening to and understanding them (IDEO, 2009). So, PBL and PrBL used from a design thinking perspective can be a way to empower people and the community, through creative and innovative processes, in the search for solutions for their own problems. Working in a collaborative and cooperative way may lead to professional development and the improvement of community life.

But what all of these approaches have in common is a focus on the learning process of the student.

PBL and Information and Communication Technologies—ICT

Together with the implementation of active learning methods, technology has a key role in the search to increase the quality, the universalization, and the democratization of education, helping to ensure diversity in schools' timing, spaces, and relationships. This is in accordance with UNESCO's *World Conference on Higher Education Report* (2009), which predicts that new approaches to teaching through the use of ICT tools should enable broader access, better quality, and better results in education.

Connected to the current networked society (Castells, 1999), the introduction of ICT is a continuing and irreversible process that has encouraged new educational models to emerge, boosting different forms of social interaction in connection with new configurations of knowledge production in academic institutions (Araújo, 2011). New spaces for pedagogical action can also be reconfigured with characteristics that aim toward "the development of competencies and skills, respect for an individual's rhythm, the formation of learning communities and social life networks…" (Behar, 2009, p. 16).

However, there is a need to be careful and not to use technology to do more of the same, just with "a new dress," like using ICT to reinforce empiricism based on knowledge transmission. Introducing ICT tools and gadgets to the classroom without an appropriate educational approach to explore it will reproduce the same that has been going on in past centuries in schools.

As can be observed in many distance learning educational proposals, the use of computers, videos, and the internet in education doesn't necessarily imply a better educational quality. Usually, its target and method are to display information on a screen to a passive student who has only to read and listen, and take exams. This model, like in the second educational revolution, keeps the teacher (or the computer) in his/her/its role of knowledge transmitter.

So, this is one of the main challenges in reinventing education: aiming toward the use of ICT to improve quality and democracy. How can we reach an *equilibrium* in the triad of accessibility, equity, and quality of education?

Araújo and Arantes (2014) understand that some technologies available today at low cost (or even for free) can support the democratization and universalization of education with quality. As seen before, the backbone of the third educational revolution is diversity in the classrooms. To avoid homogeneity, and based on the assumption that people have different ways of learning, they discuss how the design of the VLE—virtual learning environment with the introduction of specific technologies can foster the convergence of different *languages* and tools in respect of the different ways people learn.

To exemplify, the authors described a blended graduate program developed in Brazil from 2010 to 2014 to train 3,000 teachers, where accessibility was a core issue. There, the reading texts and other content were made available in the VLE in many different ways; for example, texts could be seen in a "traditional" format to be read on the screen or to be downloaded for later use, or in an MP3 format, for those who prefer to learn by listening or for those with visual impairments. The video classes were also recorded in LIBRAS (Brazilian Sign Language) and closed captioned to ensure accessibility for people with different disabilities or who are studying in a space where silence is needed. Screen reading software was available to students, as well as magnifying glasses, readers, and screen contrasts. All of these perspectives used ICT tools to guarantee the accessibility of the courses provided to the students, so that people could appropriate the academic knowledge according to their necessities and/or preference.

In a complementary approach, Araújo and Arantes (2014) discuss, also, how education, through a well-designed VLE and different ICT tools, should adopt multiple languages aiming at enriching the learning experiences of students. In this way, free or low-cost well-known platforms like YouTube (www.youtube.com) and Vimeo (http://vimeo.com), together with mobile video productions, should be incorporated into daily academic activities. The language of television, which distills important topics into short segments, is also an important language for education.

Finally, the use of ICT tools to foster and enhance collaboration, cooperation, and peer-to-peer interaction is a key element for an education connected with the needs, necessities, and dreams of a school that aims at accessibility, equity, and quality. Free or low-cost platforms, such as Skype from Microsoft, WhatsApp from Facebook, and Hangouts, Drive, and Docs from Google in the VLEs, are examples of technologies developed recently that have a promising interface to lead education toward the third revolution.

In this way, PBL approaches combined with ICT can be considered a promising way to face this educational challenge. First of all, both conceptions favor students' access to sources of information and communication. Second, both consider the need to support collaborative work processes, students in self-monitoring and self-regulating their work and the process of individual and group learning, students in performing tasks by providing tools that assist them in understanding the sequence of tasks, and teachers' pedagogical monitoring (Araújo, 2011; Coll, Mauri, & Onrubia, 2010; Fruchter, 2014).

Summarizing this topic, e-learning platforms designed with multimedia features that can support the convergence of different languages in the educational processes, mediated by digital platforms available on the internet, may give people with different abilities and disabilities the possibility of participating, interacting, and collaborating in a diversity learning set, helping to promote democracy and quality in education (Araújo & Arantes, 2014).

Although all the features mentioned above already exist and are present in different academic and ICT experiences, they are usually fragmented in specific contexts. The novelty of the approach presented here is to present all of them under a unique platform, or VLE. The development of a platform that supports the convergence of all the principles, languages, and ICT tools mentioned could be a new trend towards achieving accessibility, equity, and quality of education.

Most important: in order to be coherent this platform must fit within the active learning methodologies and PBL.

The following section provides data about selected bachelor degrees that are being implemented in Brazil to train science teachers and engineers, where the challenge of adopting PBL and other active learning methods mediated by emerging ICT technologies, is addressed.

The Virtual University of Sao Paulo—UNIVESP

In August of 2014, the Virtual University of Sao Paulo began operating in Brazil. The Virtual University of Sao Paulo is the first truly virtual Brazilian university, accredited to offer bachelor degrees in natural sciences and math teaching (biology, physics, chemistry, and mathematics) and engineering (computing and production). It opened enrolling 3,330 students in the freshman year, with 2,034 in the teaching program and 1,296 in engineering, distributed across 28 cities in the state of Sao Paulo (Brazil). Based on the Brazilian Constitution, this public university offers all of its majors for free.

The 4-year curriculum of the teacher's training program and the 5 years of the engineering curriculum are based on PBL, PrBL, and the design thinking approaches, requiring every semester that students work collaboratively to identify, prototype, and solve problems in their local communities.

Students, working in groups of five or six members, spend approximately 4 weeks formulating a specific problem to investigate, approaching and listening to community members, continually clarifying and refining the problem, and seeking and mapping information about how their theme is reflected in the daily life of the school or company they are working with. Next, they create the first solution prototype, show it to the community partners for discussion and feedback, then improve the prototype iteratively until the designers and the community partners feel that the solution is well planned. The whole process takes 16 weeks and sometimes it can get to the implementation phase of the project, or to a functional prototype. However, there is no need for the actual implementation of the solution, since undergraduate students are developing the project and the goal is to increase their skills and mindset to work collaboratively in solving real problems.

To ensure that the students have a creative and deep professional learning experience, the didactic–pedagogic model of UNIVESP's bachelor degrees incorporates five complementary pillars.

The first pillar is the transmission of knowledge. This is accomplished through prerecorded video lessons. Some of the leading experts in Brazil on the issues addressed in the courses are invited to deliver the video classes. Each of these video classes is between 15 and 20 min long. The second pillar of the model adopted at UNIVESP is problem resolution, in which they have to solve real problems similar to those they will face in the professional world. The third pillar is the interdisciplinary perspective, in which students have to develop solutions for nondisciplinary problems through a project-based approach. The fourth pillar is collaborative and cooperative work and is anchored on the importance of

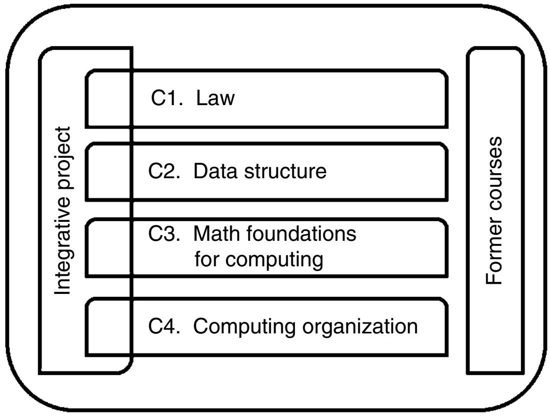

Figure 25.3 Model of Curricular Organization at UNIVESP.

social learning, or group learning, as a fundamental aspect of the co-creation and preparation to work in the professional world (Dabbagh & Dass, 2013). PrBL underlies this pillar because it recognizes the importance of the contemporary collective construction of network knowledge and multidisciplinary teams (Sawyer, 2006). The fifth pillar adopted in UNIVESP is *learning by doing*. This pillar relies on the design thinking methodology, PBL and PrBL, and the Maker movement, combined together as an effective approach to solving complex problems and creating innovations, articulating theory and practice.

Figure 25.3, which is based on the model developed by Aalborg University (Denmark), represents a typical curricular organization at UNIVESP, where the courses (C1, C2, C3, and C4) offered online support for problem and project development, in accordance with the five pillars mentioned (Araújo & Sastre, 2009).

The e-learning platforms are designed with multimedia features that can support the convergence of different languages and foster different students' abilities to participate, to interact, and to collaborate. In this way, many ICT tools are used to implement the academics of the didactic and pedagogical model. All of them are chosen to support the academic principles adopted at UNIVESP and may vary according to the needs and demands of the courses and projects.

A 3D Platform for an Immersive Learning Experience

Among many technologies that have been emerging with educational applications and being tested in many institutions such as Stanford University and UNIVESP, 3D modeling software promises to create new approaches for immersive experiences, in which learners can experience more realistically a natural, social, artistic, or biological phenomenon. A massive development effort is being made in many areas of knowledge looking for applications that could take students to a "new educational world," closer to reality. Virtual and augmented realities are some of the new trends in this perspective, pointing to new and different educational approaches.

At low cost or even for free, students can now travel inside the human body and see the organs and the synapses functioning; they can see a magnetic field in motion, enter an atom to understand the reaction of a metal with oxygen, understand the volume of a cylinder in a 3D perspective, and virtually ride a roller-coaster to study some of the forces in the thrill ride. They can even visit virtually the most important museums on earth, study the main art representations in history, and feel inside a battle during the Second World War. Finally, with augmented reality, students can access QR codes and get lots more information about the phenomenon being studied. These are amazing experiences that involve and excite students, who will better understand the phenomenon of the specific subjects in school, and for sure this is a novel approach for quality in education.

However, again, there is a need for reflection, being careful not just to adopt a "new dress" for the same old empiricist paradigm, where students have a passive role in the learning process, experiencing knowledge that comes already packaged for them to absorb and then return to in the exams. Usually, these experiences are exciting in the beginning, mainly because of the novelty, but soon students lose interest due to the passiveness of the process. They just watch a movie and have no real active role in it.

It seems to be an eternal epistemological battle.

To be coherent with the principles discussed in this chapter, a 3D platform for an immersive learning experience should incorporate possibilities for participation, interaction, and collaboration to reach the goals set for the school and university reinvention. In other words, changing only the form in which content is presented without considering the relations and the active role of students in the content knowledge production will not lead to real changes.

The point is that there are few research and concrete educational experiences exploring the use of 3D virtual ecosystems to promote a collaborative and cooperative learning. This is the approach that education should move toward: the articulation of the ICT emerging technologies with active learning methodologies.

The AEC—Architecture/Engineering/Construction—Global Teamwork Master Program, led by Renate Fruchter, Director of the PBL Lab, is an important experience in this perspective, being developed at Stanford University.

This is a cross-disciplinary Master's course based on the PrBL methodology, focusing on problem-based, project-organized activities that produce a product, and processes that bring people from multiple disciplines together. It engages faculty, practitioners, and students from different disciplines, who are widely geographically distributed. It is a two-quarter course that engages yearly about 30 architecture, structural engineering, building systems mechanical, electrical, and plumbing engineering, life cycle financial management (LCFM), and construction management (CM) students from many countries worldwide (Fruchter, 2014).

The platform used at the AEC course is called Terf®, commercialized by 3DICC Inc. The origin of this platform is the Croquet Project, an open source software kit developed to create and deliver collaborative multiuser online applications. The original authors of Croquet opened a commercial company named Qwaq, which was later renamed Teleplace and then became Terf.

Figure 25.4 Terf Prebuilt Room.

Terf is a platform that provides the creation of virtual and immersive 3D collaborative spaces for sharing content and generating an environment for the co-creation of information and the reuse of data and knowledge gathered by the students in a workgroup. The tool works for the team members as a "plunge" into a virtual 3D environment in which the participants share and work collaboratively in the organization of their problem-solving projects, where the students can interact by means of different methods and tools such as voice, videos, text editors, the internet, whiteboards, smartboards, and slideshows (see Figure 25.4; Araújo & Arantes, 2014).

According to Fruchter (2014), there are some key transformations mediated by the immersive 3D virtual collaboration environment during its application: (a) *presence*—the 3D virtual collaboration environment create a sense of "physical presence" or "being there," enabling participants to interact through their avatar with other team members' avatars; (b) *co-creation*—each AEC global student team is provided with their own 3D virtual collaboration space that they configure and reconfigure as well as repurpose to address their current task and interaction needs and create a shared work context; (c) *persistence of content in context*—this 3D virtual collaboration environment supports both synchronous and asynchronous collaboration and each AEC global team owns their virtual collaboration space data, information, and models, as well as recording of meetings, which can be persistently captured and archived in the context that they are created; (d) *from multitasking to engagement*—AEC students reported that sharing the collaboration space with their team mates' avatars built continuous awareness of their presence and led to higher degrees of participation and engagement; (e) *from viewing to experiencing*—visualizing the integrated 3D Building Information Modelling and multidisciplinary model-based performance evaluation have led to increased collaboration, early identification and resolution of clashes, and project cost and time reduction; (f) *from group to team*—the sense of presence and ownership fosters project and task-oriented collaboration events in the 3D virtual space, and informal interactions and socialization.

Fruchter (2014) understands that these transformations lead to innovative and effective new ways for teamwork to occur, addressing critical challenges for collaboration, coordination, knowledge co-creation, and sharing in distributed teams. Also, that the 3D virtual collaboration space fosters deeper reflection on cross-disciplinary impacts of discipline proposals and evolution of the projects, reducing multitasking and increasing participants' engagement.

At UNIVESP, the Terf platform was adopted in the first 12 months of the new university to support the projects developed by the students. It was used as a tool to mediate each student group's plan of action during the project development, including surveying, listening to, and capturing the perspectives of the different actors involved in the problem being studied.

Using this platform at UNIVESP, the groups are able to analyze their project progress based on the data collected up to that point, including text, videos, images, and other material. Following the principles of PBL and PrBL, in which PBL is a pedagogical strategy for posing significant, contextualized, real-world situations for students (Mayo et al., 1993), and the project-work approach is essential for training in the methodological skills of problem analysis and application (Enemark & Kjersdam, 1994), at UNIVESP we have been trying to understand how Terf can be a tool to reinvent the way we practice education. Promoting immersive learning experiences and the possibility that students and professors can work together, co-constructing and sharing in multimedia languages—breaking the "four walls" physical barriers—their perceptions, feelings, knowledge, and curiosities about problems being deeply studied, a new approach in learning is being constructed. How does this 3D immersive platform work?

A virtual campus was developed and customized by 3DICC with the characteristics required by UNIVESP's academic program. Each professor had their "own virtual campus" that could be accessed 24/7 and where the professor mediates the project development of nine groups of six students for a period of 16 weeks. The campus is composed of two main "worlds": the first one is a collective space where all the students can meet and share experiences and documents. They can configure this space by adding furniture, chairs, tables, lighting, flowers, and different types of virtual displays, such as panel, stand, fixed, whiteboards, and smartboards. Also, there is an auditorium where all the students can sit at the same time to partake in regular synchronous classes given by the professor or invited people through streaming video, using programs like Skype and Hangouts, which can be set in a display.

The second "world" is a space owned by each team or group of students to develop its specific project. Each team can also customize the space according to their needs, desires, and necessities. They can add as many displays as they want to share the reports each member produces, look at interview videos, spreadsheets, movies, pictures, open browsers, and carry out online research, etc. So, it is a multimedia space where they store and share the project information and data, in a synchronous or asynchronous way, since members can meet at a scheduled time to work together, and they can record the meeting in order to register conversations and the shared data to review, reuse, or archive. Members and professor can have access to this space at any time to study individually or collectively the materials available, or to have tutorial sessions.

To use the displays, each member connected to the platform just drags and drops any images, documents, files, or movies from their computer desktop or hard drive into the displays inside Terf, and they can point, click, and touch the shared file, interacting through audio with their colleagues and the data present in the room at that time.

The technology is simple enough for everyone to use, and no additional infrastructure is required. As a cloud-based platform, not much bandwidth is required to run the software, and for simple activities, some of the students in Brazil could participate in classes, even with a 1 MB connection. With more multimedia interaction in a group meeting, a better bandwidth is needed to have a smoother interaction.

The 3,330 students of UNIVESP have a weekly face-to-face 4-hr session to work on their project development under the supervision of a project mediator. Although for this session they attend a class located in one of the 28 cities where UNIVESP has a physical classroom, actually most of them live in nearby cities, around 120 towns, and travel once a week, for the face-to-face class. This is an important issue in a blended perspective, assuming that face-to-face sessions can improve relationships and the quality of the interactions and mentoring.

The use of a 3D immersive platform in the context of UNIVESP avoided a lot of displacements and commuting from its students. The face-to-face sessions could happen every other week in the physical classrooms, but in the other week, the mentoring session occurred on Terf. With that, the quality of the projects was kept, and the university could use the classrooms to host more students in the weeks students met on Terf.

In summary, mentioning some examples of universities that have academic courses using PBL and project-based activities, 3D modeling applications can play a role in innovation, coherent with the need for education reinvention stated in this chapter. But in order to accomplish that these ICT technologies must be immersive and allow and foster participation, interaction, and collaboration.

Final Remarks

After presenting a brief historical overview of education, describing how it became universalized in the past decades in more democratic societies, the initial pages of this chapter discussed how the arrival of a totally new generation of kids in school, bringing their differences and heterogeneity, is impacting education as a whole, challenging professionals and students to reinvent content, form, and relationships. Of course, this framework is also affecting higher education.

This is the main reason for UNESCO's claim that there is the need to search for new approaches that can foster better conditions to expand access while promoting the quality and success of education.

In this chapter, thinking about what is expected from education to form the democratic citizen of the knowledge society, there is a defense of an epistemological perspective based on constructivist theories and active learning methodologies such as PjBL and PBL, design thinking, and, more recently, the maker movement.

Emerging ICT technologies has proved useful in promoting accessibility and equity in education, but not necessarily in fostering quality.

This is a real challenge for those who understand the crucial role that education has in the development of societies and individuals, in the search for democracy and equity, and the construction of a more just and happy society.

In this way, among the many emerging technologies, the focus should be not so much on novelty, but on how they can be useful as tools to promote accessibility, equity, and quality in education.

Thus, a new trend in education, here advocated, is the conjunction of emerging technologies such as 3D, virtual, and augmented reality with active learning methodologies such as PBL, aiming toward the reinvention of education and the construction of new pedagogical architectures. This is based on the assumption that it is useless to adapt the new technologies to the old pedagogical models, in which actors are passive. Active learning pedagogies will become more powerful and efficient as tools for societal development when they are associated with these emerging technologies, which accomplish the role of knowledge mediation.

PBL and PrBL as emerging pedagogies and emerging technologies like 3D virtual, virtual, and augmented reality can be a way to answer the challenge posed for twenty-first-century societies, of obtaining quality in education for everyone, if implemented in a constructivist perspective.

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26

PBL and Networked Learning: Potentials and Challenges in the Age of Mass Collaboration and Personalization

Thomas Ryberg

PBL and Networked Learning: Potentials and Challenges in the Age of Mass Collaboration and Personalization

Problem-based learning (PBL), active learning, and various orchestrations of learning and technology (blended learning, e-learning, distance education) have become increasingly pervasive in debates across the entire educational spectrum. Widely within education there is a growing interest in adopting more active, student-centered approaches to teaching and learning, and new technologies and media are viewed as a means to realize these ideals. This interest in technology as an enhancement to learning lives among practitioners, researchers, and policy makers. It is fueled by both research and practice-based experiences but equally by commercial interest as education is an increasingly interesting and massive market for traditional and new stakeholders. This has led to a growing concern with solutionism, meaning the belief that a particular pedagogical challenge or problem can be fixed through a technological solution, or that technology implementation in-and-of-itself will result in innovative pedagogy and classroom practices (Jones, 2015; Selwyn, 2014).

The principles of PBL have spread from medical education to becoming more broadly adopted principles in primary, secondary, and tertiary education, although there are differences in how PBL is orchestrated in a second-grade classroom and as part of a university degree. Even within higher education PBL practices can vary from being applied as one problem per day as part of a course to collaboratively produced student projects that span 3–4 months and address complex real-world problems.

Therefore, capturing essential aspects of both PBL and digital technologies and learning is a difficult enterprise. However, this chapter will pursue this by

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initially discussing some central aspects or characteristics of PBL. It will particularly relate these to understandings emerging from traditions working with critical pedagogy and networked learning. It then discusses different types of collaborative engagement and how PBL group work can be viewed as four generic collaborative work processes. It illustrates how digital technologies, and more specifically social media, have the potential to support these modes of work. From the critical perspective of networked learning, the chapter also identifies challenges arising from incorporation of social media, which are further discussed in the concluding discussion.

PBL—A Conceptual Model and Principles

As the diversity of this handbook suggests, the notion of PBL covers a multitude of practices, and it is a pedagogical approach, which is applied differently whether implemented in K–12 or higher education contexts. Even within higher education there are multiple PBL models, such as the Aalborg PBL model (Kolmos, Fink, & Krogh, 2004), or the Maastricht model (Kolmos & Graaff, 2003). It can therefore be useful to understand PBL as a set of overarching, yet flexible principles derived from across a number of different conceptualizations (Dirckinck-Holmfeld, 2002; Kolmos & Graaff, 2003; Savery, 2006; Savin-Baden, 2007). For example, most authors suggest that in PBL a problem must be the starting point for learning. Further, that problems should be authentic, exemplary, ill-structured or real-life problems; that students build on their previous experiences; and that problems are best addressed through active engagement involving research activities, decision making, and writing. The learners should have a high degree of autonomy and responsibility for their learning, which should encompass elements of peer assessment. In addition, principles of interdisciplinarity are often highlighted in relation to PBL because the problem, rather than a disciplinary curriculum in isolation, should be the driver of the learning and enquiry process. Finally, PBL is predominantly conceived of as a collaborative or cooperative pedagogy with elements of group work, though the dependency on others can vary across different orchestrations.

These considerations have led to the development of a conceptual model which can be used to think of PBL as a flexible pedagogy that can take many shapes (Ryberg, Koottatep, Pengchai, & Dirckinck-Holmfeld, 2006). The model suggests that one can view PBL as a continuum across three dimensions stretched out between teacher and learner control (see Figure 26.1). The three

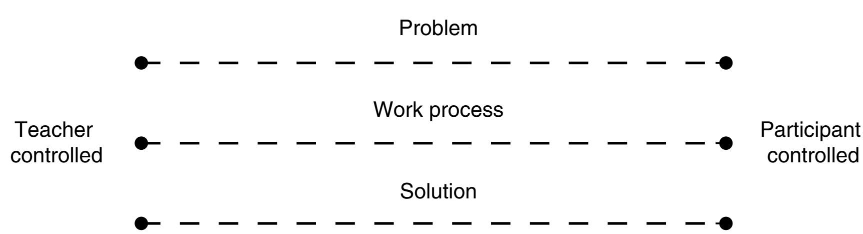

Figure 26.1 Continua between teacher and Participant Control in PBL Processes.

central dimensions proposed are: the problem, the work process, and the solution (space). These can be either teacher controlled or learner controlled. For example, is the problem given to students by the teacher, or should the learners identify the problem themselves? Do the learners control how they work? When to do what, and what methods and theories to use, or do they follow a work plan decided by the teacher? Is the solution space open-ended or is it fixed?

The model presents a way of conceptualizing and designing various orchestrations of PBL and has been used to develop, design, and analyze online courses as part of a European Union (EU) project (Tambouris et al., 2012).

Networked Learning and PBL

While there is much research into PBL, the broader area of technology and learning is massive in magnitude and topics. It spans all areas of education and encompasses everything from iPads in kindergartens, learning management systems (LMS) in universities, massive open online courses (MOOCs) as lifelong learning, and teens' informal use of social media. Further, it is enveloped in broad fields such as e-learning, distance education, and technology enhanced learning. While PBL is relevant within all these fields, this chapter argues that networked learning is an area of research whose theoretical and philosophical underpinnings align particularly well with PBL. While some use networked learning as synonymous with (or as a more contemporary term for) e-learning, it is also an area of research in its own right. The research area of networked learning grew out of a series of research seminars in the late 1990s, and developed into the biennial international Networked Learning Conference series, with the first conference held in 1998. More recently a Springer book series titled "Research in Networked Learning" emerged, and an encyclopedic entry on networked learning was added to the *Encyclopedia of Educational Philosophy and Theory* (Jones, Ryberg, & de Laat, 2015). The field of networked learning is generally interested in learning that is mediated by digital technologies, including social networking sites and other social media that support user interaction and content generation, although it should be noted that the field predates the rise of social media. However, more than an interest in digital technologies, the theory and pedagogy of networked learning is concerned with developing approaches to learning that encourage learners to be ethically responsible and critical citizens in both their practice and lives.

This resonates well with PBL theories that view PBL as more than an instructional strategy and instead as a deeper-seated philosophy of engaging students with real-world, societal problems, where they become change agents and develop as critical citizens. Thus, similar to PBL, the area of networked learning has strong roots in humanist, emancipatory perspectives of education and critical theory (Hodgson, McConnell, & Dirckinck-Holmfeld, 2012; Jones et al., 2015). This also means it stands out from the sometimes hyperbolic solutionism characterizing parts of the educational technology landscape. As discussed by Jones (2015) and Selwyn (2014) education has always been portrayed as on the brink of a paradigm shift assumedly caused by new technologies. However, in practice changes are often more incremental and slow-paced than the rhetoric surrounding edtech would suggest. Particularly from a PBL perspective it seems odd hearing claims of how technology X will change education to be more student-centered with increased collaboration, as if these pedagogical ideas had been invented along with said technology. The actual progression of fundamentally rethinking relations between learners and teachers within education does not follow automatically from implementing a technology. In fact, new technologies and creative practices are often enrolled in the existing institutional setups and become stabilization mechanisms enforcing the dominant pedagogy already in place. LMS, for example, were envisioned by many hopeful educators to realize more student-centered, collaborative pedagogies. Now they are often positioned as enforcing a teacher-driven, instructional perspective, whereas notions of personal learning environments (PLEs) are viewed as the new techno-liberatory means to realize a student-driven pedagogy. In contrast to the widespread solutionism, networked learning is a field that takes a critical perspective on new and emerging technologies:

> Each new technology is promoted by its advocates as requiring a radical break from the past and the revolution in education is always just around the corner. [...] Networked learning by contrast stands as a critical research-based strand which adopts neither of these positions. Networked learning casts a cold hard eye on the evidence, informed by a set of flexible but robust values that I claim should inform education. (Jones, 2015, p. 3)

The values that Jones is referring to are summarized by Hodgson et al. (2012, p. 295) in the following way:

- Cooperation and collaboration in the learning process.
- Working in groups and in communities.
- Discussion and dialogue.
- Self-determination in the learning process.
- Difference and its place as a central learning process.
- Trust and relationships: weak and strong ties.
- Reflexivity and investment of self in the networked learning processes.
- The role technology plays in connecting and mediating.

Although not everyone would necessarily agree with all of these points, they do reflect a general ethos within the networked learning community (Hodgson, Laat, de, McConnell, & Ryberg, 2014; Ryberg, Sinclair, Bayne, & de Laat, 2016). It is further clear that there is overlap between the values and principles of PBL and networked learning, as also pointed out by McConnell, Hodgson, and Dirckinck-Holmfeld (2012) and Dirckinck-Holmfeld (2016). Self-determination, working in groups and communities, and discussion and dialogue are key principles in both networked learning and PBL. However, the notion of learning together can take many forms: from very strongly tied collaborations where participants are mutually dependent on each other to more loosely tied organizations of work where the connections to others may be weaker, such as inspiration and exchange rather than working closely together as a team.

The principles and values underlying both PBL and networked learning are well-aligned with recent digital technologies referred to as (initially) Web 2.0 and more recently social media, though it should be noted that networked learning is not confined to particular digital technologies. The advent of Web 2.0 tools gave rise to terms such as learning and e-learning 2.0 (Downes, 2005; Redecker, Ala-Mutka, & Punie, 2010) and in general spurred an increased interest in collaboration, self-directed learning, and online communities because of the emerging Web 2.0 technologies' focus on individualized networking, as well as social collaboration, user-generated content, and exchange. Therefore, some of the underlying values of both PBL and networked learning, such as collaboration, self-determination, and learning in communities, were revitalized with the popularization of Web 2.0 technologies and social media. Web 2.0 or social media have equally spawned an interest in PLEs and personal learning networks (PLNs) (Attwell, 2007; Dabbagh & Kitsantas, 2012) as will be discussed in the following sections.

PBL and Collaboration in the Digital Age

This section briefly outlines collaboration processes that are relevant across a wide range of PBL orchestrations and discusses some recent trends that challenge PBL, while also holding some interesting potentials. The section focuses on collaboration, as team or group work seems to be the most commonly shared trait across different PBL orchestrations and because collaboration is equally a key principle within networked learning.

In identifying some central processes of collaboration, which cut across a range of PBL orchestrations, this chapter takes a point of departure in insights generated through studies of long-term, collaborative, student-driven problem-oriented project work. While this type of PBL, which is practiced in Roskilde (RUC) and Aalborg University (AAU) (Andersen & Heilesen, 2015; Holgaard, Ryberg, Stegeager, Stentoft, & Thomassen, 2014; Kolmos et al., 2004) might not be the most widespread or well-known type of PBL, it exemplifies some very complex student-managed collaboration processes. In short, this type of PBL entails that students work with problem-oriented project work each semester and the project accounts for half the credits for a semester. This process lasts for more than 3 months where the students work together in small groups (three to five members) on addressing or solving a self-chosen open-ended problem. This results in a written report (50–100 pages), including potentially a product, which is assessed through an oral group exam lasting between 1 and 5 hr.

This pedagogical model has been practiced in both RUC and AAU since their establishment in 1972 and 1974, respectively. While the models have changed over time and have been implemented with some variance across different faculties, AAU and RUC—after 40 years—remain universities that are strongly grounded in PBL and are internationally well-known PBL universities, together with McMaster and Maastricht Universities.

Such complex and collaboratively demanding forms of PBL can be used to identify work processes that are also part of shorter-lived and less collaboratively intensive forms of PBL. For example, in their paper on virtual project-based learning Tolsby, Nyvang, and Dirckinck-Holmfeld (2002) identify three central collaborative processes: coordination, resource management, and negotiation of meaning. Coordination concerns the organization of work: who is doing what and when. Resource management is about sharing and organizing tools and resources that are part of the work. Negotiation of meaning is the twofold process of continuously debating, discussing, and engaging (participation), as well as deciding and giving form to the decisions and thoughts (reification). Similarly, Khalid, Rongbutsri, and Buus (2012) identified a number of PBL activities: sharing, discussing, reading, presenting, writing, communicating, reflecting, and diagramming, and further relate this to particular tools and different phases in a problem-oriented project work. Hack (2013) maps various literacies to the different phases of the 7-step PBL model (Schmidt, 1983) (clarify terms = locate information; define the problem = identify important questions) and then relate these steps to various Web 2.0 technologies). Dalsgaard and Sorenson (2008) identify four particularly important functions to create a typology for Web 2.0 and learning (dialoguing, networking and awareness making, creating, sharing). Dabbagh and Kitsantas (2012) developed a framework for three levels of social media use ranging from personal information management to social interaction and collaboration to information aggregation and management and suggest particular Web 2.0 technologies and learning activities related to each of those, and across the three levels.

In our own research we have developed a categorization consisting of four categories of work processes (Holgaard et al., 2014):

- inquiry and exploration;
- resource management (sharing, storing, annotating);
- dialogue and communication;
- production (sharing and collaborating).

These four categories are a more detailed unfolding of the "work processes" mentioned in Figure 26.1. Figure 26.2 presents these four categories.

Each of these categories can be more or less student or teacher controlled. For example, a teacher might require students to communicate through a specific system or set limitations or expectations for the inquiry processes. Further, the control of the problem and solution space also affects the work processes more generally. If a problem is determined by the teacher this would lessen the

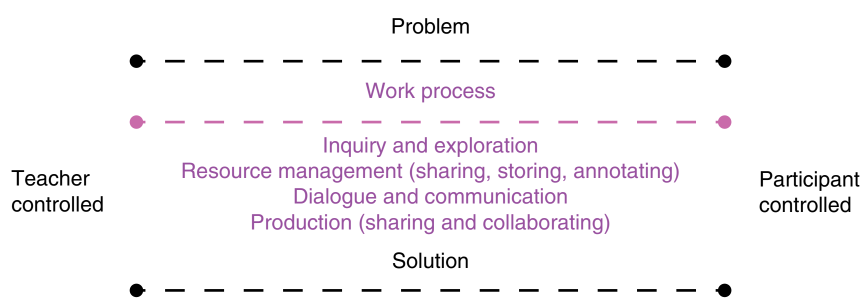

Figure 26.2 Four Categories of Work Processes.

amount of inquiry and exploration and the need to collect and manage resources by the students.

The four categories of work processes are in many ways generic work processes and not connected with particular digital technologies. However, some of the traits of the digital technologies more specifically characterized as social media align well with these categories. Furthermore, as social media are characterized by being both heavily individualized as well as inherently social, they function at different levels of social scale and can bridge individualized and collaborative forms of PBL. This will be explored in the following sections, with a particular focus on PBL group work, although social media can equally support more generally the values and pedagogies in networked learning such as dialogue, discussion, collaboration, networking, and community building.

Different Types of Collaboration and Interactional Dependencies Across Social Scale

What is interesting about social media is their ability to function at different levels of social scale (from an individual to a wider collective) and bridge different types of collaboration (Dalsgaard & Paulsen, 2009; Dron & Anderson, 2014). For example, a social bookmarking service can be viewed from different levels of social scale. It is a highly individualized service where a person archives her own bookmarks. At the same time, she can create groups where she works with others on creating a collection of bookmarks on PBL. She can further connect to other people she has overlapping interests with and follow what they bookmark. In a more abstracted sense the whole service rests on user-generated content, meaning everyone is dependent on others to produce and tag content. Social media are therefore often layered and allow for small-group collaboration as well as a more abstracted sense of everyone who is collaborating to produce content.

Dron and Anderson (2014) have identified different levels of social scale that have varying interactional dependencies. They term these: group, network, sets, and collectives. Groups are people working together on a shared task or object (e.g., a PBL group). The network and sets are looser types of organization where there are shifts in membership and not necessarily one shared objective. Networks are usually personal networks like friends on Facebook, whereas sets could be, for instance, a professional network among teachers or a news group for Star Trek fans. Collectives are the sum or aggregation of individual, uncoordinated actions such as all users collectively generating content. Similarly, Dalsgaard and Paulsen (2009) explore how learning processes can sit in-between collaborative interdependencies and individual engagement, thus alternating between individual learning, cooperating, and exchanging with others, to types of engagements such as PBL group work where participants are mutually dependent on each other (which they term collaboration). In Figure 26.3, these types of engagement are captured as shifts between strong and weakly tied interactional and communicational dependencies combined with the categories from Dalsgaard and Paulsen (2009) and Dron and Anderson (2014).

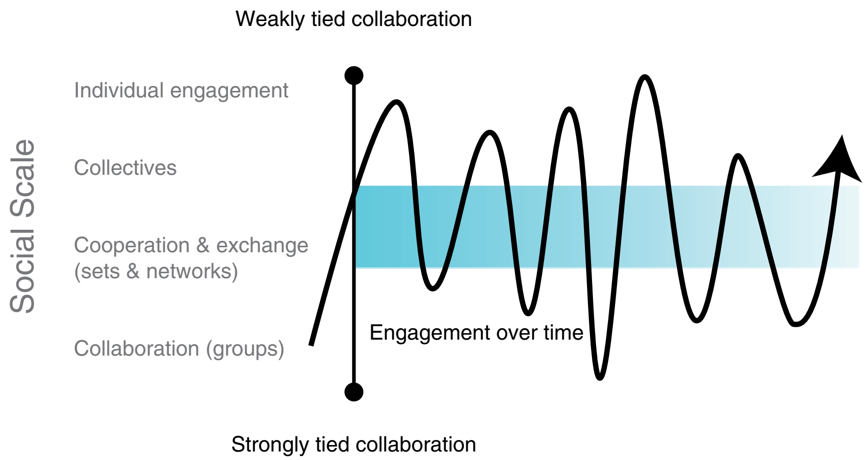

Figure 26.3 Individuals' Shifts Between Strong and Weakly Tied Collaboration.

The middle horizontal layer in Figure 26.3 represents the individual's engagement over time. The vertical axis represents the strength of the collaborative and communicative dependencies with others (ties) and span from individual engagement to collaboration. These are different levels of social scale. For example, PBL in groups requires very high degrees of collaborative and communicative dependencies (strongly tied collaboration), whereas doing minor individual editing on a Wikipedia page happens with little direct interaction or dependency on others (weakly tied collaboration). Thus, the vertical axis expresses the strength of the relationship with others and usually social media facilitate layered engagements. Twitter, for example, allows us to follow and communicate with our best friends, and equally to congregate with an unknown/faceless mass of people around a hashtag. Likewise, Facebook allow us to maintain a social network of friends, as well as collaborating within a smaller PBL group.

The four categories of work processes (inquiry and exploration, resource management, dialogue and communication, production) mentioned earlier can also stretch across the span from individual engagement to collaboration. Inquiry or production processes can be more or less dependent on others and often we switch dynamically between these types of social scale (working alone to working with others). While this chapter is not meant as a practical tool guide, some examples of contemporary uses of social media can be useful for illustration. However, we should remind ourselves that technologies are often short-lived and remain attentive to the underlying processes of work that are more generic.

In the current landscape of PBL as permeated by digital technologies and social media the mastery of contemporary and emerging technologies are part of the process of being a PBL learner or facilitator. It concerns the ability to navigate and establish PLNs and PLEs that support the four work processes mentioned in the previous section, while being mindful of at what times particular types of collaboration (strong or weakly tied) are important.

Inquiry and Exploration

Inquiry and exploration processes involve exploring the problem space one is working with. Whether the problem is given to or should be formulated by the students, there is usually a need to consult and collect more knowledge to contextualize a problem. If all the material were already available to students, this would defy the purpose of PBL. In terms of digital technologies, the area of information search is what immediately comes to mind. Obviously, students need to be capable of information search and using library databases to conduct a literature review. However, from a social media perspective the challenge is also to establish a PLN and become knowledgeable about other types of resources that are available outside the professionally curated spaces of the libraries and the formal educational spaces. Examples of these resources are: social networks and academic networking services (Twitter, Researchgate.net, Academia.edu) and resource-oriented networks (Zotero, Mendeley, Diigo).

As explored in the previous section, social media are layered services that work across different levels of social scale and allow the individual to form different types of social networks. Such social networks can be used to compose PLNs (Dalsgaard, 2009; Haythornthwaite & de Laat, 2010; Ryberg & Larsen, 2008). PLNs and social networks are not novel. However, their visibility, availability, and their digital materiality are of a more recent nature. The social networking site Twitter is an example of a potential learning network. Here users can follow each other and post tweets others can reply to, quote or retweet. While Twitter can be used to follow pop-stars, politicians, and comedians, many researchers have begun using Twitter for professional purposes and to disseminate knowledge (Stewart, 2015). Likewise, academic social networking sites such as researchgate.net and academia.edu are sites where students and researchers can connect to other scholars and upload or comment on papers. Similarly, there are services where researchers and others share and build bibliographies or social bookmarks, as will be explored in the next section.

Thus, in relation to students' PBL processes of exploration and inquiry, information search in library databases and search engines can be extended to include exploration of relevant social networking sites as a part of constructing a PLN. These engagements span the continuum of collaborative and communicative dependencies. For example, there might be smaller private PBL groups sharing resources, which require access or membership, but PBL learners can equally traverse a whole network to find multiple resources. In PBL groups the individual members can use their different learning networks or resource persons and engage in individual exploration that feeds back into the group's shared repository. We can think of it as rhythmic pulsations where the members set out to explore their extended learning networks and then return home with refreshed perspectives and new information.

Resource Management: Sharing, Storing, Annotating

Another important aspect of collaborative and individual PBL processes is the management of resources. This includes storing, sharing, and annotating references, bookmarks, documents, and pictures. This is relevant both at the group and individual level. For the group, proper management of resources is important to complete their work, and for the individual it is important to create personal resource repositories for future work in other groups. There is a vast number of social media tools learners can use to store and share an equally vast number of different types of resources. Some examples are:

- notes, clippings, bookmarks (Evernote);
- images (Pinterest, Flickr, Instagram);
- social bookmarking sites (Diigo, Delicious);
- bibliographic reference managers (Zotero, Mendeley);
- file sharing services (Dropbox, Onedrive).

Most of these services are layered and allow for sharing and annotation at different levels of social scale: from the individual to a small PBL group to a wider network of people. Thus, across a student cohort the students could choose to maintain a group for sharing relevant resources, and they could create smaller online groups for sharing resources related to their PBL group work. Consequently, learners can create and draw on networks of different social scale and levels of interactional dependencies in retrieving relevant resources. These can potentially provide more diverse and rich networks for the individual student (Dalsgaard, 2009; Ryberg & Wentzer, 2011). For example, Ryberg, Davidsen, and Hodgson (2018) report how groups of architecture and design students at AAU use Google+ and Pinterest to share design ideas and inspiration across all groups in a semester as well as for internal collaboration in the smaller project groups.

Dialogue and Communication

In relation to group work, digital technologies and social media add a level of flexibility. Learners can potentially work in groups where they never or rarely meet physically. For PBL groups who do meet on a regularly basis, digital technologies extend the communicative flexibility of the group so they can communicate asynchronously in-between the physical meetings or meet synchronously online. Additionally, groups can use various digital technologies and social media to organize the work and manage tasks over time. Examples of digital technologies and social media supporting dialogue and communication include:

- messaging on Twitter, Slack, or Facebook, texts, e-mails;
- video or audio calls (Skype, Google Hangout, Adobe Connect);
- forum/discussion boards and blogs (Facebook, Moodle, Discourse, Wordpress);
- shared calendar, project management tools, and to-do lists (Google Calendar, Kanbanflow, Trello).

Most of the services work across social scales as they support one-to-one communication as well as many-to-many communication. Forums can be used by smaller groups or they can be used to communicate across an entire cohort. For example, at AAU students often use Facebook groups to communicate in their smaller project groups but simultaneously have a Facebook group for the entire class. While synchronous meetings are good for dialogue and instant coordination, PBL groups can also use asynchronous tools, such as forums, shared calendars, or to-do lists, as a way of maintaining and keeping a record of the communication that documents what the group agreed on, who is responsible for what task, and what is the timeline for completing the group's tasks. Such a shared record can also help the PBL group reflect on their problem-solving process and how their understanding of the problem has developed over time. The need for communication and coordination among the students in PBL groups is related to the complexity of the problem and the duration of the project work. Shared calendars or online project management tools are particularly relevant for PBL groups who work on longer-term and more complex projects.

Production: Sharing and Collaborating

An important part of group work (if there is a collaborative product as part of the PBL process) is the co-production of texts or other outputs (code, models, or designs). In this regard, cloud-based word processing tools or file sharing services are relevant. For example, these types of service include:

- online collaborative writing tools (Google Docs, Microsoft 365, Etherpad.org);
- file sharing and synchronization services (Dropbox, Google Drive, OneDrive, ownCloud).

Online collaboration writing tools are services where smaller or larger groups of people can edit a document simultaneously. They allow learners to share documents online and offer collaborative writing in the same document. Thereby, they reduce the need for version management as everyone is always working in the document. Thus, these systems allow for parallel or synchronous writing. File sharing or file syncing services allow learners to share files and folders that are synced and updated across all devices after one of the members saves a file. However, they support primarily serial or asynchronous writing. For example, two members are not able to work on the same document simultaneously without creating conflicting copies.

Regardless of their technological affordances, collaborative writing tools require common norms for editing in a group. Even if all members can technically edit all parts of a document, issues can arise regarding who is allowed to edit which sections of a document. Groups must therefore make decisions as to whether the document is a collaborative whole or whether some members are main authors of particular sections and chapters (and perhaps there are institutional requirements in terms of visibility of authorship). These are PBL group work challenges that not only concern collaborative writing, but the adoption of any technology for group work. As discussed in the next section, it is not only a matter of using new tools—it is equally a matter of adopting new and perhaps unfamiliar practices.

Potentials and Challenges

The preceding sections have very briefly outlined different ways in which digital technologies and social media can—and already—support PBL group work and how they can realize networked learning pedagogies and values, such as collaboration, community building, discussion, and dialogue. The aim of those sections was not to give a thorough introduction to technologies that can support various types of PBL or networked learning, but to outline some generic work processes that underpin many different orchestrations of PBL. These orchestrations can differ in the temporal extension of the collaboration (a day, a week, or months), whether students are required to deliver a shared product, and who defines the problem or the ways of working as outlined in Figure 26.1. For example, PBL groups that are working together for shorter periods of time might not need project management tools or shared calendars. Additionally, a facilitator might enforce the use of certain tools or provide materials that would lessen the need for students' exploration of wider literature or for file sharing tools.

Regardless of these differences, there are obviously potentials for using digital technologies and social media in PBL groups and there are clear links between the fundamentally collaborative and social dimensions of social media and PBL. It is also evident from research within AAU that students are already using social media to support their problem-oriented group work (Davidsen & Ryberg, 2016; Guerra, 2015; Khalid et al., 2012; Rongbutsri, Khalid, & Ryberg, 2011; Ryberg, Buus, & Georgsen, 2012; Ryberg, Davidsen, & Hodgson, 2018; Ryberg & Larsen, 2012; Thomsen, Sørensen, & Ryberg, 2016; Tolsby, 2009). These studies show that, while certain tools and services are omnipresent in students' work (Facebook and Google Drive/Docs), the academically oriented services such as bibliographic reference managers or social bookmarking tools are less common. On the one hand, the studies show students are conservative and stick to tools they know well rather than exploring new options. On the other hand, when conducting more detailed observations of how actual groups use the tools, the studies uncover a wealth of interesting and creative ways of using technologies (Rongbutsri et al., 2011; Tolsby, 2009). Additionally, these studies reveal that students' practices vary within and across groups, programs, and semesters. For example, some groups use Facebook only for messaging, whereas other groups use Facebook for lengthier discussions and file sharing; others prefer to use Dropbox for filesharing, and yet others use Google Drive for that purpose. While many groups use Google Docs for collaborative writing, they may adopt very different strategies. Some students prefer working on their own and add only finalized texts in a shared document. Others write in parallel and transparent to each other (Andreasen, Winther, & Hanghøj, 2014).

What can be gleaned from these studies is that we can learn a great deal from the students' creative practices, but also that students need help and support to develop good academic and scholarly practices in the use of these technologies for PBL. This somewhat contradictory situation is a stepping stone for development.

Potentials: Co-Development and Mastery of New Emerging Practices

Building on the more critical networked learning perspective it was stated earlier that new technologies do not automatically change practice, and that we should put pedagogy first when designing curricula and learning interactions. However, it is also clear from the preceding sections that new practices are emerging among students and researchers because of digital technologies and social media. For example, PBL group work is changing, as it is becoming increasingly a hybrid between face-to-face and online collaboration. Nevertheless, from a networked learning perspective we need to keep in mind that technologies do not unidirectly and automatically cause qualitative changes. Rather, changes unfold from students' and researchers' co-development and mastery of new practices with technology. More than thinking of technologies as tools to learn, we should direct our attention toward developing new scholarly and academic practices with the technologies. Forming online personal networks, sharing and disseminating research is not only a matter of appropriating particular tools and technologies. Rather, it is a new way to engage with the public, students, and other researchers, something that some scholars refer to as digital or open scholarship (Weller, 2011) as an extension to traditional scholarship. It is a new way of practicing being an academic. Likewise, mastering Google Docs is not limited to knowing its technical capabilities; rather it is the mastery of collaborative writing at scale: how to orchestrate and coordinate collaborative writing in a small group or large network and accepting, improving, and discussing other's input. Even the act of writing together might be alien to many students, who have grown up in a heavily individualized school system with little textual co-production or group work. From a networked learning perspective, it concerns developing more open, distributed, and collaborative scholarly practices with technology.

Here lies a grand challenge of how we can help students in developing the relevant competences for working together in a new digital and hybrid landscape consisting of multiple tools and spaces. PBL groups no longer necessarily occupy the same physical space when working together and, even if they do, they might be working apart or with others in their wider learning network. Their work has become distributed across time and space(s). It is multilayered and extends beyond the smaller group and into wider networks and collectives. These are changes in the PBL landscape that a networked learning perspective can help us grasp and develop.

At AAU, such challenges are being addressed in various local initiatives. For example, in the program "Communication and Digital Media," first semester students are working in Google+ in an attempt from the facilitators to increase transparency and collaboration among students. Students have been asked to share smaller collaboratively written group exercises with the entire cohort, annotate text online in their group, and make it available to others. The intention is to help students develop new academic practices with technology (e.g., reading and annotating text together) (Davidsen & Ryberg, 2016). In addition, the same first-semester students participate in a 1-day course on information and communications technologies (ICT) and PBL study practices underpinned by networked learning and PBL principles. This course is designed by fifth-semester students in the same program, who spend 6 weeks planning and carrying out this mini-course (as part of a course where their project is to develop a learning design). The aim is that the fifth-semester students—together with facilitators/researchers—use their own experience in developing and reflecting on academic practices with digital technologies and social media, which they subsequently present to the new students. This has been one way to work with the development and mastery of emerging networked learning practices, such as community building, dialogues and reflexivity, and investment of self in the learning processes.

However, as will be discussed in the following section, there are also challenges arising in the landscape of PBL in a digital age. These include commercialization of educational spaces and tools; solutionism and hype within edtech, and the fragmentation of collaboration.

Challenge: Commercialization of Educational Spaces and Tools

What should stand out from the previous sections of this chapter is how social media services are already penetrating and underpinning higher education and PBL practices. When adopting a more critical networked learning perspective, it becomes clear that many of these services are commercial giants or eager venture startups that lie well outside any form of institutional control. Many social media were not built with an educational purpose in mind and some authors have voiced vocal critiques of social media as heavily commercialized spaces living off conviviality over dissent (Friesen & Lowe, 2012) or as spaces ill-suited to argumentation and academic discussion (Kirschner, 2015). More perhaps than drawing the eyeballs of the users toward academically interesting content the underlying algorithms and concepts might be more attuned to presenting commercial content (while capitalizing on harvesting the users' digital footprints) (Friesen, 2010). In addition, many of social media services have terms of service that cause some people to shy away from using them due to privacy concerns. Venture-funded startups may live or die and can unexpectedly change the underlying rationale for their service. Even Google has a history of discontinuing popular services and the once user-driven Mendeley service for sharing bibliographic references was taken over by Elsevier—a company that many academics dislike due to their lobbying against open access. In contrast, academic social networking sites such as academia.edu and researchgate.net tout open access and encourage academics to share papers in their repositories based on opaque business models, which are at odds with traditional publishers as papers are made available outside the paywall of journals while being legally under copyright of these.

The argument here is not that education should be a noncommercial zone. Rather that the commercial interests within education have become more layered and complex. Questions to consider include: Are there unseen costs and drawbacks of using popular and easily available services such as Google Docs or Facebook? Do institutions have a responsibility to ensure students have access to safe storage of files or can we leave that responsibility to the students' choices of technology? Should we as PBL facilitators adopt tools in our teaching that may suddenly be discontinued, or have nefarious policies for data sharing? How do we manage students' use of file sharing services in which it may be illegal to share certain kinds of information because the servers are outside EU jurisdiction? Should institutions provide alternatives?

These are questions that cannot be easily answered. However, it is important that educators and institutions play a more active and critical role in provoking critical reflections on the tools and infrastructures we use in higher education. Particularly as many of these technologies and services are oversold and hyped.

Challenge: Solutionism and Hype Within Educational Technology

As mentioned previously, education has always been on the brink of a major disruption or paradigm shift with the coming of new technologies: radio, TV, internet, social media, MOOCs, big data. These have all been envisioned to become game-changers that would disrupt education. However, education has in many ways proven remarkably resistant to change; or changes are more incremental than the rhetoric surrounding new technologies would suggest (Jones, 2015; Selwyn, 2014). Jones (2015) discusses MOOCs as an example of solutionism where a new technology is proposed as a solution to the recurrent theme of education is broken, and where an alliance of Silicon Valley venture capital, Ivy League universities, and tech companies stepped up to solve the problem. However, as Jones argues the 2012 xMOOCs were not particularly innovative from a pedagogical or networked learning perspective, but they fit well into the currents of time:

> The rise of MOOCs in terms of public attention and large-scale implementation coincided with the adoption of austerity policies in advanced industrial countries following the financial crash of 2008. This coincidence has meant that MOOCs have been incorporated in agendas that are focused on the reduction of cost, both to the prospective student and to the public purse. […] The MOOC moment fitted into a more general debate amongst policy makers that advocated a particular kind of educational reform based on the identification of new technology as a source of "disruptive innovation" that could lead to "unbundling" the university. (Jones, 2015, p. 130)

This reflects that there is a strong external push from (new) businesses that are interested in entering the market for educational technology and are doing so by tapping into the vocabulary of disruption, paradigm shifts, and solutionism. This is mentioned as it is particularly important within the field of PBL. Innovative learning does not flow from technology alone. Pedagogical innovation requires radical pedagogical ideas. Many PBL principles and orchestrations of PBL in higher education are radically different from how teaching and learning is often organized, and we should not forget that PBL and ideas of progressive education (based on Dewey, Vygotsky, and Freire) have flourished and developed outside the influence of the edtech circuit. In line with Jones (2015) and Selwyn (2014) we need to put stronger effort into understanding, critiquing, and reflecting on the politics of educational technology; and with their roots firmly grounded in critical perspectives the fields of networked learning and PBL are fertile areas for such discussions.

Challenge: The Fragmentation of Collaboration

The previous sections have highlighted how social media can enable PBL groups to work across different levels of social scale as illustrated in Figure 26.3. Further, we are witnessing the emergence of two new forms of work and collaboration due to these sociotechnical changes, namely PLNs/PLEs and mass collaboration. These are two modes of work and learning students and researchers will need to master, while they are also challenging the notion of tightly knit collaboration essential in some types of PBL (Ryberg et al., 2012).

As argued it will be increasingly important for researchers and students to be able to create PLEs and PLNs, to become critical learners in a digital age. There are undoubtedly learning potentials in the ego-centric learning networks formed through social network sites and through traversing, harvesting, and contributing with information, ideas, and resources. For example, they can encourage students to become self-directed learners. However, while there are many strengths and potentials to these modes of learning, PLEs are underpinned by heavily individualized notions of learning, which challenge the collaborative aspects of PBL. Dirckinck-Holmfeld and Jones (2009) building on Weller (2007) have suggested that a strong focus on PLES might erode the commonality of experience, lessen the exposure to different approaches, and rely on the harvesting of personal or private data. The following quote captures these thoughts:

> PLEs may encourage a narrow private view that is resistant to change and encourage a "customer" focus that relies on consumer choice of educational goods that are often not appreciated until after the educational experience has taken place. (Dirckinck-Holmfeld & Jones, 2009, p. 264)

As Ryberg et al. (2012) argue, PLEs can be a means to engage in mutual inquiry, reflexive dialogue, and problem-based and collaborative activities. Simultaneously, we should be aware that the social and collaborative aspects of PLEs/PLNs are often seen from the viewpoint of the individual. The focus is the individual's retrieval of content from their networks rather than the mutual construction of knowledge.

At the other end of the scale we are seeing the emergence of mass collaboration. Mass collaboration is a more diffuse, uncoordinated mass of people contributing individually or in clusters to sustained or more ephemeral constructs. Examples of sustained mass collaborations could be Wikipedia pages or the development of open source software. These examples allow for both more permanent as well as temporary contributions and collaborations. For example, multiple people can independently add to a Wikipedia page. Some might find pleasure in going through all Wikipedia pages to enforce the Oxford comma, whereas others favor contributing to a specific knowledge area together with others. The point is that a common resource is built through multiple contributions across different levels of social scale that are not necessarily centrally coordinated. This has been referred to as stigmergic collaboration by Elliot (2006), who distinguishes this type of mass collaboration from small-group collaboration ($n < 25$) and from co-authoring:

> The use of stigmergic communication to sidestep social negotiation effectively fast-tracks the creative gestation period, removes social boundaries and as a consequence lowers the "costs" of contribution by eliminating the need to become acquainted with and maintain relationships with fellow contributors. (Elliot, 2006, para. 13)

Elliot does not suggest avoiding relationship with fellow contributors is a positive thing, but that it enables stigmergic processes. Similarly, we can think of the process of sharing and tagging social bookmarks as a kind of stigmergic collaboration where each contributor adds to the quality and richness of a site by their small contribution.

Mass collaboration can also be of a more ephemeral nature where there is a short-lived activation of massive participation across many networks. For example, multiple people congregating around a particular hashtag such as #academichipster where people can tweet about what an academic hipster might be: “Was going to contribute to #AcademicHipster but now it’s too mainstream” (MacInnis, 2016). Such a hashtag may gain massive traction over a few days and then slowly melt, thaw, and resolve itself into a dew.

Mass collaboration has many strengths and potentials, and as facilitators we could engage students in production of knowledge resources for the common good: involve large groups of students to contribute to a shared manifest on teaching in the twenty-first century or implement large-scale PBL where students work across borders on grand challenges that are too big for one group to tackle in isolation. However, the quality of contributions in mass collaboration products can be difficult to judge and it would be difficult to gain an overview of the diffuse and chaotic work processes. For example, how can and should one contribute? Is a Wikipedia page of high quality? Is a site trustworthy and good because many have stored it on a social bookmarking service? Furthermore, the notion of collaboration does become quite stretched, and for this type of collaboration it might be difficult to support a deep and engaged learning dialogue or mutual exchange and exploration of a topic. Mass collaboration might at times become multiple, isolated contributions that leave little room for communication, dialogue, and thinking and doing together. This, for instance, has been a critique of some MOOCs (xMOOCs) that might be massive in numbers but where there is little organized collaboration and exploitation of the massive participation. Thus, their design seems to reflect a traditional notion of flexibility within distance education where learners engage on their own and at their own pace. This format of online education is a challenge to many conceptions of PBL where collaboration and exchange is central. A promising and interesting opportunity in this regard could be MOOCs built on PBL and networked learning principles. Perhaps what we could term COOPs (community-oriented open projects), where groups and networks of students engage in open cooperative or collaborative inquiry supported by experts. These could feature practice-based research, be change-oriented, and emphasize collective reconstruction of sociomaterial practices over individual acquisition of knowledge. For example, large numbers of student groups working with real-world problems such as poverty or climate change mediated by digital technologies and social media.

Concluding Discussion

This chapter has argued that PBL is a pedagogical philosophy or a set of pedagogical principles that can be applied in a variety of ways, particularly differentiated by the autonomy or power delegated to the students in terms of ownership over the problem, the work process, and the solution space. Further, some of the central principles of PBL are: authentic real-life problems; active engagement involving research activities, decision making, and writing; high degree of autonomy and responsibility for own learning; and group and collaborative work. These principles align well with the research area of networked learning and with the concepts that are heralded along with social media (such as user-generated content, collaboration, networking, and sharing). The chapter presented a framework for understanding PBL work processes through four categories: inquiry and exploration; resource management; dialogue and communication; and production. A discussion and description of how various digital technologies and social media can support these processes across different levels of social scale was provided.

In conclusion, there is much potential in working with social media to support PBL group work, but there is also more to be learned about how students (and researchers) can use these tools to support and qualify collaborative work processes. Specifically, how can synchronous writing support qualitatively better collaboration in a PBL project? How should students alternate among various meeting forms during their work? How can students maintain and build common resources that are useful for both the group as well as the individual? Furthermore, tensions surrounding the increasing adoption of social media among students (and staff) have been discussed, such as the commercialization of educational spaces and tools; solutionism and hype within edtech; and the fragmentation of collaboration.

There are some observations that should be drawn out. As a research community we should remain vigilant in maintaining a strong grounding in the pedagogical principles of PBL. This becomes particularly important in relation to integrating digital technologies and social media as there is a tendency of hype and solutionism within educational technology where new technological solutions are valued over pedagogical resourcefulness in bringing about educational change. This tendency to solutionism has a longer history, but the increasing commercialization of educational spaces seems to aggravate these tensions when technological innovations such as MOOCs, big data, and social media are framed as game-changers. However, they often come to enforce quite traditional, instructivist modes of learning and teaching. Therefore, we need to ground our PBL thinking in established, critical, and reflexive theories within educational technology such as the area of networked learning. We need to make sure that pedagogical philosophies and principles, as well as critical thinking and theory, become the drivers of educational innovation, rather than technology-driven solutionism. It has further been argued that change unfolds from students' and researchers' co-development and mastery of new practices with technology. Therefore, we should direct our attention toward developing or emerging new scholarly and academic practices with the technologies.

There are great opportunities for supporting novel forms of PBL with digital technologies. However, there are also challenges to central pedagogical ideals in PBL. If we conceive of PBL as a pedagogy building on strongly tied collaboration and mutual engagement among the participants, then highly individualized notions of personalized learning, PLNs, and PLEs can potentially challenge this mode of work. Likewise, mass collaborations have interesting potentials as a form of work and communal learning, although this type of collaborative engagement runs the risk of becoming isolated and built on individualized contributions with little room for co-construction of knowledge or dialogue.

Thus, a central challenge in the years to come is how we mediate between and knit together the individualized PLNs of students with a strong commitment to mutual development of knowledge and dialogue in tightly knit collaborative groups, as well as facilitating students' engagement in meaningful larger scale or mass collaborations. This includes developing pedagogical formats and designs where students alternate and switch between these types of engagement either as part of PBL processes, or as distinct modes of PBL at different levels of social scale. Reflecting on and designing for these new modes of collaborative engagement are important to ensure that PBL remains an important learning experience in a globalized, networked world. In this endeavor, the research and insights that have been generated within the field of networked learning can supplement and complement research into PBL.

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27

Project-Based Learning and Computer-Based Modeling and Simulation

Shelby P. Morge, Sridhar Narayan, and Gene A. Tagliarini

Introduction

When considering the integration of technology and project-based learning (PBL), resources such as blogs and wikis, videoconferencing tools such as Skype, and collaborative tools such as Google Apps for education are commonly mentioned (Partnership for 21st Century Learning, n.d.). However, the use of computers for modeling and simulation (M&S) in support of PBL is less readily recognized. This is counterintuitive given that computer-based modeling activities lend themselves readily to open-ended inquiry, require students to learn experientially, provide students considerable leeway in selecting a path toward a desired outcome, encourage collaboration, and result in artifacts that demonstrate student learning—all of which are attributes of PBL.

In this chapter we demonstrate how computer-based M&S can serve as a powerful complement to PBL. The role of computational thinking (CT) in the development of computer-based M&S is discussed. Three examples of generative modeling environments are introduced and their strengths and limitations demonstrated by application to problems from a variety of science, technology, engineering, and mathematics (STEM) disciplines. These specific problems model the physical properties of a rolling, falling, and bouncing ball, the epidemiology of a viral outbreak, and swarming, flocking, herding, or schooling behavior. The models show various degrees of scientific fidelity applied to each of the problems. Unlike other technology tools that may be relatively simple and hence intuitive, computer-based modeling tools can present a significant learning curve to both the teacher and the student. The chapter concludes with a discussion of important factors that need to be considered in practice, for example when computer-based M&S is used in the classroom.

The color versions of all the figures referenced in this chapter can be found online at this URL: http://people.uncw.edu/narayans/WileyPBL/figures.html

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STEM

In traditional STEM instruction, science, technology, engineering, and mathematics are often taught separately and without connections. However, research has shown that students understand things better when they are able to build upon existing knowledge and make connections (Van de Walle, Karp, & Bay-Williams, 2013). Current standards and expectations call for investigations and integration in order for students to develop interest in STEM fields and long-term understanding of STEM content (National Research Council, 2011). Present-day STEM education initiatives support the transformation of the typical teacher-centered classroom by encouraging a curriculum that is driven by real-world problem solving, discovery, exploratory learning, and requires students to actively engage in finding solutions, similar to the real-world work of scientists and mathematicians. This shift in instruction is supported by the integration of technology that provides creative and innovative methods for problem solving, application of content, and presentation of findings (Fioriello, n.d.; Successful STEM Education, n.d.). The classroom environment that incorporates this type of instruction corresponds well with the PBL methodology.

PBL

PBL is viewed as an appropriate instructional methodology to support STEM education because it is organized in such a way that students gain knowledge and skills by working for an extended period of time to investigate and respond to an engaging and complex question, problem, or challenge. The challenging problem or question makes learning meaningful for students because it incorporates real-world topics that span, and thus connect, subject areas. Other important elements of PBL include group work, authentic assessment strategies, and student voice and choice in the problem-solving process (Larmer, 2014; Larmer & Mergendoller, 2015). Effective PBL requires teachers to “let go” and support student learning on an as-needed basis through mini-lessons and guiding questions instead of telling students each step to take in order to solve the problem. This opens the door to student inquiry and gives students ownership of their work. Studies have shown that when implemented well, PBL can increase retention of content and improve students’ attitudes toward learning (Vega, 2012). In a summary of meta-analyses, Strobel and van Barneveld (2009) indicated that PBL is more effective than traditional instruction when it comes to long-term retention, skill development, and satisfaction of students and teachers.

Teachers planning and implementing PBL in their classrooms are engaged in problem-based teaching practices such as: design and plan, align to standards, build the culture, manage activities, scaffold student learning, assess student learning, and engage and coach (Larmer & Mergendoller, 2015). Savery and Duffy (1995) explained that students engage with the problem, generate ideas and possible solutions, determine what they currently know and do not know, establish learning goals, conduct research to acquire knowledge and skills needed to develop a solution to the problem, reflect on the problem using the new information, and reflect on their problem-solving process. There may not be uniform agreement on this problem-solving process, but our experiences implementing PBL with students (Moallem, Morge, Narayan, & Tagliarini, 2016) have led us to believe that PBL involves the following seven steps. We note that this is typically a repetitive process, especially for Steps 3 through 5.

1) Read the problem statement.
2) Research the topics in the problem statement. Addressing such questions as: What are important variables to consider when modeling this problem? What should I include or leave out?
3) Develop a plan to solve the problem.
4) Construct the problem space by building the model.
5) Test the model.
6) Make recommendations to answer the original problem.
7) Reflect on the solution and problem solving process.

One way that students may engage in this process is by using computers to complete research and develop their model.

Computer-Based M&S

The terms modeling and simulation are often used interchangeably. The field of M&S is particularly interested in models that are used to support the implementation of an executable version on a computer. Modeling may be described as the purposeful abstraction of reality, resulting in the formal specification of a conceptualization and underlying assumptions and constraints. The execution of a model over time is understood as a simulation (Banks, 2010). Students are often involved in the development of their own models or they work with existing models to test ideas and determine results. M&S complement PBL because they allow the user to work with and explore environments that may not be easily accessed in the traditional classroom setting, such as disease propagation, or the launch of a projectile. In addition, M&S support teachers in meeting the various needs of their students because they often offer many different representational formats including diagrams, graphics, animations, sound, and video (Eskrootchi & Oskrochi, 2010).

Although models and simulations can be interesting and engaging, they cannot work on their own to address all students' learning needs. The use of M&S within the context of PBL requires careful planning and implementation by the teacher. Teachers must design or find a suitable real-world problem that addresses STEM content objectives and plan appropriate scaffolding to support student learning and authentic assessments to analyze student learning. This requires the teacher to possess both strong content knowledge and a keen awareness of students' abilities. In the context of two projects involving middle and high school STEM teachers and their students, Using Squeak to Infuse Information Technology (USeIT) and Integrating Computing in Mathematics Education (INCOME), Moallem et al. (2016) found that students who were challenged by their teachers to think about targeted mathematical and scientific concepts developed higher-quality final projects. The students also mentioned learning specific mathematical and scientific concepts in their daily reflections. Thus, pedagogical content knowledge, or teachers' interpretations and transformations of subject matter knowledge in the context of facilitating student learning (Shulman, 1986) is as important as knowledge of content. Hennessy (2006) claimed that successful technology use and effective student learning of science is dependent on the teacher's knowledge of the technology, and how a particular tool is best utilized for particular purposes, classroom or laboratory settings, and students. As teachers use their knowledge to support students in the use of computers with PBL, they both engage in CT.

CT

The phrase "computational thinking" (CT) was first used by Papert (1993) and later popularized by Wing (2006). CT refers to problem-solving approaches commonly applied by many, including computer scientists, who seek to solve problems by using computers. CT exploits multiple dimensions of problem abstraction for the purpose of automating solutions by using computers. Elements of problem abstraction that arise during problem solving include decomposition, modeling, and representation. Additional abstractions appear as one formulates algorithms for finding solutions or as one applies recursive analysis to the problem. Once a problem has been formulated and candidate algorithms for finding solutions are identified, one must design, implement, deploy, and maintain a computer system that automates the process of providing solutions. Cuny, Snyder, and Wing (as cited in Wing, 2010, p. 1) describe CT as the "thought processes involved in formulating problems and their solutions so that the solutions are represented in a form that can be effectively carried out by an information-processing agent." The combination of PBL and M&S encourages students to engage in CT.

Blending CT, M&S, and PBL

Current reform initiatives in education have established that one of the goals of education is for students to think critically. When computer-based M&S is paired with effective PBL strategies, students are provided the opportunity to engage in the CT needed to solve the problem posed. This partnership between the user and technology allows for deep qualitative effects on how problem solving occurs (Lebow & Wager, 1994). When investigating the use of PBL with a technology-rich science project, Eskrootchi and Oskrochi (2010) found students who participated in the manipulation of the experimental model and simulation performed best on understanding the science concept (watershed) and showed positive attitudes. Basu et al. (2016) also found that students who engaged in CT with middle school science curricula using CTSiM (a learning environment where students learn their science by building and simulating models of science phenomena) showed significant learning gains on pretest–posttest scores in science domains like kinematics and ecology.

Students who experience PBL seek solutions to complex, open-ended, real-world problems by creating abstract analytical models of the problem domain and then implementing those models as computational prototypes for study. Thus, the study of a problem leads to a model representation, which is amenable to automation through a computer program. In our experience (Moallem et al., 2016), students who developed computer models in PBL contexts could explore various input combinations and behaviors of the system by revising their model to respond to various input combinations in a safe environment. Our analysis of student-created PBL projects suggested that when students were given a challenging problem to solve, were provided appropriate time to think, plan, design their model, then evaluate it, and were further challenged by their teachers to apply mathematical and scientific concepts in their model, they not only showed interest and high engagement in their own learning, but they also constructed a much deeper understanding of STEM concepts. The students' processes of developing models using computers also showed that when they were guided and had received proper scaffolds, they showed improvement in their thinking and problem-solving abilities. In the next section we share examples of projects that integrate M&S, PBL, and CT.

Illustrative Examples of M&S, PBL, and CT

Numerous tools are available to support computer-based M&S. They range from the ubiquitous Excel spreadsheet, to modeling environments targeted at young learners such as Squeak Etoys, Alice, and Scratch, to general purpose programming languages such as Java or Python, to specialized agent-based modeling (ABM) tools such as NetLogo (Wilensky & Rand, 2015). In this section we briefly demonstrate the use of three different modeling environments, namely Squeak Etoys, NetLogo, and Python, to develop example simulations for three representative problems from STEM disciplines: rolling ball (physics), disease propagation (epidemiology), and swarming (biology). We share a possible PBL problem, expected product, high-level instructions on creating a simulation in a given modeling environment, and the CT in which students may engage.

The three modeling environments presented here are merely representative examples of the wide variety of environments available. Their inclusion here can be attributed to the authors' familiarity with the environments, and does not automatically constitute a recommendation of the environment or its suitability for any particular activity. The decision to adopt an environment can only be made by a teacher following a careful, hands-on evaluation of an environment of interest, and an assessment of its suitability for a proposed activity with a particular audience. See the Appendix for more information about the environments used in this chapter. As with the modeling environments, the three modeling activities presented here are merely representative examples of the myriad modeling activities that are possible. They do not constitute a tutorial on the use of a modeling environment, nor do they represent a complete implementation that is ready for use in a classroom. While broadly based upon the Seven Step PBL process outlined earlier, these examples do not include exhaustively detailed instructions for teachers on how to implement the activity in a classroom environment because that would require specialized knowledge of the content being taught and individual students in the class. Furthermore, the first example is more fully developed to illustrate the iterative nature of the M&S process as it incorporates increasing levels of scientific fidelity. Finally, the descriptions of the modeling activities include snippets of computer code that are necessary to convey a sense of the complexity inherent in computer-based modeling and the maturity required to use a particular modeling environment. While technical details are minimized to ensure that the work remains accessible to a wide audience, removing all technical detail would do a disservice to the reader by giving a false impression of the challenges of integrating PBL with computer-based M&S.

Example 27.1 Modeling and Simulating Gravitational Effects Using Squeak Etoys

Step 1. Problem Statement

In order to position recovery vehicles, the National Aeronautics and Space Administration (NASA) seeks to anticipate the re-entry trajectory of a man-made satellite by creating a model and a computer simulation that will enable the mission team to study re-entry and evaluate various mission options.

Step 2. Research the Topics in the Problem Statement

Since numerous physical interactions may affect a satellite's re-entry trajectory, one may decide to begin by approximating the path by progressively including more of the influences. One might reason that, while in orbit, the satellite is similar to an object on a table. However, since the satellite is in motion, the trajectory might be more like an object moving across a table top. When the satellite is brought down from its orbit, the path it takes should be similar to that of a ball rolling off a table and then falling toward Earth. Further, upon re-entry the satellite would experience resistance from the atmosphere, so one may elect to model various degrees of resistance. Thus, depending upon the level at which this project is used, students may need to explore such mathematical and scientific concepts as coordinate systems, gravity, motion, friction, mass, elasticity, or acceleration.

Step 3. Develop a Plan to Solve the Problem

This first example project entails modeling and simulating a rolling, falling, and bouncing ball. The plan involves progressively increasing the scientific fidelity of the simulation. As a result, Steps 3–5 of the proposed Seven Step PBL process are repeated, in order to accomplish the successive refinements. For an implementation environment, the discussion here employs the media authoring and modeling toolkit known as Squeak Etoys to create a graphical simulation of the behavior of a ball that is rolled off the top of a table onto a floor. M&S affordances of Squeak Etoys, as well as progressive refinements of the model and simulation, will be illustrated in the discussion that appears in Steps 4 and 5 below. Programming in general and with Squeak Etoys in particular entails two primary elements:

1) Creating *objects* to represent elements of the problem domain.
2) Writing *scripts* to impart to those objects behaviors that represent interactions within the problem domain.

Step 4. Construct the Problem Space by Building a Model

In order to build a model, one must first choose representations of the model's elements. In this example one needs to represent a ball, a table, and a floor. In response, one might construct the objects indicated in Figure 27.1, where a ball is represented by an Etoys ellipse, while the table and floor are constructed using rectangles.

Depending upon the sophistication of the students, the teacher may vary the degree of mathematical, scientific, and computational rigor as follows:

Mathematical and Scientific Considerations
The simulated objects reside in a two-dimensional space. For example, a *ball*, commonly conceived as a three-dimensional object, is represented by a *disc* in two dimensions. Similarly, the table and floor are represented by conveniently sized rectangles. The teacher may employ language appropriate to the mathematical preparation of the students and the Squeak Etoys environment supports many common mathematical notions, as well as a variety of variable types. The

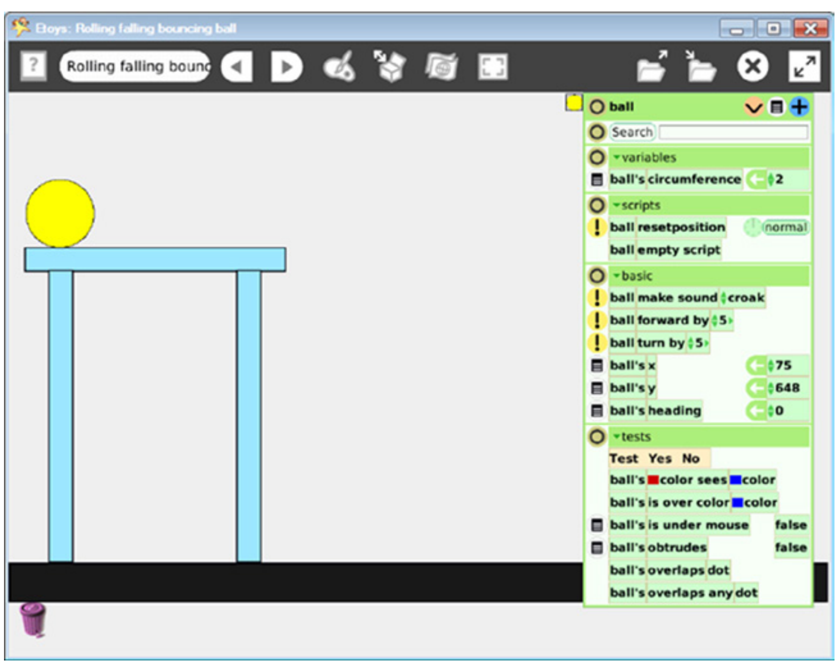

Figure 27.1 Screenshot of representation of objects in a computer simulation.

decisions regarding how to represent features of the problem domain as entities within a simulation environment always lead to a variety of idealizations of the scientific details of the problem.

Mathematical and Computational Considerations
The position of an object in the simulation may be described using Cartesian coordinates. Notice that the property sheet, open in the window shown on the right-hand side of Figure 27.1, indicates both the x- and the y-coordinate for the ball. Beginning students may initially explore the effects of changes in the coordinate values by modifying them in the property sheet and later the coordinates may be changed under program control.

Scientific and Computational Considerations
Since a simulation of motion is planned and the simulation may not be implemented satisfactorily on the first few tries, there is some value in creating a script that will assure that elements of the display will be in their proper positions for a consistent start of the simulation. Such "reset" or "initialization" operations are common practice for simulation programmers.

After choosing object representations, one must next impart behaviors. For example, one might begin modeling the motion of the ball by moving it horizontally. Fortunately, horizontal motion is easily implemented by creating a script that increases the x-coordinate of the ball. Figure 27.2 illustrates the motion of the ball by periodically recording its position by leaving copies of the ball's

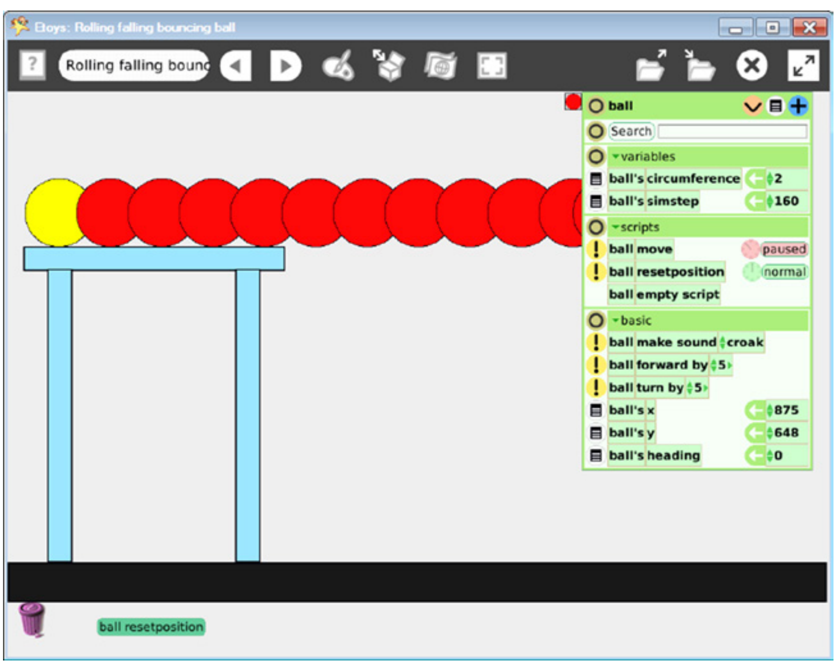

Figure 27.2 Screenshot of constant horizontal displacement.

graphic representation. The original position is shown by the far-left ball (shaded yellow in the online version of the figure) and subsequent positions are shown by the balls to the right of the original (red in online version).

Clearly, the ball changes position, as reflected by the change in x-coordinate values from x = 75 (see Figure 27.1) to x = 875, as indicated by comparing the property sheets shown in Figures 27.1 and 27.2. However, there is no visual evidence that the horizontal motion is accompanied by any rotation, and the ball does not exhibit any vertical motion upon leaving the table. In order to facilitate students' thinking about the simulation, the teacher might lead students to consider adding refinements to the scientific fidelity of the simulation separately, such as:

How Could one Create Evidence of the Ball Rotating?

One possibility might be to mark the ball, near its edge, with something, say simulated gum, i.e., an artifact whose position is fixed with respect to the ball. In this step in the example, another Etoys ellipse is used to represent the gum, and the ellipse representing the gum is *embedded* within the ellipse representing the ball.

Next, one may observe the trajectories of both the ball and the gum. Unfortunately, the large red images that shadowed the ball's path earlier would make it difficult to observe the paths of both the ball and the gum. Therefore, the simulation uses pen trails to track the centers of the ball and the gum. An illustration, which also includes a sample script that determines the motions of both objects, appears in Figure 27.3.

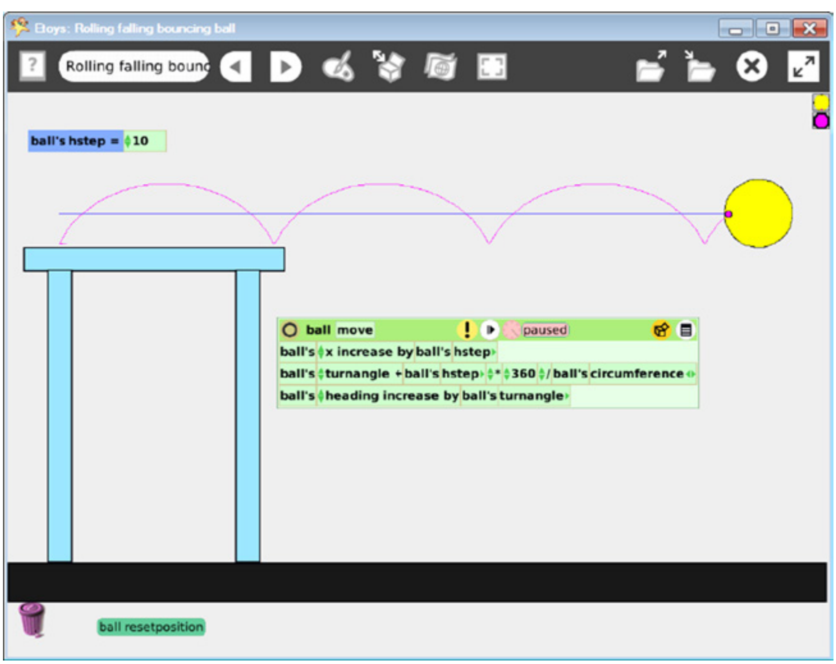

Figure 27.3 Screenshot of simulated rotation and a sample script.

Notice that the path of the ball, signified by the straight pen trail (blue in the online version), is still horizontal; its x-coordinate is simply increased by a fixed number of units, denoted by *hstep* in the script shown in Figure 27.3. However, the trajectory of the gum, shown as an arcingpen trail (pink in the online version), is very interesting; mathematically speaking, it is a cycloid.

How Does one Coordinate the Ball's Rotation with its Horizontal Displacement?
Notice that the horizontal displacement of the ball has been used to determine the turn angle, represented in the script by a variable named *turnangle*, for the ball. This is a direct application of ratios and proportions and is intended to improve scientific fidelity of the simulation by changing the ball's orientation (heading) to match its horizontal motion. By using the radius of the ball, one may calculate its circumference as well as the angle through which it must rotate as the center of the ball moves horizontally above the table. Specifically, assuming that the center of the ball advances *hstep* units horizontally between consecutive updates of the display and that the *circumference* of the disc representing the ball is known, then the turn angle that the disc rotates as it advances is proportional to 360° as the horizontal step, *hstep*, is to the circumference. Algebraically, *turnangle*/360 = *hstep/circumference*; equivalently, *turnangle* = 360 × *hstep/circumference*.

What are Some Squeak Etoys Tools that Facilitate Experimentation?
Figure 27.3 also shows an Etoys tool known as a "watcher," which enables someone using the simulation to inspect or modify values of a parameter. In this case, the watcher appears as a small rectangle with two subfields: one contains the words "ball's hstep," and the other contains triangular arrowheads pointing up/down along with the number "10." The phrase "ball's hstep" identifies the parameter whose value is being displayed; in this case, the size (in units of pixels) of the horizontal steps applied to the ball. Thus, each simulation step increases the x-coordinate by 10 and moves the ball's center 10 pixels to the right. The field with the up/down arrowheads allows the parameter value to be changed while the simulation is running; hence, they enable a student immediately to observe the effects of parameter changes upon the simulated behavior.

Step 5. Test the Model

At this point, the simulation *approximately* represents rolling motion with a constant horizontal displacement; however, inspection of Figure 27.3 clearly shows that the current approximation fails to capture the effects of gravity. A teacher might ask, "How could the simulation be refined in order to model gravitational attraction more accurately?" To begin, when the ball is subject to gravitational attraction, its trajectory over the table is different from its motion in free space. Over the table, the table presents a force equal in magnitude and opposite in direction to that of gravity, so that the table supports the ball. In free space, the air resistance does not counteract the gravitational attraction, and the ball falls. The simulation can account for both situations. Once again, for pedagogical purposes,

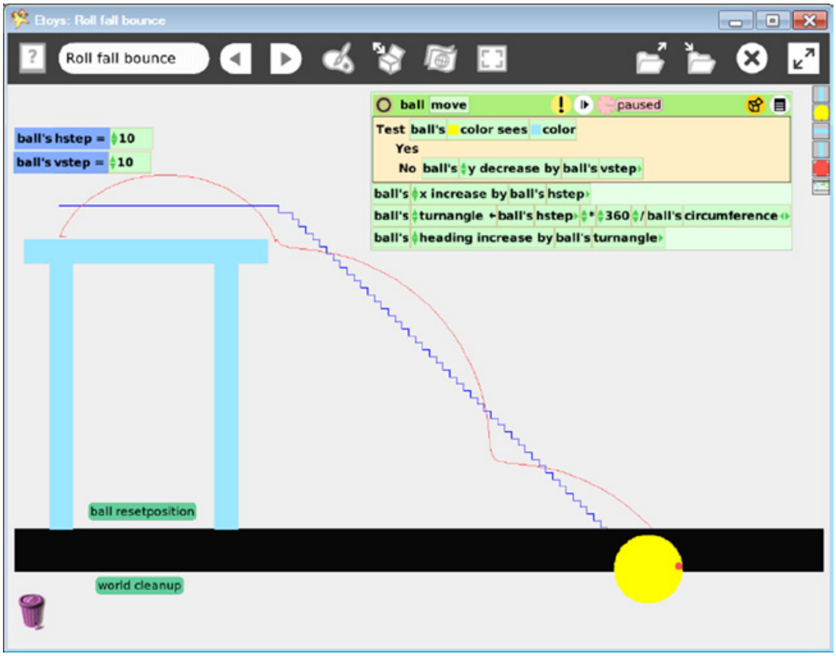

Figure 27.4 Screenshot of constant vertical displacement after leaving the table.

one may separate the effects of modeling the resistance of the table from modeling the behavior of the ball in air.

One may use a coarse model over the table by holding vertical displacement, represented in the simulation by the variable *vstep*, to the constant value zero while the ball is on the table. In Etoys, there are programming tools to determine if objects are in contact. For example, one may ask if a color on one object overlaps a color on another object. As illustrated in Figure 27.4, a test has been added to the move script for the ball to determine if the pale gray (yellow in the online version) of the ball is touching ("sees") the mid-gray (blue in the online version) of the table (or any object).

From the display one may readily observe that additional aspects of the problem have been modeled, while some of the original elements have been preserved. The motion of the ball on the table and the gum on the ball appear to follow their expected, previous trajectories. Also, the continuing rotation of the ball in the air is evident from the cycloidal trajectory of the gum. Further, a lack of physical fidelity in the current state of the simulation of the motion in air is revealed by the jagged, stair-step, pen trail trajectory associated with the center of the ball. The ball appears to fall, but it does *not* follow the anticipated parabolic trajectory. Finally, in Figure 27.4, the ball appears to have passed through the floor, rather than rebounding from it.

In order to improve the scientific fidelity of the simulation again, the vertical displacement (rate of *change in vertical position*) should be increased by the acceleration (rate at which the *change in vertical position* **changes**) due to gravity.

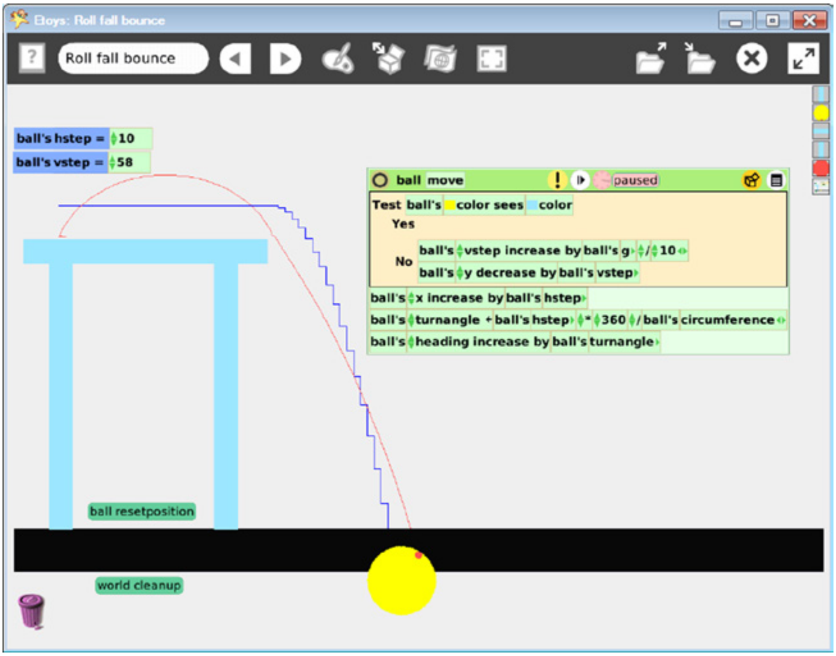

Figure 27.5 Screenshot of falling, rolling ball with gravity.

Thus, a student may add to the model acceleration due to gravity, denoted by *g*, which in turn, may be used to change the vertical velocity represented by the variable *vstep*. Figure 27.5 illustrates the motion of the ball when acceleration due to gravity is modeled by changing *vstep* once the ball has left the table.

Notice that when the vertical displacement is increased by g, additional scientific detail has also been incorporated including a decision regarding the time units and how they are represented in the simulation. For this example, updates occurred 10 times per second; hence, g was divided by 10 so that acceleration due to gravity was represented in distance units per second per 10th of a second.

As the student continues to assess and refine the model, it becomes apparent that an appropriate model of the interaction with the floor must be included. What should happen when the ball reaches the floor? First, the student will realize that the simulation must determine that the ball has made contact. The teacher will likely have to guide the student to understand that the floor must be capable of imparting a force to the ball that is similar in magnitude but opposite in direction to the motion of the ball. Thereupon, the vertical component of the velocity of the ball must change (reverse) its direction. Figure 27.6 shows changes to the move script that will model the behaviors. A new test has been added to determine if the pale gray of the ball (yellow in the online version) has come into contact with the black region of the floor. If so, the floor imparts its resistance and the vertical displacement (*vstep*) changes its sign and thus changes its modeled direction. Figure 27.6 also shows two new button controls "ball startsim" and "ball pausesim," which are used to start or pause the simulation, respectively. These

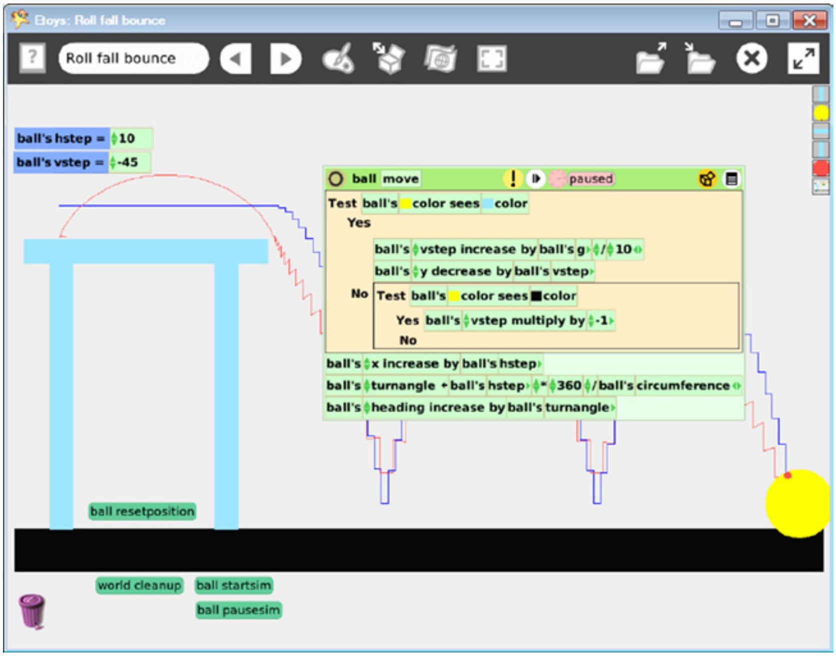

Figure 27.6 Screenshot of script revisions and additional control buttons.

controls allow one to run the move script without having the script remain open, and thus allow for a clearer view of the behaviors being modeled.

Figure 27.7 provides an unobstructed view of the trajectory of the ball and the attached gum. Notice that the simulation now exhibits many of the expected characteristics of an actual rolling, falling, and bouncing ball, as well as an approximation to the trajectory of the gum.

As one continues to test the model, it becomes apparent that there are still more elements of the physical reality that could be modeled, such as:

- The ball's horizontal motion should experience friction along the table top, in air or along the floor.
- The elasticity of both the ball and the floor may differ according to the materials being simulated.
- There should be deformations of the ball or floor during their contact.

Step 6. Make Recommendations to Answer Problem Statement

In order to employ the simulation to forecast the trajectory of an actual satellite (or any other falling object) the student must establish some additional correspondences between the simulation and the physical environment. Specifically, the student must determine how the units of distance will correspond to the pixels of the display. For example, pixels might represent square meters or square miles, depending upon how precisely the trajectory must be modeled and the role of the simulation in visualizing the trajectory.

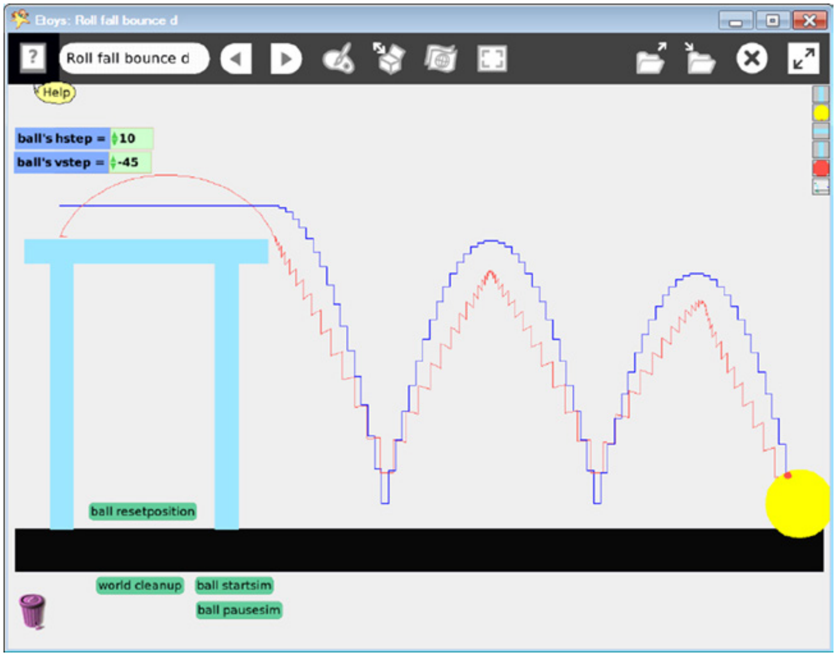

Figure 27.7 Screenshot of trajectories of a simulated rolling, falling, bouncing ball and gum

Likewise, while this example was developed assuming updates would be computed every .1 s, the base time units for an actual simulation would reflect yet another decision that has an impact upon the granularity of the model. For example, a minute-by-minute time step might suffice for modeling the trajectory. In any event, one would need to implement the effects of these decisions before an actual trajectory was predicted.

Step 7. Reflect on the Solution to the Problem and the Problem Solving Process

After completing their model and answering the problem statement, students respond to questions such as: Does the model help us provide a solution that makes sense? What could we have done to make it better? What did I contribute to the model and the problem-solving process? How well did my team work together? What could we have done more effectively?

Example 27.2 Modeling Disease Propagation Using NetLogo

Step 1. Problem Statement

The Centers for Disease Control and Prevention (CDC) wishes to study how the Zika virus might propagate through a population. Create a model and a computer simulation that will enable CDC scientists to study different scenarios for propagation of the virus.

Step 2. Research the Topics in the Problem Statement

After some investigation, one discovers that the dynamics of the spread of a disease are governed by parameters such as the level of interaction among members of the population, the ease with which the disease is transmitted from one person to another, the mobility of the members of the population, and the ease with which infected members recover. For an implementation environment, the discussion here employs NetLogo to create a graphical simulation of the dynamics of disease propagation within a population.

Step 3. Develop a Plan to Solve the Problem

In a manner similar to programming with Squeak Etoys, creating a model in NetLogo entails two primary elements:

1) Creating *objects* to represent elements of the problem domain.
2) Writing *scripts* to impart to those objects behaviors that represent interactions within the problem domain.

Step 4. Construct the Problem Space by Building the Model

Create a representation for the people in the simulation and the environment they inhabit. In the NetLogo environment one might construct the objects indicated in Figure 27.8. Each person is represented by a stick figure, while the black rectangular

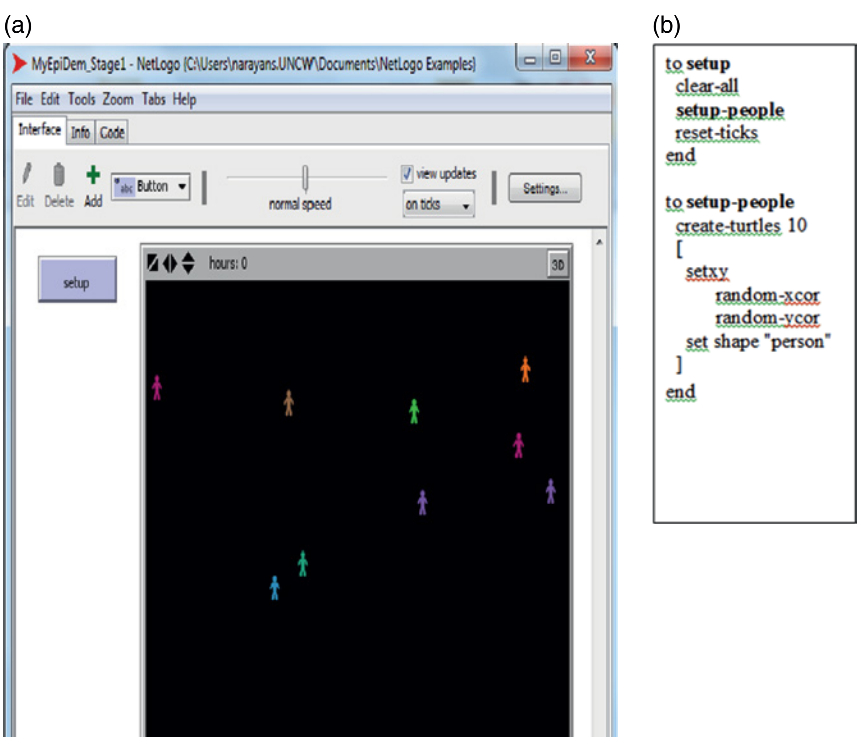

Figure 27.8 (a, b) Screenshot of objects in a NetLogo simulation of disease propagation and corresponding code.

area represents the "world" in which they live. The people (turtles) reside in a two-dimensional space. The world they inhabit is represented by a rectangle. The position of an object in the simulation is described using Cartesian coordinates. The coordinates may be changed under program control. The text box to the right shows the two scripts associated with the simulation at this stage. The **setup** script is executed when the setup button on the left is clicked. That script, in turn, executes the **setup-people** script that creates 10 turtles, locates them at random locations within the world, and makes them look like people.

Allow People to Move Around and Mingle

Movement of people is accomplished by creating the **move** script shown below, which, when executed, causes a person to turn right (**rt** command in the script) a random amount between 0 and 360°, and move forward five steps (**fd** command in the script). Repeated executions of this script simulate the movement and mingling of people in a population.

```
to move
 rt random-float 360
 fd 5
end
```

Create Scripts to Infect (and Visibly Identify) an Individual

The script **make-sick** shown below, accomplishes this by coloring sick people red. In addition, the script assigns an appropriate value, reflecting the health of the person, to a variable named *infected?* This variable represents a property of a person and is used in a later script to identify infected people.

```
to make-sick
 set infected? true
 set color red
end
```

Create a Script to Selectively Infect One Individual

The script **infect-one** allows a randomly selected individual to be infected. Note that this script makes use of the **make-sick** script defined earlier.

```
to infect-one
 ask one-of turtles
 [make-sick]
end
```

Build the Capacity to Transmit an Illness

The **perhaps-infect** script transmits an infection, with probability 1.0 (or 100%), to turtles on neighboring patches.

```
to perhaps-infect
 let nearby-uninfected (turtles-on neighbors) with [ not
 infected? ]
 if nearby-uninfected != nobody
  [ ask nearby-uninfected
    [
     make-sick
    ]

  ]

end
```

Create a script (named go in this case) that, on each clock tick, causes the people in the simulation to move around, and the infected individuals to potentially transmit the illness.

```
to go
 ask turtles [
   move
 ]
 ask turtles with [infected?]
 [
     perhaps-infect
 ]
 tick
end
```

Disease Propagation is Simulated by Repeatedly Executing the Go Script

On each tick of the simulation clock, all people in the simulation are instructed to move, and then potentially infect neighbors.

While not shown here, as described in the previous example, Steps 5–7 of the PBL process can be applied to the disease propagation model. The basic disease propagation simulation described above allows students the opportunity to extend it in numerous ways, described in the questions below.

- As currently modeled, any contact with an infected individual causes the infection to be transmitted. How could the model be revised so that infections are transmitted with some fixed probability?
- What happens to the dynamics of disease propagation as the probability of transmission is varied?
- As currently modeled, all individuals move a fixed distance on each clock tick. How can the model be revised so that the user controls the extent of their movement?
- What happens to disease propagation if a strict quarantine is imposed and the movement of individuals is strictly regulated?
- Modern transportation, for example, air travel, has facilitated the rapid movement of large numbers of people. How can this phenomenon be reflected in the model? How does this affect the dynamics of disease propagation?

- Some people may succumb fatally to their illness. How can this be captured in the model?
- Some illnesses, like Ebola, claim their victims rapidly. How does this affect the dynamics of disease propagation? How does this compare to the dynamics of an AIDS-like disease that typically only has fatal consequences years after the initial infection.
- Some diseases can be cured, or sometimes individuals develop immunities postinfection. How can this be modeled? How does this affect the dynamics of disease propagation?

Example 27.3 Modeling and Simulating Swarm Behavior Using Python

Step 1. Problem Statement

Suppose a professional animator is working on a movie. One of the scenes is supposed to present a herd of dinosaurs moving through meadows in a valley. The director is seeking to create an animation that exhibits lifelike movement of the herd members, and your objective is to provide a computationally tractable approach to creating the model and to simulating the behavior.

Step 2. Research the Topics in the Problem Statement

After some investigation, one discovers that the collective motion behavior of swarms, herds, schools, and flocks arises from three interacting objectives: staying close to the group, going with the group, and allowing individual space for each group member. These objectives are cohesion, alignment, and separation, respectively. Accordingly, the third example project uses the Python programming language and its Turtle module to simulate three swarm member behaviors:

1) Cohesion—moving toward the average location (center) of the swarm.
2) Alignment—making an individual's orientation similar to the average heading of the swarm members.
3) Separation—providing some individual space for swarm members.

Notice that each behavior description intentionally incorporates an element of ambiguity implied by the words "toward," "similar," and "some." The ambiguity of these words conveys ideas such as, many swarm members will:

1) stay with the group, but others may venture less cohesively away;
2) move with the group, but others will align themselves more independently; or
3) position themselves closer to others, while some may stray from the group.

As a general purpose programming language, Python possesses language constructs that provide sequencing, selection, iteration, and modularization, as well as many libraries, known as modules, which in turn provide a wide selection of functionalities. For simulation and visualization, two Python language libraries called "modules" are particularly important: the "random" module and the "turtle" module. The random module enables the programmer to generate random values that can be used to model nondeterministic behavior.

The Turtle module, which possesses roots in Logo, provides for objects, known as *turtles*, whose properties can be readily modified and used in calculations that would naturally arise when modeling motion. For a graphical display context, the module provides the ability to create a window, with convenient dimensions and extent, in which to display turtles. Thereupon, the programmer may create turtles, place them within the window, and impart simulated behaviors.

For simulating motion, some key properties of each turtle include its x- and y-coordinates, which give its location in a display window, and its heading in degrees (with default orientation having a 0° heading to the right and a 90° heading being upward in the window). Module functions setx(valuex) and sety(valuey) allow a turtle's coordinates to be set to valuex or valuey, respectively. In addition, the functions xcorr() and ycorr() return the values of the coordinates of a turtle. The function setheading(angle), which may be abbreviated seth(angle), allows the programmer to assign an orientation to a turtle.

Step 3. Develop a Plan to Solve the Problem

The simulation seeks to display some objects that represent swarm motion in a way that resembles what one might observe when watching a group of biological entities. To represent individuals and their motion in a swarm, this simulation employs the Python turtle module. For this particular simulation, some mathematical tools are useful. In particular, in order to make use of the Python turtle module, the user must first be familiar with the Cartesian coordinate system, angles, and headings. Indeed, the need for skill with basic angle operations is heightened if, as was done here, the programmer assumes that the swarm should remain within the field of view represented by the display window. If the window represents fixed boundaries, then the motion of the swarm near a boundary should mimic observed physical behaviors, such as the angle of incidence for light matching the angle of reflection, or a bird nearing a wall is not likely to turn 180° to avoid it. As with the other examples cited here, the decision to adopt this constraint is an example of one way to increase the scientific fidelity of the simulation and, in this case, it provided fruitful ground for exercising mathematical knowledge of angles.

In addition, it is helpful to understand a common function for finding a weighted average of quantities x and y. Let a and b be constants with $0 \le a, b \le 1$ and $a + b = 1$. Then $z = a\,x + b\,y$ is a weighted average of x and y. Clearly, as a approaches 1, z is more *similar* to x than y; conversely, as a approaches 0, z is more *similar* to y. Interestingly, this concept extends to vector quantities **x, y, and z**, as well. This weighted average concept will be used to implement the idea that an individual's properties (e.g., heading, speed, and location) need to become ***similar*** to those of its neighbors.

Step 4. Construct the Problem Space by Building the Model

One Python implementation can be found in the linked source code file. It consists of slightly more than 100 lines of code that can be considered in three major components: initialization, function definitions, and the main driver loop. The initialization segment includes code to import the random and turtle modules. In addition, specific values are chosen arbitrarily for parameters such as the screen size, the number of turtles to be used, and the speed for rendering the animations.

```
import random
import turtle
#Set parameters
wn = turtle.Screen()
lbx = -700
ubx = -lbx
lby = -700
uby = -lby
wn.setworldcoordinates(lbx, lby, ubx, uby)
avgFish = turtle.Turtle()
avgFish.color("red")
avgFish.pensize(2)
```

The function definitions provide the code necessary to determine the average speed, location, and orientation of members of the flock. In addition, there are functions that set the speed and heading parameters of individual turtles to a weighted average of their own speed and heading properties so that they become similar to those of the average characteristics of the flock being modeled. An additional function employs the results of the average finder function as well as the speed and heading matching functions in order to move each turtle.

```
def findavgs():
##code to accumulate sums and find averages
##Return the average heading, speed and location
 return (avghd, avgspeed, avgx, avgy)
def matchspeed(f):
 fractionofavg = 0.05
 fractionofself = 1.0 - fractionofavg
 f[1] = fractionofavg*avgs[1]+fractionofself*f[1]
def matchheading(t):
  ##Code to orient a member similar to the group average
heading
def movef(f):
  ##Code to make a move
  ##Code to detect proximity another swarm member and
backup if necessary
  ##Code to set the angle of reflection to the angle of
incidence when nearing a wall
```

Finally, the main driver loop, repeats a two-step process of (a) finding the averages of location, speed, and orientation for the swarm members; and then (b) adapting the individuals accordingly. The number of times that this two-step process is executed is the total number of times that the entire flock will adapt during the simulation.

```
for i in range(3000):
  avgs = findavgs()
  for member in swarm:
    matchheading(member[0])
    matchspeed(member)
    movef(member)
```

Step 5. Test the Model

Figure 27.9 displays the results of a typical swarm simulation. The trajectories of the swarm members are illustrated with the gray trails. The red trail (see online version of Figure 27.9) marks the trajectory of the average location of the swarm members. The initial state of the dispersed swarm is shown to the right of the center of the display window, where a stamped copy of each individual was recorded. The stamps reveal not only the initial position of each individual, but also its initial orientation. One may also observe from tracing the trajectories that the individuals eventually reorient and reposition themselves to become a more coherent, mutually aligned, and closely assembled but separated collection of swarm members.

Step 6. Make Recommendations to Answer the Original Problem

Inspecting Figure 27.9, one observes that the members of a swarm may begin in random relationship to each other, but move to exhibit an emergent, collective

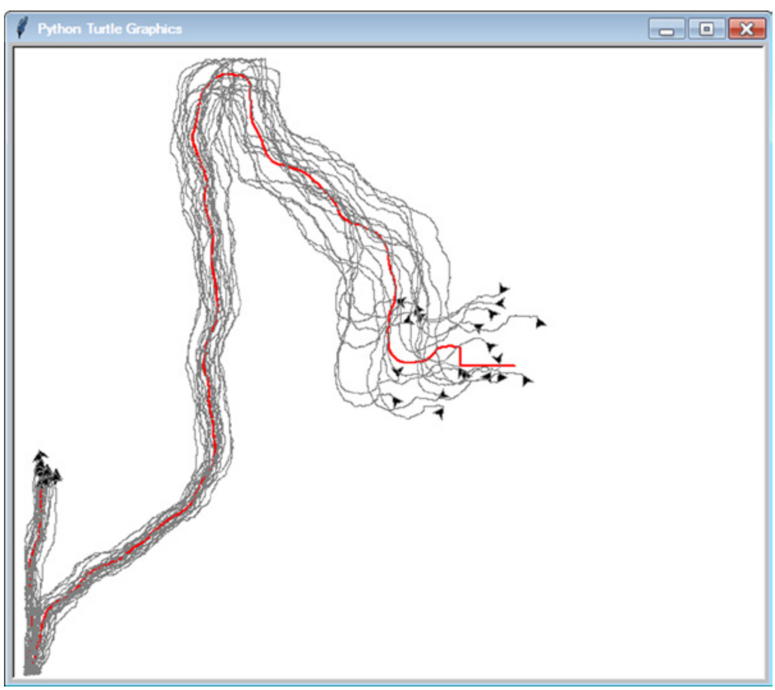

Figure 27.9 Screenshot of sample simulation output of a swarm model.

movement that seems consistent with behaviors exhibited by observing various animals. Since the motion arose by simulating the effects of the principles of cohesion, alignment, and separation, it appears that an animation of biological swarming may be sufficiently successful for choreographing a movie application.

Step 7. Reflect on the Solution and the Problem-Solving Process

By examining the Python code, one may readily note that there is an almost bewildering array of language details that must be acquired prior to implementation, and this is a relatively short program. The mechanics of using modules requires knowledge of referencing syntax in order create turtles or generate random values. Data structures, such as lists, are common to Python programming for collections of objects, so list management operations and dereferencing schemes must be mastered. Thus, while Python provides a very broadly open-ended, generic simulation capability, acquiring skills to exploit that generality demands a serious commitment to mastering the nuanced details of a specific programming language.

Additional Considerations for M&S, PBL, and CT

Though a powerful complement to PBL, the practice of M&S comes with several cautions. In this section we describe some of the issues we have encountered when working with teachers and students to implement M&S (Moallem et al., 2016). Unlike other technology-based tools, the M&S environment itself may present a significant learning curve. No matter which modeling environment is used, computer-based M&S involves computer programming at some level. Even using a relatively familiar tool like a spreadsheet may require some knowledge of programming in the form of spreadsheet formulae, or macros. Modeling environments like Squeak Etoys or NetLogo require a substantial knowledge of the associated programming constructs that may require initial skill development before working in the environment. Using a general purpose programming language like Python requires programming skills and knowledge of Python programming constructs (see Appendix for more information). However, in most cases, the programming knowledge required is well within the reach of a motivated learner.

When first introduced, users are often drawn to the animation capabilities of the modeling environment. For example, a favorite project among middle school teachers exposed to Squeak Etoys within the context of the UseIT project (Moallem et al., 2016) was the "Water Cycle" project. Often, this was implemented with some carefully sketched cloud-like shapes, scripted to gradually rise up into the sky. At some prescribed height, the cloud-like shapes would trigger animated rain that would eventually lead to the rising clouds. With their heavy, almost exclusive emphasis on animation, these projects had little by the way of scientific fidelity, and offered almost no opportunities for experimentation and extension. This does not mean that the development of computer-based animation has no pedagogical value. On the contrary, it represents an early use of a computer modeling environment and can be seen as a logical next step in pedagogy that already uses words, pictures, and physical models to communicate ideas. However, a computer-based modeling environment is underused when an activity that starts with animation is not extended to culminate in a full-fledged model that allows for adaptation and hypothesis testing.

On some occasions, the complexity desired in the model may exceed the capacity of the modeling tool. For example, as users gain familiarity with a tool, the models that they wish to construct become more complex. Sometimes, this can lead to a situation where the tool may be incapable of meeting their needs, or it may be exceedingly difficult to achieve the desired behavior using the tool. For example, the Squeak Etoys modeling environment provides the ability for an object to detect contact with, say, another yellow object. However, if there are several yellow objects, detecting contact with a particular one is significantly harder. Thus, some things may be unable to be modeled. The modeling needs may exceed the capacity of the modeler.

Again, as users gain familiarity with a tool, the models that they wish to construct become more complex. This can lead to a situation where the user's limited knowledge of the tool (or of underlying programming principles) may hinder the modeling activity. For example, a user may wish to construct a Squeak Etoys model where a collision between a red ellipse and a yellow rectangle causes the two objects to swap colors. This cannot be done easily in Squeak Etoys. Worse, precisely what happens following collision may be unpredictable. Sometimes both objects may turn yellow, while both objects may turn red at other times. While problems such as this can be remedied by learning, it underscores the fact that M&S can impose a significant cognitive burden on teachers and students alike.

An experienced teacher will address problems that arise in the classroom by confidently and creatively seeking solutions together with the student, thus exemplifying and embodying PBL. It also requires motivation and perseverance on the part of the student to figure out how to do things independently while concurrently inspiring collaborative investigation. While computer-based modeling can be introduced as early as in late elementary school, the age appropriateness of the modeling environment needs to be carefully considered. For example, the Squeak Etoys environment offers a tile-based, drag-and-drop visual programming interface that is easy to use, and preempts syntax errors. The environment offers visually appealing elements, such as geometric shapes, and easy access to animation. Thus, it appeals to a young audience. On the other hand, an environment like NetLogo requires considerably more preparation on the part of the user; for instance, in using a programming language and debugging code. Thus, a NetLogo-like environment may only be suitable starting in late middle school or high school. Using an environment like Python may only be recommended starting in late high school. See the Appendix for more information about the suitability of the environments.

Another issue that bears mentioning is the ease of use versus control tradeoff. As previously mentioned, all computer-based modeling requires computer programming in some form. Modeling environments offer different levels of support for modelers. For example, the Squeak Etoys programming language provides support for commonly performed actions like detecting when two objects come into contact with one another. Similarly, the NetLogo programming language provides support for easily identifying all objects on neighboring patches, or for randomly selecting, and interacting with, one member of a collection of objects. Thus, these environments readily support many commonly performed modeling activities. On the other hand, as a general purpose programming language, while the Python programming language provides constructs that can enable a capable user to accomplish any modeling goal, it may not have any built-in support for accomplishing any particular modeling goal. It may require a considerable initial investment of effort for a user to accomplish tasks that are far easier in other environments. Once a user becomes familiar with the programming language, they may be able to complete almost any modeling activity.

In many ways, a STEM classroom is an ideal environment for introducing computer-based M&S. The class may readily generate problems suitable for modeling, may already incorporate PBL, and thus provides a natural context for introducing modeling in an integrated fashion. On the other hand, an M&S environment can require significant time and effort to introduce, and compete with the content-related needs of the class. A separate class, for instance a "computer class," dedicated to learning computer-based M&S may offer more time for learning the proper use of computational tools. However, instructors of such classes may not have the STEM content knowledge to facilitate the proper use of the environment and to make the necessary connections between computer-based M&S and STEM disciplines.

Thus, there are several issues to consider when blending computer-based M&S and PBL in the classroom. The knowledge of the programming environment on the part of the teacher and the students, the STEM content knowledge of the teacher and students, capabilities of the modeling environment, and a school's computational resources can all play a role in the effectiveness of the activity.

Conclusion

PBL and computer-based M&S naturally and powerfully complement one another. Computer-based M&S activities lend themselves readily to open-ended inquiry, require students to learn experientially, provide students considerable leeway in selecting a path toward a desired outcome, encourage collaboration, and result in artifacts that demonstrate student learning—all of which are attributes of PBL. In many ways, computer-based modeling can be seen as a logical next step in pedagogy that already employs words, pictures, and physical models to communicate ideas. For example, the initial introduction of the notion of our solar system may be verbal and convey the idea of planets orbiting a stationary sun. Students may then be asked to draw a picture of the solar system. Later, students may build a physical model of the solar system. In this regard, a computer-based model of the solar system can be seen as a logical next step in this continuum of pedagogical approaches. An early implementation focused on animation may be revised to form a model that allows questions such as "What if the Earth's orbit were circular?" to be asked and answered. Students may build their own models or modify an existing model to answer this question working in small groups to test ideas and discuss results. The model may also facilitate more complex astronomical ideas such as eclipses to be understood in an emergent manner. This will support students' understandings of real-world STEM concepts through authentic experiences similar to those of scientists and mathematicians. Thus, computer-based modeling can be seen as a powerful tool that can complement and enhance PBL.

Appendix

Table A.1 Comparison of Modeling Environments

	Programming language		
Feature	**Squeak**	**NetLogo**	**Python**
Available for free download for most common platforms	Yes. Can also be installed and executed from a USB drive	Yes	Yes
Programming language philosophy	Object-oriented programming. Every entity is an object. One programs behaviors and properties for objects	Object-oriented language designed specifically for agent-based modeling. Agents are entities in a simulation that have properties and can respond to messages	General purpose programming language that supports imperative, object-oriented, and functional styles of programming
Method of programming	Tiles represent constructs. Programs are assembled like Lego® blocks	Textual representation of code. Built-in graphical user interface builder provides easy access to widgets such as buttons, sliders, etc.	Textual representation of code. Building graphical user interfaces requires external libraries and programmer sophistication
Ease of compliance with language syntax	Tiles and graphical interface enforce syntax. Impossible to introduce incorrect syntax	Programmer must supply correct textual syntax	
Parameter testing/ exploration	Program logic may be altered during execution. Effects observable immediately	Program logic can be altered only when program is not running. Requires recompilation	
Minimum preparation	Beginning readers (estimated at least fourth grade),	Careful and disciplined readers,	
	with problem-solving skills including abilities to: 1) Select a representation 2) Identify behavior that would lead to a solution 3) Subdivide a process into components whose assembly will provide steps that solves a problem Capable of expressing reasoning that may include sequential execution, selective execution, repetition		

(*Continued*)

Table A.1 (Continued)

Feature	Programming language		
	Squeak	**NetLogo**	**Python**
Bulk data management	Limited file input (image and audio files), but no generic file input or output	Language constructs for reading and writing data files, and for export and import functions (e.g., export data, save and restore state of model, make a movie)	Generic file input and output tools
Support for animation	Any objects may be animated under program control	Built-in Turtle graphics. Mobile agents (turtles) move over a grid of stationary agents (patches)	Only with external modules such as Turtle graphics, or PyGame
Modeling complexity	Models may be incrementally extended to incorporate increasing scientific fidelity		
Visual appeal	Drawing capability with basic sketching tools	Customizable turtles. Built-in support for line, bar, and scatter plots. NetLogo 3D supports modeling of 3D worlds	Only with external libraries such as those for Turtle graphics
Best suited for	Late elementary to early middle school grades	Late middle school grades and higher	High school and higher
Example STEM phenomena modeled	• Projectile motion • Disease propagation • Biological flocking • Chemical interactions • Planetary motion • Combustion • Predator–prey • Arithmetic operations		
Documenting projects	Flaps provide convenient option for documentation	Each project has a separate tab for documentation that can include formatted text and images	Up to the programmer discretion
Model repositories	http://squeakland.org maintains collections of projects organized by grade level and subject area	NetLogo includes the Models Library, a large collection of prewritten simulations representing a variety of domains that can be used and revised. Several model-based inquiry curricula using NetLogo are available	None associated with the Python language

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28

Problem-Based Learning in Digital Spaces

Maggi Savin-Baden and Roy Bhakta

Introduction

Problem-based learning (PBL) has become a central learning approach in many curricula but this collaborative style of learning is often perceived to be threatened by the movement toward online learning. The increasing adoption of PBL and the parallel growth in online learning each reflect the shift away from teaching as a means of transmitting information, toward supporting learning as a student-generated activity. To date PBL has been seen as a relatively stable approach to learning, delineated by particular characteristics and ways of operating. Most of the explanations of and arguments for PBL, thus far, have tended to focus on (or privilege) the cognitive perspectives over the ontological position of the learner. For example, early forms of PBL had a strong emphasis on solving the problem; Eva, Neville, and Norman (1998) suggested that by teaching principles of problems, students will then use these principles to solve other similar problems. These arguments were drawn from work such as Ausubel, Novak, and Hanesian's assimilation theory of learning (1978), which suggested that learning occurs when a learner is presented with new information whose external or internal characteristics enables the learner to associate it with previous learning. Thus, advanced organizers, or a bridge between new material and existing ideas, were seen as instrumental for learning. Approaches that combine cognitive and developmental fields tend to be more helpful when adopting PBL since they take account of the ontological position of the learner. The teacher's concern here is in enabling students to develop both understandings of the nature of knowledge and ways of handling different conceptions of the world, so that knowledge acquisition is seen as an active process. For example, the work of Belenky, Clinchy, Goldberger, and Tarule (1986) and Baxter-Magolda (1992) acknowledges that what is missing from many curricula is recognition of the role and relevance of learning from and through experience, which can prompt the shaping and reconstructing of people's lives as learners and teachers.

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The emergence and development of PBL is marked by change. Compared with many pedagogical approaches, PBL has emerged relatively recently, being popularized by Barrows and Tamblyn (1980) following their research into the reasoning abilities of medical students at McMaster Medical School in Canada. Barrows and Tamblyn's study and the approach adopted at McMaster marked a clear move away from didactic approaches to learning in which individual students answer a series of questions from information supplied by a lecturer. Rather, this new method they proposed involved learning in ways that used problem scenarios to encourage students to engage themselves in the learning process, a method to become known as *problem-based learning*. In this early version of PBL certain key characteristics were essential. Students in small teams would explore a problem situation and through this exploration were expected to examine the gaps in their own knowledge and skills in order to decide what information they needed to acquire in order to resolve or manage the situation with which they were presented.

PBL has expanded worldwide since the 1960s and, as it has spread, the concepts associated with it have changed and become more flexible and fluid than in former years. In terms of PBL in the twenty-first century, implementing this collaborative approach to learning is considerably more challenging in online learning contexts, due to difficulties associated with effective discussion between geographically and spatially disparate learners. This chapter reviews the literature on this, suggests ways of utilizing PBL in digital spaces, and presents the findings of a recent study that explored whether students could detect a covert pedagogical agent in online PBL sessions. The final section of the chapter argues for the need to move toward participatory pedagogies and discusses implications for practice.

Research and Literature

PBL in digital spaces is defined here as students working in teams online with the focus of the learning being on a problem or scenario. Students are expected to work collaboratively to solve or manage the problem and may work in real time or asynchronously, but what is important is that they work together. In digital spaces, PBL includes the use of synchronous and asynchronous collaboration such as chat, shared whiteboards, and video conferencing, as well as the use of virtual worlds (VWs) and virtual humans. Facilitation occurs through the tutor having access to the ongoing discussions without necessarily participating in all of them. Tutors also plan real-time sessions with the online PBL team in order to engage with the discussion and facilitate the learning. A useful recent example of using and evaluating online PBL is provided by Ng, Bridges, Law, and Whitehill (2014) in the area of speech and hearing sciences, which is presented in more detail later in the chapter.

For students, the shift to new forms of learning, different from the more traditional didactic approaches they have experienced in school and further education, is often challenging. Using PBL in digital spaces introduces students to two new elements of learning: PBL and learning online. Students' lack of experience with one or both of these will have an impact not only on their experience of, and outcomes of PBL and online learning, but also on other forms of learning within the curriculum. If other curricula components are lecture-based, students invariably find the management of the online component troublesome and challenging. This is because there are few curricula where PBL is used as the only approach to learning and thus students have to manage not only the interplay of knowledge across modules but also different approaches to learning. However, there are also issues about the reasons for using PBL in digital spaces in the first place. For example, it is questionable as to whether there is value in using real time online PBL for students undertaking the same program at the same university, unless it is used because of long distances between campus sites where students are using the same PBL scenario. There is also a need for questions to be asked about whether having asynchronous teams adds something different to online PBL. Certainly, in distance education, across time zones and campus sites, asynchronous teams would be useful and suit different students' lives and working practices. However, this raises problems about how cooperative and collaborative it is possible to be, in terms of sharing learning and ideas and developing forms of learning that are genuinely dialogic in nature. Yet the pedagogical benefits of collaboration include being able to approach problems from a multitude of viewpoints, tackle open, abstract, or complex problems, and co-create knowledge and learning as Veerman and Veldhuis-Diermanse (2001) suggested, and are discussed in relation to the work by Ng et al. (2014) next.

Online PBL

Many educators have begun to utilize the potential offered by numerous online collaborative tools (e.g., Skype or Google Drive) to support PBL teaching in an online space given the prevalence of cheaper and more reliable internet connectivity (International Telecommunication Union, 2016). Online methods can be useful where traditional face-to-face teaching is not feasible or significantly less convenient. These could be students from geographically disparate locations or those studying part-time who would ordinarily struggle to participate in group-based work due to other commitments. One such example is a study involving approximately 40 third-year undergraduates studying speech and hearing sciences. Ng et al. (2014) compared the use of PBL carried out online with PBL carried out face to face. For this study participants were split into five PBL groups, one of which was randomly selected to work on the PBL tasks online using the cross platform Adobe Connect (2012) to facilitate group collaboration. Each group worked through five problem scenarios each spanning 6 hr over a 1-week period. There were no statistically significant differences across the groups in terms of knowledge or skill attainment between those in the face-to-face PBL groups (M = 71.00%, SD = 7.562) and those in the online PBL group (M = 69.88%, SD = 7.680). However, the online PBL group's self-report evaluations suggested that students preferred online PBL rather than face-to-face PBL, perceiving it to be a better use of available time, and thought that they had learned more and had greater engagement. This also suggests that the online PBL experience was no less effective in promoting learning than conventional face-to-face learning.

Similarly, a pilot study involving 34 trainee teachers for children with impairments examined the usefulness of online PBL as part of their distance learning studies (McLinden, McCall, Hinton, & Weston, 2007). The online PBL task involved the students who were split into six groups, each working on two PBL case studies (Case study 1 was run over 10 weeks and included five tasks while case study 2 ran over 8 weeks and included a further four tasks). The subtasks presented to the students within each case study were in a linear format, with solutions being generated through participation in an online role play (students assumed the role of an appointed trainee teacher). To enable students to collaborate on the problem, a virtual learning environment (VLE) was used that incorporated a wide variety of tools that the students could use (e.g., chat rooms, blogs, diaries, discussion forums, bulletin boards, e-mail, and file sharing). Assessment of the online PBL activity was through self-report questionnaires that focused on student perceptions of engagement with online PBL, and an evaluation of the case studies being used. The results suggested that participants felt the online PBL activities supported the development of their knowledge and understanding of the key concepts related to the learning objectives. Furthermore, participants felt that the structure and content of tasks and scenarios used within the case studies were useful and aided their learning. One of the key findings of the study suggests that students became more independent when working on the second scenario as fewer perceived the need for additional support from the tutors when working on the second case study. Although, the study does not refer to attainment, it is evident that online PBL was perceived as a useful and relevant method of learning by the learners. However, the results also suggest that for students to make full use and to engage with the online PBL, they would need an appropriate induction and support during the early stages or initial case studies.

While the studies mentioned above suggest that online PBL instruction can be as effective as face-to-face instruction, the opportunities of using technology to replace or augment some of the features of traditional PBL have also been explored. For example, Poulton, Conradi, Kavia, Round, and Hilton (2009) conducted a study that aimed to examine the impact of enriching the PBL experience by replacing paper-based ("static") scenarios with scenarios converted into virtual patients generated using Open Labyrinth based on the Labyrinth (Begg, Ellaway, Dewhurst, & Macleod, 2007) platform. Learners were able to get immediate feedback (visual and textual) regarding the proposed solutions (through textual input) and potential consequences of the decisions being agreed upon. A total of 72 students participated in the study and were divided into 10 groups who tackled five PBL scenarios. For the first 4 weeks, groups alternated between online linear and branched versions (online nonlinear) of four PBL scenarios. Each week, five of the groups used the linear version of the virtual patient while the remaining five groups used the branched version of the virtual patient online scenario. The branched version differed from the linear version in that it incorporated consequences that resulted from choices that students made while working on the problem. These consequences then changed how the virtual patient was presented to the students, thus affecting subsequent decisions and possible solutions. During the final week all participants were presented with the branched version. Evaluation of the study was based on self-report questionnaires that focused on scenario preferences (paper, linear online, nonlinear online) and user experiences of PBL and interviews with tutors. The results suggest that the majority of participants (70%) felt that the introduction of nonlinear scenarios was beneficial and more engaging than the use of linear scenarios, with a strong preference for using nonlinear scenarios in future study. Furthermore, the use of linear scenarios in an online setting was viewed as pointless and no better than the use of a paper-based scenario. However, this was not fully reflected in the evaluations. When asked to rank in order of preference, approximate percentages of the rankings suggest that 66% opted for linear online scenarios as their third choice, 33% as their second, and only 1% as their first. Preferences for paper-based scenarios were 20% as their third choice, 38% as second choice, and 42% as first choice. The nonlinear online scenario version was ranked by 57% as first choice, 29% as second, and 14% as third. This tendency to rank the paper-based version higher than linear online scenario was likely due to the students' preferences for having printouts of the PBL scenario as suggested by the self-report questionnaires.

In a similar way to meta-analyses of face-to-face PBL (e.g., Walker & Leary, 2009), the literature on online and blended PBL seems to suggest that they are as potentially effective in supporting the learning process as traditional teaching (e.g., McLinden et al., 2007; Ng et al., 2014). However, at present it would appear that more studies are required that involve larger samples, a control, and are comparative in nature.

Learning Through Simulations and VWs

Learning through simulations and VWs such as Second Life (SL) has become a central learning approach in many curricula but the socio political impact of VWs learning on higher education remains underresearched. VWs are three-dimensional graphical online environments, which users can change and manipulate, as well as work in simultaneously on specifically tailored or self-developed projects. Much of the recent research into learning in VWs centers on games and gaming and is largely underpinned by cognitive learning theories that focus on narrow and linear forms of learning and highly bounded problem solving with the main focus being on attaining the "right answer" or game plan (Gee, 2004; Rieber, 1996). Most research to date has examined students' experiences in VWs (Savin-Baden, 2013), live chat in VWs (Steils, Tombs, Mawer, Savin-Baden, and Wimpenny (2014), and perspectives about what and how online learning has been implemented (Savin-Baden, 2008b). Practicing skills within a VW offers advantages over learning through real-life practice, in particular the exposure of learners to a wide range of scenarios (more than they are likely to meet in a standard face-to-face program) at a time and pace convenient to the learner, together with consistent feedback.

Using PBL in VWs such as SL embraces issues such as student diversity and improving student engagement (Wimpenny & Savin-Baden, 2013) connected with complex curriculum design and the need for complex PBL scenarios to be developed. VWs as a means to facilitate collaboration while involved with PBL have been identified as viable and worthwhile (Bignell & Parson, 2010). Similarly, the usefulness of VWs for enhancing pedagogical approaches such as PBL and constructionism was explored by Good, Howland, and Thackray (2008). The study examined the impact of using SL in conjunction with real-world activities to support 41 undergraduate students who were tasked with creating learning experiences that could be used to teach other students. Students were split into eight groups, which were each paired with a client from one of the Sussex Learning Network partner institutions. Each client then specified a learning requirement or problem related to a current vocational learning area and fit into an existing curriculum need that would be problematic to teach in real life. After an initial meeting with the client and an agreed-upon initial outline of the learning experience, each student group aimed to create innovative learning experiences using the SL platform that solved a specific learning or training requirement. On completion of the task, groups presented their learning experiences to the clients and were given feedback. Students were assessed through a portfolio of work that comprised: (a) the learning experience itself, (b) a short film shot in world demonstrating the learning experience, (c) group document that included details of the project and development process, and (d) an individual report reflecting on the process drawing on literature, critiquing the end product, and discussions of how VWs could or couldn't be used for learning. Data collected from the groups included the portfolio outputs and other online data collected from applications such as Google groups, wikis, e-mail documents, and course assessments. Based on the data collected during the study, Good et al. highlight that, in addition to the difficulties in designing appropriate assessment strategies, instructors should be aware that poor implementation of VW PBL can lead to deficiencies in the range of skills or knowledge learned. Furthermore, they suggested that using VWs can potentially help minimize the challenges faced when using PBL strategies in the real world including:

1) *Positioning*—in-world interactions suggest students viewed facilitators more as peers who were co-learners and less as authority figures with a complete set of knowledge in the given domain.
2) *Openness*—the VW provides the opportunity for solutions, simulations, and artifacts to be experienced and generated that are not constrained by real-world factors such as material costs, time, or geography.
3) *Ownership*—the openness of the environment means students are free to create and modify in world artifacts generated by themselves and others with reduced need to consult a tutor/lecturer.

Good et al. suggest that these benefits result in greater perceived ownership over the learning taking place and an increased sense of independence, since there are generally other sources of support and information such as the wider user base of the VW and their peers.

Additional studies have been carried out to examine the usefulness of VWs in supporting student learning and also the problems associated with using a learning environment where students may have little experience with the technology. For example, a study by Vosinakis, Koutsabasis, and Zaharias (2011) involving

10 university students (divided into three groups) studying either system design engineering or information and communication systems engineering used PBL activities to facilitate learning around the area of user interface design within the Open Simulator (OpenSim) VW platform. Through a combination of participant interview, feedback, and in-world observations, a number of challenges were observed including the voice chat being problematic due to server issues (there were several occasions where voice chat between participants was lost) resulting in reducing the ability of participants to communicate; lack of familiarity with using VWs resulting in a greater focus on the PBL environment/platform and reduced efficiency in using the available tools for completing the task, thus hindering their final achievement; and users wanting the ability to use traditional desktop applications with which they were familiar. However, a number of benefits were also highlighted, including:

1) The VW enabled asynchronous working on the tasks and the sharing of students' own work, and raised awareness of progress being made by others in their group.
2) Results of the learning activity were perceived as a group effort that was helped by the VW, which promoted similar collaborative features within the groups as would be observed in real-world PBL.
3) Voice and text chat were rated the most useful tools in collaborating and helping to achieve mastery of the subject material (possibly due to a lack of familiarity with the other tools).

Unfortunately, it is unclear if the use of PBL in the VW was better or worse than a comparable activity outside a VW.

The difficulties and potential benefits of utilizing VWs for teaching bioethics was explored by Hack (2015) with the aim of exploring how different teaching approaches would work within a virtual world. Hack described a case study that involved 101 part-time postgraduate students who used BioSim (an example of OpenSim) within a 12-week module as an environment for learning using PBL, flipped lectures, and role-play activities. The VW activities were voluntary and students had the opportunity to attend all three types of activities. Their evaluation involved collecting data on attendance and student grades (on a research proposal), a module evaluation survey, and a questionnaire focused on their learning experiences. Results suggest that the majority of participants felt that all three types of activities were generally useful or very useful, and engaging or very engaging. The results do not give a clear answer as to which method of teaching was rated better. Interestingly, the overall failure rate on the course decreased from approximately 11.25% (traditional teaching) to 4.4% using BioSim. Only 47% perceived that the activities within BioSim encouraged and motivated them to spend more time working on the assessment (i.e., research proposal), and only 53% thought of themselves as engaged with the assessment task. However, at the end of the course, 63% of the students suggested wanting more assessments within BioSim.

A comparison of grades on the research proposal assessment suggests that the 52 participants who took part in the mock role play scored higher (M = 63.6, *SD* = 7.8) than the 43 who completed the task using the online discussion board only (M = 60.3, SD = 6.8), $t(93) = 2.39$, $p = .019$. Based on the above data and the qualitative data from the module evaluations, Hack suggests that VWs can provide opportunities for authentic learning by providing a space that can be used for collaborative learning activities and the sharing of persistent and temporary artifacts that aid collaboration (e.g., audio, images, and posts). Yet there were also a number of barriers identified through the module evaluation that could pose difficulties for students effectively using a VW for learning, due to nonadoption or engagement with the technology (e.g., learning preferences, poor digital literacy, or technical preferences).

The issues relating to the usability of VWs and the implementation of PBL within VWs are not limited to any one particular platform. A recent study by Mavridis, Konstantinidis, and Tsiatsos (2012) involved a total of 17 participants and compared OpenSim and SL platforms to explore how best to exploit them for supporting collaborative learning using PBL. The OpenSim platform was evaluated by seven postgraduate students as part of a postgraduate studies program on virtual learning environments through the completion of a self-report questionnaire focused on functionality, difficulties encountered using the platform, and ease of collaboration. The SL platform was evaluated by 10 undergraduate participants studying multimedia systems as part of an informatics course through a two-phase process. Phase 1 provided researchers the opportunity to assess participants' previous knowledge of VWs and allowed participants the chance to become familiar with the SL environment and associated in-world collaborative tools. During Phase 2, researchers gathered data to assess usability requirements while helping facilitate the collaborative activities being undertaken by pairs of students. The results of their study suggest that participants undertaking learning tasks using the SL platform did not suffer from the same problems associated with lack of functionality and unfamiliarity that users of OpenSim had. In particular the voice communication features of SL were fully functional and key to effective collaboration, whereas the OpenSim platform suffered from technical problems that resulted in voice communication functionality becoming unavailable several times; consequently students felt their ability to communicate being restricted. Based on the results of the study, Mavridis et al. (2012) recommend that VWs used for learning need to include features that allow application sharing from within the virtual environment to enhance the collaborative functionality of the environment. The authors also suggest that for effective collaboration and engagement with PBL in the VW, students should be given the opportunity to become familiar with the VW and in-world collaborative tools over several sessions for an extended period of time. Finally, they suggest that efforts should be made to encourage the use of VWs for learning by utilizing the skills possessed by students already (e.g., social media tools), thus making the use of such environments more commonplace and increasing familiarity with similar tools and environments.

A framework for implementing PBL activities in VWs has been proposed and tested by Vosinakis and Koutsabasis (2012). In their study, 10 postgraduate students enrolled in a design of interactive and industrial products and systems course were divided into two groups of five to work on a human–computer interface problem focused on the design of a touch interface for a cafeteria, cinema, or theater, for 3 hr per week over a 12-week period as follows:

- One week for familiarization with technology and the proposed problem.
- Three weeks analyzing the problem through exploration and definition of the problem, and proposing methods for reaching a solution, all results being presented in the VW.
- Five weeks creating potential solutions and prototypes using in-world tools.
- Two weeks for students and tutors to evaluate prototypes with feedback and queries in the form of in-world annotations and comments.
- One week presenting group solutions and discussing the knowledge acquired during the problem-solving process.

Students' evaluation of the VW PBL activity was generally positive, with participants rating (between 0 and 10) their ability to use a number of in-world collaborative tools such as text chat ($M = 9.3$), projectors ($M = 9.0$), message boards ($M = 9.0$), and chat recorders ($M = 7.3$) favorably. Tools that were less familiar, such as drawing boards ($M = 4.0$) and sketch boards ($M = 5.8$) were rated lower. Furthermore, self-report ratings (0–10) of all seven competencies using VW features (such as walking/flying, inventory management, building objects, and rotating/scaling/resizing) improved from first use ($M = 5.87$) to last use ($M = 9.31$). The results of this study suggest that VWs are effective tools for facilitating collaborative learning through PBL. However, present technologies are limited in the sophistication and detail of the prototypes that could be constructed in-world. The results of the study also suggest that, although VWs can be effective for facilitating PBL activities, successful implementation is more than just designing an appropriate scenario and using a proprietary VW. Their framework suggests three highly related stages that should be followed for implementing PBL within VWs: (a) the design of appropriate PBL activity, (b) the creation and set up of an appropriate VW environment incorporating tools to support collaboration and the creation of relevant "in-world" artifacts, and (c) effective and appropriate evaluation strategies to examine the use of in-world tools, environment, and the learning taking place. Furthermore, they suggest that VWs offer a number of advantages over other online technologies that could be used to facilitate PBL, namely the ability for all individuals to share and be aware of the progress of other participants in a persistent environment combined with the ability to customize and adapt their environment and appearance.

The studies to date suggest a number of key benefits to using VWs either in conjunction or in place of face-to-face PBL activities to support and develop problem-solving skills, which include:

- Rich and authentic scenarios involving simulations, locations, and in-world artifacts that can not necessarily be achieved in real-life PBL due to financial, time, or other constraints.
- Increased ownership of the learning and motivation of learners.
- Learners can create in-world artifacts and be part of an authentic simulation.

However, there are also several key issues that can hinder the effective use of VWs for learning; for example:

- Technical limitations resulting from hardware and bandwidth requirements.
- Lack of familiarity with VWs and in-world tools can result in a steep learning curve for new users.

The facilitation of teaching and learning through the use of technologies such as VWs has expanded rapidly in higher education in recent years (Hew & Cheung, 2010; Wang & Burton, 2013). These developments have stimulated discussions about opportunities for educational change and the development of more flexible curricula that take account of the experiences and perspectives of students and tutors (Savin-Baden, 2008a). In some ways, a VW would seem to be an unusual platform (or world) to be adopted in higher education, but it is one that seems to have been embraced by many tutors who see its value since a VW offers a similar sense of interaction to face-to-face PBL through the use of avatars, as exemplified in the PREVIEW project described later in this chapter. However, it is important to understand that different forms of PBL affect learning, student engagement, and the way in which problem scenarios are designed. For example, work undertaken by Chan, Lu, Ip, and Yip (2012) examined paper-based scenarios and video scenarios. The authors hypothesized that, since video-triggered scenarios tended to be less well defined than paper-based scenarios, students were likely to need more discussion time on problem identification and description. However, they found the reverse was true. The authors also had concerns that the video may provide information overload and distraction but this was also unsupported.

Recommendation for Effective Use of PBL in Digital Spaces

Programs where PBL in digital spaces have been successfully implemented and maintained over time invariably have been the ones where time and adequate resources have been spent in equipping tutors from the outset, for example Ng et al. (2014). It is therefore important to plan the introduction of PBL into the curriculum 1 or 2 years before the whole curriculum is changed. This will allow sufficient time to decide on the kind of program that is to be designed and to prepare tutors adequately for the introduction of this new approach. The broad recommendations for educational development of tutors in face-to-face and PBL online are that:

1) The preparation for facilitators needs to start as early as possible, at least 1 year in advance of the commencement of the program in which online PBL is to be used.
2) The development of scenarios should involve all groups of tutors contributing to the delivery of a particular module.
3) The production of learning resources is vital to the success of online PBL, and related departments need to be involved from the outset.
4) In-depth discussion about assessment values and methods should be a key component of any tutor development program.
5) It is important to equip tutors by providing educational development that will enable tutors to become confident online PBL facilitators, such as a specifically designed course.

6) Tutors should work with learning technologists to develop appropriate online learning materials.
7) Help should be provided to enable tutors to develop structured sessions such as team activities and booked chat sessions, and to provide reading lists that make clear to the students that facilitation is about supporting and guiding rather than directing.
8) Tutors need to understand that the pace of learning can be very different in online PBL—with fast, busy discussion boards and frenetic chat sessions in some weeks and slow ponderous posting with considerable reflection and silence in other weeks.

New Developments for PBL in Digital Spaces

One example of a new development is the PREVIEW demonstrator project (Problem-Based Learning in Virtual Interactive Educational Worlds) that investigated the creation and testing of PBL scenarios in SL. This project emerged out of concerns that VWs were being adopted and adapted for higher education with relatively few pedagogically driven motives. It was also developed so that students could attempt scenarios in life-like situations without damaging a patient or client. The aims of the PREVIEW project were to develop, deliver, and test eight PBL scenarios within SL for paramedic and health care management education, ensure user-guided development, and share technology and good practice. Over a period of 9 months two categories of PBL scenarios were initially designed: *information-driven scenarios* and *avatar-driven scenarios*. Information-driven scenarios presented information through VW content, such as video footage, images, and audio with links to external content, such as relevant web pages. Avatar-driven scenarios used nonplayer characters, termed pedagogical agents, where the student interacted with the pedagogical agent to gather necessary information. It explored the use of novel features such as pedagogical agents, together with different ways of presenting scenarios in two learning contexts: a foundation degree in paramedic science, and a BA in social and health care management. Specific developments emerged from the PREVIEW project (Conradi et al., 2009), which have since been developed further in response to the need for pedagogically driven scenarios that fit with a VW. These include:

- *Machinima*—PBL scenarios featured machinima videos, for information-driven scenarios, which provided an overview of the virtual situation for students. A machinima is a video created in-world, in real time. These were made using screen recording software called Fraps and by enabling lip sync within SL so the characters' lips appeared to move when they spoke. The machinimas are then streamed in to SL and shown on a large screen to participants.
- *Holodeck*—a SL object called a holodeck was developed to allow dynamic redesign of the virtual space, in this case a care home. The holodeck responds to commands from buttons in the virtual care home reception, and transforms the office space according to the choice made. In practice this meant that it was possible to have four different office spaces, each relevant to the specific

scenario. The holodeck also generated content to the main care home building for one scenario, to give the impression of a postfire situation. The holodeck could be used for both information- and avatar-driven scenarios.

- *Pedagogical agents*—these nonplayer characters are artificially intelligent SL avatars, which respond to things said in local chat. These were used in two scenarios and took on the roles of a counselor and manager, respectively. These agents were programmed via a web service, which allows advanced detection of keywords and phrases. The agents were used to prompt students to ask questions and interact with the PBL environment.

Pedagogical agents have the potential for use in a diverse range of educational and commercial settings as a means of supporting individuals with learning and to provide relevant information in an engaging manner. Research into the area of pedagogical agents has begun to explore the interactions between humans and pedagogical agents, and in particular how agents are perceived and how useful they are. An example provided in this chapter is one such study that examined the use of pedagogical agents in online PBL chat rooms.

Pedagogical Agents in Online PBL

A study was undertaken to examine human interaction with sophisticated pedagogical agents and the passive and active detection of such pedagogical agents within online PBL. A pedagogical agent (or chatbot) is a software application that can provide a human-like interaction using a natural language interface. Examples of these are Siri, Cortana, Alexa, or the virtual online assistants found on some websites, such as Anna on the Ikea website. The passive detection test is where participants are not primed to the potential presence of a pedagogical agent within online PBL. The active detection test is where participants are primed to the potential presence of a pedagogical agent. The study used PBL online, so as to give a focus for discussions and participation, without creating too much artificiality. It was also used with a view to developing the possibility of virtual facilitators and virtual mentors in the future.

Methodology

The study sought to examine the detection of a pedagogical agent either passively or actively within online PBL. This study is novel and groundbreaking as to date there is little, if any research that explores the detection of pedagogical agents in the context of online PBL. Earlier work (Savin-Baden, Tombs, Bhakta, Burden, & Smith, 2014; Savin-Baden, Tombs, Burden, & Wood, 2013) was used as a design frame and to underpin this current study as well as the PREVIEW project, which guided the scenario design.

The mixed-methods study was undertaken using a repeated measures design with the type of detection being manipulated. Participants worked online in groups of four or five. The evaluation was undertaken by using a comparative design (Parlett & Hamilton, 1972; Patton, 1990). Each group undertook the passive scenario first and then the active scenario. A crossover design was not feasible due to the nature of the passive test: had the active scenario been undertaken first it would have been problematic trying to run the passive detection task as participants would have become aware of the presence of pedagogical agents in the study. The study comprised two different weeks, the first was the passive detection task (Week 1) in which students undertook online PBL but were not informed about the pedagogical agent. There was then a gap of 4–5 weeks in order for students to continue with their studies, as well as have time to consider whether they wished to be involved in Week 2. Week 2 was the active detection task, where participants were told that there may be a pedagogical agent in the group. During each week participants engaged with one scenario over three sessions of 1 hr.

Procedure

Prior to commencing the sessions, it was explained to the participants that the research question concerned the effectiveness of online PBL, and that they would be asked to try out and evaluate two PBL scenarios, one per week. Informed consent was obtained from participants prior to the start of the study. All sessions were run online with participants interacting with each other within an online chat room. Psi (a XMPP chat client) was chosen for use in this study due to its features that included ease of use, automated chat room log creation, and ability to easily integrate the pedagogical agent into the chat rooms. Before the start of Week 1 sessions, participants were also asked to complete a demographic information questionnaire. A total of 217 students expressed initial interest in participating in this research and, of those who subsequently consented formally to take part in the research, a total of 42 students finally took part. During Week 1 participants were unaware of the pedagogical agent's presence within the PBL sessions. In Week 2 participants were made aware of the possible existence of a pedagogical agent before the first session.

Data collection

Qualitative data were collected via semi-structured interviews. Quantitative data were collected by exploring the correct and incorrect detection rates during both weeks of the PBL and through questionnaires after engaging in the PBL (Likert-style items that gathered data on participants' evaluations of other group members for Week 1 and evaluation of the pedagogical agent at Week 2).

Findings

Data from the study aimed to explore the differences in passive and active detection rates of a pedagogical agent within a chat room, but in fact, few students detected the agents. The findings from the Week 2 questionnaires suggest a number of key areas that would need to be addressed to improve the ability of a pedagogical agent to go undetected:

- Reduce repetition of phrases.
- Improve the ability to give responses that are appropriate to the context.
- Expand the bank of "explanations" for responses to help explain and provide the ability to give opinions.
- Develop techniques that help give the illusion of the humanity pedagogical agent, either in general or by answering a particular statement or question.

Qualitative interviews elicited a number of themes relating to language genre, the "tells" that gave away the agent and the apparent human characteristics of the autonomous agent. The notion of a "tell" used in poker is a helpful metaphor that reflects the characteristics which resulted in the agent being revealed to the students. In poker there is an assumption that it is possible to pick up cues about the other players' hands. Here it is used to illustrate the idea that in online settings humans use conversational cues in order to read other people, and in learning contexts to understand the norms and behaviors implicit in online groups. The three main tells were the agent:

- not picking up changes in conversational moves;
- delivering confused utterances;
- providing inconsistent responses.

Many students attributed human characteristics to the pedagogical agent and some became highly irritated by it. Despite several students being concerned about the pedagogical agent confusing other group members and providing responses that were inappropriate, for one student the pedagogical agent was seen as a useful member of the group. Mirroring or projection normally takes place in face-to-face settings but it could indicate in this study that students who identify with the pedagogical agent are less likely to detect the pedagogical agent. The study suggests that the ways in which students positioned the agent tended to influence the interaction between them. Thus, those who assumed the agent was an incompetent student ignored him, and those who believed he had language difficulties felt sorry for him. Students' positioning of the agent—as shy, arrogant, or confused—was a mechanism used for rationalizing the feeling that something was awry or uncanny. While the original studies on the uncanny valley effect (the theory which posits that as virtual characters approximate human appearance they become distracting) were associated with visual appearance (MacDorman, Green, Ho, & Koch, 2009; Mori, 1970), it is evident that students in this study experienced a cognitive and psychological uncanny valley. Turkle (2010) has suggested that people's desire to engage with robots has a sense of the uncanny. This is because, for some, engaging with robotics offers people opportunities to connect with something emotionally and feel supported, even loved, without the need to reciprocate. However, student willingness to disclose sensitive information to pedagogical agents has been attributed partially to those pedagogical agents being almost like a person (Savin-Baden et al., 2013). One of the issues in this study was that the agent was focused mainly on the pedagogical task and this may have hampered interaction with the students. Perhaps inclusion of more social interaction responses and frame factors may have made it less noticeable. Although learning in online spaces brings a sense of arriving and departing without actually doing so, there remains relatively little relaxation of the coded practices of conversations in these spaces. Yet in the second scenario it seemed that some of the nontask dialogue improved perceptions of the pedagogical agent's ability to interact with the students.

The qualitative results of the study provide insights into how pedagogical agents interact with students in real educational settings. However, it was clear that several important improvements could be made to the agent, such as using more vernacular phrases, including humor in responses, and inserting positive comments and statements. Based on the results of the study, future research should examine the feasibility of virtual mentors that can act to support students. While the creation of a physical virtual human android is still a long way off, the creation of digital human avatars, even if not actually sentient or "intelligent," is far more achievable and could be highly useful. Yet it would seem that this also prompts questions about the ways in which PBL in digital spaces could be more innovative and focus on pedagogies that are participatory.

Participatory Pedagogies

It is suggested that in order to enhance learning and teaching through the use of educational technologies, and in particular PBL in digital spaces, there needs to be a focus on participatory pedagogies. Participatory pedagogies are defined here as forms of learning and teaching that harness the use of digital media and participatory cultures and action (Savin-Baden, 2015). In practice these pedagogies are often hidden, enmeshed, and transcend disciplines, structures, and learning boundaries. The result is that they are both difficult to locate and delineate clearly, and are also often informal and difficult to understand in terms of their impact and value on education, culture, and identity. They include such activities as learning through social networking, searching and retrieving information, researching information, using information, games, collaboration, and shared interests. Participatory pedagogies comprise new media, produsage, connected learning, mobile literacy, and connectivist pedagogy.

New media

This describes media at the intersections of books, television, and radio with interactive media and social networking. Such media are seen as new in that they are not tied to any context, platform, or situation, but are associated with culture, identity, belonging, and voice. In the context of this book they encompass informal and formal learning settings, as well as those at the interstices of both.

Produsage

Bruns (2008) argues for *produsage*, or the collaborative and continuous building and extending of existing content in pursuit of further improvement (Bruns, 2008; Bruns & Schmidt, 2012), characterized by:

- Community-based activities whereby the community as a whole can contribute more than a closed team of producers.
- Fluid roles where producers participate as is appropriate to their personal skills, interests, and knowledge.
- Unfinished artifacts: content artifacts in produsage projects are continually under development, and therefore always unfinished.
- Common property so that contributors permit (noncommercial) community use, adaptation, and further development of their intellectual property.

Connected learning

This form of learning is one in which it is recognized that learning occurs across and through media and contexts used by young people, often in informal and innovative ways. It is a means of learning, a way of delineating and analyzing learning while experiencing changes in social, economic, technological, and cultural contexts. It is also a framework for understanding learning:

> Connected learning posits that by connecting and translating between in-school and out-of-school learning, we can guide more young people to engaging, resilient, and useful learning that will help them become effective contributors and participants in adult society. (Ito et al., 2013, p. 46)

For some teachers and lecturers there is an assumption that mechanisms and structures need to be in place to enable young people to make connections, so that they are able to translate knowledges and practices between formal and informal learning environments. Yet for many people (of whatever age) connected learning is a central practice in their daily lives.

Mobile literacy

In former years the focus was on mobile learning—defined as learning for learners on the move (Sharples et al., 2013). Mobile literacy is based on the assumption that considerable learning takes place not only inside the classroom, but also that people create sites for learning within their surroundings. Mobile learning is a digital learning space that introduces challenges about what constitutes learning and pedagogy. It has implications for how formal schooling is carried out and how the curriculum is negotiated, and offers students opportunities to manage the relationship between formal schooling and independent informal exploration and problem solving. Mobile literacy is also part of the new sense of connectivist pedagogy that is occurring more formally.

Connectivist pedagogy

The central premise of connectivism is that learning takes place with and through networked information and resources. This means that learning is not just seen as accessing information but also as an evaluation of the value and relationship between different forms of knowledge. Thus Siemens (2008a, 2008b) argues that learning takes place through the connections that students make between knowledge, opinions, resources, and views, accessed via search engines and online sources. There would seem to be strong pedagogical links between connectivist principles (Downes, 2006; Siemens (2008a, 2008b) and other forms of group-based peer learning in formal settings, since the approaches to learning focus on the students' ability to make connections between the forms of knowledge they encounter, as exemplified in Table 28.1.

The Idea of "Affordances" of PBL in Digital Spaces

The increasing adoption of PBL and the parallel growth in online learning each reflect the shift away from teaching as a means of transmitting information, toward supporting learning as a student-generated activity. However, there has

Table 28.1 Forms of Participatory Pedagogies

Forms of participatory pedagogy	Definition	Characteristics	Key authors
New media	Media at the intersections of books, television, and radio with interactive media and social networking	1) Genres of participation 2) Networked publics 3) Peer-based learning 4) New media literacy	Ito et al. (2010)
Produsage	Collaborative and continuous building and extending of existing content in pursuit of further improvement	1) Open participation 2) Fluid roles 3) Unfinished artifacts 4) Common property	Bruns (2008)
Connected learning	Learning occurs across and through media and contexts by young people, often in informal and innovative ways	1) Connecting and translating between in-school and out-of-school learning 2) Learning as change in social, economic, technological, and cultural context	Ito et al. (2010)
Mobile literacy	The ability to use social media and media for learning through the mobile web	1) Understanding information access 2) Understanding hyperconnectivity 3) Understanding the new sense of space	Parry (2011)
Connectivist learning	Learning takes place with and through networked information and resources	1) Nurturing and maintaining connections to facilitate continual learning 2) Ability to see connections between fields, ideas and concepts is a core skill	Siemens (2008a, 2008b)

Adapted from Savin-Baden (2015).

been increasing questioning and querying about the notions of "affordances" of PBL and, increasingly, questions about the idea of affordances of PBL in digital spaces. The subtextual assumption here is that by teaching principles of problems, students will then use these principles to solve other similar problems. Inevitably, this raises questions about the extent to which problem solving can be classified as a generalizable skill and whether some knowledge is necessarily foundational to other knowledge or indeed transferable from one context to another. Such a difficulty can also be seen in the literature relating to affordances. The concept of affordances has been increasingly used in research and technology since the late 1980s. The term originated from Gibson, who developed the ecological approach to visual perception in which he argued that we use natural vision, thus when no constraints are put in the visual system, we examine something by moving up to it and viewing it from all sides (Gibson, 1979). It is therefore possible to see how this term has been misappropriated when we realize that he argued: “The *affordances* of the environment are what it offers, the animal, what it *provides* or *furnishes*, for good or ill” (p. 115, original emphasis). The use, then, of affordances seems at one level to have provoked an overemphasis on what particular technologies prompt or allow us to do, bringing with it a sense of covert control. This chapter has provided an overview of pedagogically driven suggestions relating to the use of PBL in digital spaces, while acknowledging that both the theorizing and the practices related to using VWs in higher education are not unproblematic, as explained next.

Practical Challenges

PBL in digital spaces encompasses a wide range of teaching and learning practices. However, there still remain a number of difficulties with current practices that bear further research and consideration. For example, to date, curriculum design for VWs has tended to center on the (social) constructivist theory of learning (Inman, Wright, & Hartman, 2010; Wang & Burton, 2013) based on the perception that such spaces *promote* a social constructivist view of learning. However, many of these arguments are misplaced since it is *social constructionism* which suggests that individuals construct reality with each other, knowledge is relational, and that it may be uncovered by examining interactions and meaning-making between and among individuals (Berger & Luckmann, 1966). *Constructivism* suggests that individuals create their own realities and that it is those individual realities that researchers must address (Piaget, 1929). However, the difficulty with the argument for constructivism is that there is often a focus on the technology and the affordances of technology, rather than the social development and the deployment of its use.

A further challenge is the lack of links made between educational models and theories across contexts and disciplines. One example of this is the lack of connection made between sense-making theories (Dervin, 1998) and PBL (Savin-Baden, 2007, 2014), whose pedagogical processes and strategies are almost an exact match. For example, the argument of sense-making theory is that by using a sense-making tool, it will be possible for people to recognize a knowledge gap, seek information, analyze, and synthesize information to create an understanding, and then possibly produce a task output: a report, decision, or other type of output. This mirrors the PBL process.

The final challenge is that human–computer interactions have been the focus of much debate (e.g., Turkle, 1996, 2005; Žižek, 2005). Yet Pirolli (2009) has argued that humans have limited ability to store information, seeming to imply that learning is about gaining knowledge or finding the right information. The argument advocated by Pirolli, then, constitutes a teaching design approach, which focuses upon what knowledge and content tutors wish to teach students. Other approaches such as activity-led learning, collaborative learning, and high-level constellations of PBL online (Savin-Baden, 2007) are advocated because such approaches focus on what students need to learn. While much of this can be argued for in face-to-face teaching, it does seem to be particularly apparent in online settings and VWs.

Conclusion

In terms of digital spaces, the exploration of new and different spaces suggests that spatial practices within higher education and PBL in digital spaces in particular will increasingly shape social and pedagogical production. There are still questions about the merit of developments in the use of digital technologies and new approaches to learning, particularly whether they are educationally valuable and really do have the potential to engage students effectively. The challenge, we suggest, is to resolve who decides what is to be learned and what counts as knowledge in digital spaces.

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29

An Exploration of Problem-Based Learning in a MOOC

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Introduction

Massive Open Online Courses (MOOCs) are a specific form of online courses. MOOCs typically contain mainly individual learning activities with limited interaction with other students and teachers. This chapter describes the instructional design of the MOOC "Problem-based learning: Principles and design. Students at the centre!", which stresses collaborative learning activities in the context of a MOOC.

The term Massive Open Online Course (MOOC) was first used by David Cormier in 2008 (Cormier & Siemens, 2010) to describe a 12-week online course, "Connectivism and Connected Knowledge," designed by George Siemens and Stephen Downes and offered at the University of Manitoba, Canada, in Fall semester 2008. Twenty-five students took the course for free and for credit while another 2,300 participated as "open" enrollees. Since then, the term MOOC has changed connotations; it has been applied to a variety of online and blended courses that are often larger scale and more directive in nature. Hollands and Tirthali (2014) interviewed representatives of 69 stakeholder organizations, including educational institutions already providing MOOCs or planning to do so and platform providers. They conclude that the word "massive" in MOOCs refers to a large number of participants. "Open" usually refers to the possibility for anyone with adequate internet access to participate in the course, typically without entry requirements and for free. Online refers to availability via the internet, and most interviewees agreed that to be labeled a "course," a MOOC should be bounded by time, that is, have a beginning and an end point. It should provide a coherent set of resources and follow a sequence of activities organized by an instructor in order to address specific learning objectives or goals.

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The majority of existing MOOCs are structured as weekly sequences of activities, often instruction provided in short lecture videos supported with supplementary individual readings and/or assignments, and assessment in the form of automatically graded quizzes, peer assessment, or—when possible—automatic grading of, for example, computer code. Participants can interact with each other and with the course facilitators via online discussion forums. This kind of MOOC has often been called an xMOOC (Bates, 2014; Hollands & Tirthali, 2014). These xMOOCs aim primarily at delivering education at a large scale, and involve structured and sequenced direct transmission of knowledge with limited interactions between participants. Other MOOCs, among which the first one organized by George Siemens and Stephen Downes described above, aim at a different form of learning in which the teacher has a far less prominent role. These "connectivist" MOOCs (cMOOCs) aim at facilitating learning through participant interactions with a network of individuals (Downes, 2008; Hollands & Tirthali, 2014; Mackness, Waite, Roberts, & Lovegrove, 2013). Participants in cMOOCs are encouraged to create, share, and build upon each other's artifacts. The success of the cMOOCs is highly dependent on participant interaction, for example, via discussion forums, Diigo groups, or Twitter. Course outcomes are often unique products, such as blog posts, images, diagrams, or videos generated by participants using a variety of social media.

MOOCs have become a global trend, and some have suggested that they will change the whole concept of higher education (e.g., Waldrom, 2013; Yuan & Powell, 2013). Famous universities like Massachusetts Institute of Technology (MIT), Harvard, and Stanford are offering MOOCs. Thus, MOOCs open up high-quality educational content to students who would otherwise not be able to attend, such as working professionals and students from less advantaged backgrounds. In a way, they enable genuine self-directed learning: students themselves choose what they want to learn and when. They simply choose the best available courses online, and they decide themselves which content is relevant to them and how they would like to participate (even though in xMOOCs the available content is predetermined by teachers). For some MOOC participants, the learning content may not be the only reason to participate: MOOCs also offer occasions to network and connect with other people.

MOOCs are also characterized, however, by large dropout, typically 85–95% (Devlin, 2013). They have been criticized for lack of sound instructional design (e.g., Holton, 2012; McAndrews & Scanlon, 2013). Alternative ideas are being developed stressing learner participation and engagement (Ahn, Butler, Alam, & Webster, 2013). However, the massive scale of MOOCs limits the applicability of proven instructional design principles. The amount of teacher support for individual participants is necessarily limited and, therefore, MOOCs are very different from other forms of face-to-face or online learning in terms of teacher feedback and guidance.

Maastricht University (UM) has a strong tradition in problem-based learning (PBL), focusing on small-group learning centered on authentic problems (e.g., Barrows & Tamblyn, 1980; Dolmans, de Grave, Wolfhagen, & Van der Vleuten, 2005; Moust, Bouhuijs, & Schmidt, 2014). At UM the most typical form of PBL is face-to-face: tutor groups meet regularly at the university in the presence of a tutor. These meetings are structured using the Seven Jump approach, which includes a prediscussion/brainstorm meeting, followed by individual self-study and a meeting to report/postdiscussion (Maastricht University, 2015; Moust & Roebertsen, 2010). Variations on this approach are used as well, for example, PBL with study teams, PBL with expert teams and project work (Moust & Roebertsen, 2010), and various ways to use digital support for PBL (Donkers, Verstegen, de Leng, & de Jong, 2010; Verstegen, Spruijt, Dailey-Hebert, Clarebout, & Fonteijn, 2016). Online forms of PBL have been used on a limited scale mostly with part-time Master's students. De Jong, Savin-Baden, Cunningham, and Verstegen (2014) found that synchronous forms of PBL using video conferencing tools could be very similar to face-to-face PBL. With motivated participants, good technical facilities, and careful preparation the performance of students and quality of the discussion can be equally good. De Jong et al. (2014) found that students were positive about online PBL, especially when it had advantages for them (e.g., when working part-time students do not have to travel to go to tutorial sessions). However, Van Tilburg (2014) found that this does not hold up for first-year full-time students, who are used to face-to-face meetings and see no advantage in online PBL. Experiences elsewhere have shown that PBL using asynchronous online tools, such as discussion boards or wikis changed the procedure and the form of discussion. This often led to less interaction and less deep discussion between students (for references, see Verstegen et al., 2016).

At first sight, PBL is in contrast with the large-scale and limited teacher support of MOOCs. On the other hand, MOOCs do offer new ways to stimulate self-directed learning and to connect people from all over the world and to reach out to a far larger public than in other forms of online PBL that are small-scale and labor-intensive. Therefore, a MOOC project was set up with the following aims:

- to gain first-hand experience in implementing MOOCs;
- to explore the implications of offering open online education;
- to explore to what extent the PBL format can be used in the context of a MOOC;
- to stimulate innovation in PBL formats and practices within the university and to enable research in this domain.

PBL was chosen as the topic for the first MOOC because UM has ample expertise in this domain and because this enabled the project to be a university-wide project with input and participation of staff from all faculties. To remain in line with the university's educational philosophy the aim was to design the MOOC in line with the design principles of PBL in order to stimulate constructive, contextual, collaborative, and self-directed learning. Thus, the "MOOC: Problem-based learning: Principles and design. Students at the centre!" (Figure 29.1; https://novoed.com/problem-based-learning) is about PBL, and it also uses the PBL approach (as much as is possible). In other words, it applies the "practice what you preach" principle.

The university-wide project team consisted of 34 people, including representatives from all faculties: Health, Medicine and Life Sciences, Law, Psychology and Neuroscience, Business and Economics, Arts and Social Sciences, and Humanities and Sciences, and some student-assistants. More information about the project can be found Verstegen et al. (2016).

Figure 29.1 Flyer Page of "Problem-based learning: Principles and Design. Students at the Centre!"

Design and Implementation of the MOOC

This section discusses the design of the PBL MOOC and illustrates how the design was implemented on a MOOC platform. Note that the design described here is the final design including the small changes that were made in the pilot study. The section ends with a description of some design dilemmas. In the next section, the execution of the MOOC will be described (both the pilot study and the first fully open run) and some lessons learned will be reported.

PBL is based on established insights from educational research that stresses the importance of stimulating active, contextual, collaborative, and self-directed learning. It is characterized by collaborative learning in small groups facilitated by a tutor (Visschers-Pleijers, Dolmans, Wolfhagen, & Van der Vleuten, 2004), learning initiated by problems (Hmelo-Silver, 2004) and new information to be acquired during self-study (Barrows, 1996). The student-centered character, stimulating an active attitude in students, is typical for PBL (De Rijdt, van der Rijt, Dochy, & Van der Vleuten, 2012).

The MOOC "Problem-based learning: Principles and design. Students at the centre!" is centered on a set of authentic or professionally relevant "problems" and participants are asked to discuss and interact with each other in small teams. They are asked to collaboratively generate questions or issues that need further study. Subsequently, they are stimulated to individually search for and study relevant sources, some provided in the MOOC, and others found elsewhere. These are then discussed collaboratively again. One major difference with face-to-face PBL is that in this MOOC design, for cost-effectiveness reasons, there is no tutor to guide the teams. The design does include course facilitators, but these have a different role: the facilitators do not provide guidance to each team; they keep a general overview, answering questions (on the general discussion fora) and may give some general comments or give some tips to all participants based on their observations of all teams.

In "MOOC terms" the design has characteristics of cMOOCs because it stresses collaborative learning and facilitates networked learning. The design also has characteristics of xMOOCs because it is far more structured than the original cMOOCs, suggesting an ordered set of activities to collaboratively explore a problem and define learning questions (brainstorming phase/prediscussion), followed by individual self-study and collaboratively discussing potential answers to the learning questions (reporting phase/postdiscussion).

General set-up and target group

The MOOC "Problem-based learning: Principles and design. Students at the centre!" is implemented in NovoEd (https://novoed.com) mainly because this platform explicitly supports small-group work. Each team is given a public profile page and a private team space with options to chat, share, and exchange files, and schedule meetings (see Figure 29.2).

The defined target group consists of people with a professional or personal interest in education in general, and forms of PBL in particular. This will often be teachers, tutors, instructional designers, curriculum coordinators, and other educational leaders, but may also include current and future students of Masters or PhD programs in the educational field or other students interested in PBL.

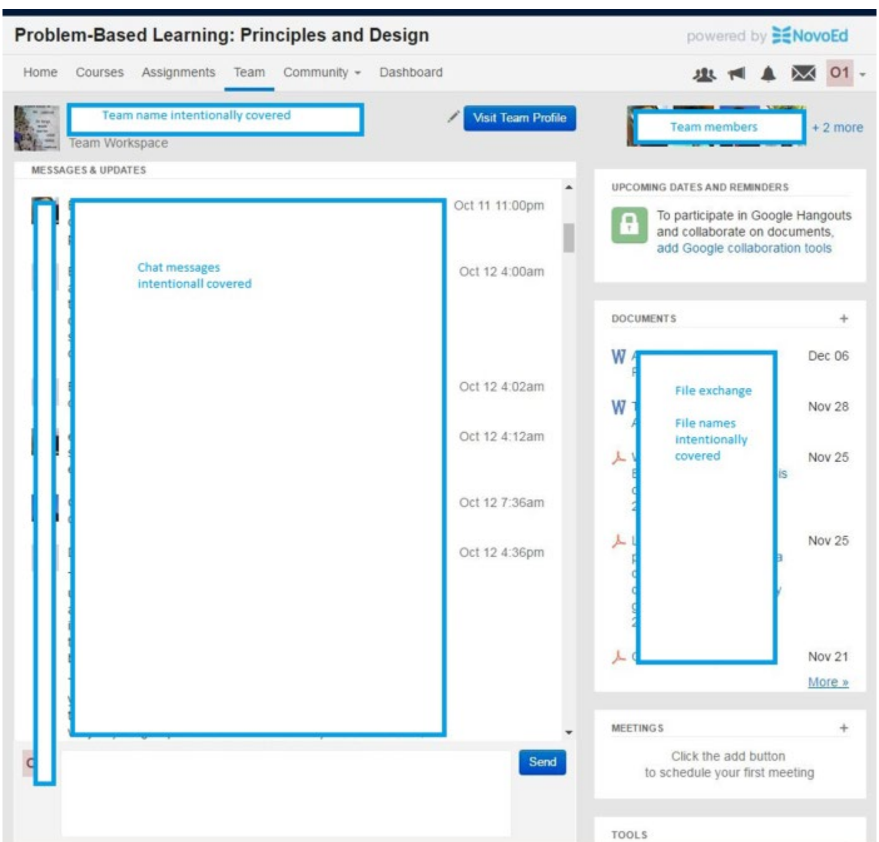

Figure 29.2 Team Space with Public Profile Page and Private Chat Facilities, File Exchange and Facilities to Schedule Meetings.

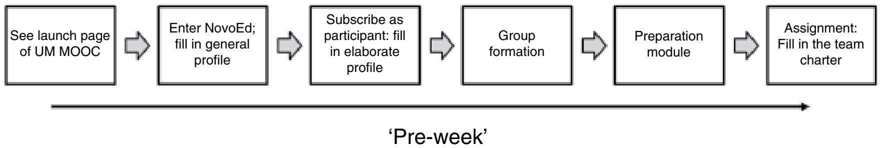

Figure 29.3 The "Pre-week" in the MOOC "Problem-Based Learning: Principles and Design. Students at the Centre!"

The MOOC is, however, at the moment not embedded in any UM curriculum; students cannot earn study credits.

The MOOC is designed to last 9 weeks with a study load of 4–8 hr per week. Figure 29.3 shows that the first week is a "pre-week" dedicated to learning more about the structure of the course and forming teams, including working on a team charter assignment. Subsequently, participants are asked to work in groups on authentic problems in a similar way to face-to-face PBL tutor groups, except that they work online and do not have a tutor. Students who actively participate and finish the course are given a Certificate of Participation, but the design does not include a formal exam (see the next session for a brief description of participants who took part in the first runs of the MOOC and how they were recruited).

Apart from the small-group work, some general activities are incorporated in the design, illustrated in Figure 29.4:

- A set of mini-lectures about important aspects of PBL.
- General discussion fora accessible to all participants, with some prespecified topics, but also the freedom to start new threads.
- Weekly Google Hangouts sessions by the facilitators: sessions of 20–30 min where the facilitators react to questions, elaborate on specific topics (e.g., related to the tasks of the week), react to main issues in the discussion fora, or give concrete tips for often-encountered problems. These sessions are recorded and made available for those who cannot attend live.
- Networking opportunities in NovoEd allow participants to connect also with participants who are not in their own team (e.g., searching for other participants based on profile information and contacting them, identifying other interesting teams, and following their public page and/or inspecting their assignments).

Constructive and contextual learning: Authentic problems in three tracks

The course is centered on a set of authentic or professionally relevant problems. An example of a problem is included in Table 29.1. In line with four-component instructional design (4C/ID; van Merriënboer & Kirschner, 2018), the problems take different forms and participants have some freedom to set out their own learning trajectory. The problems are organized into three different tracks that are targeted at different types of participants:

- Track 1: The role of the tutor in PBL. This track focuses on the teacher in the role of tutor. This is often the first role that beginning teachers take in a PBL curriculum.

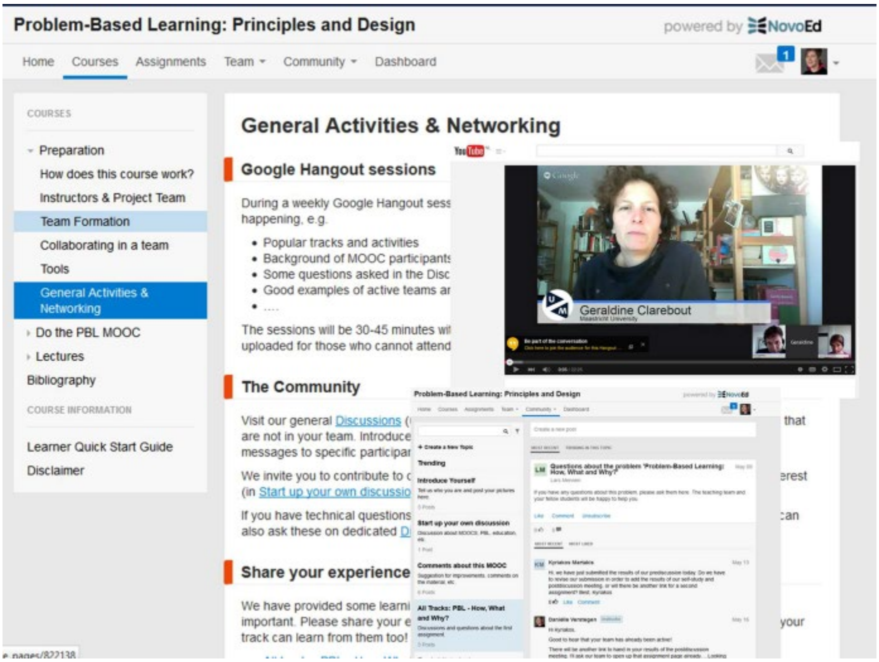

Figure 29.4 General Facilities and Networking Options.

Table 29.1 PBL Problems organized in 3 Tracks

Week 1–2	Week 3–4–5–6	Week 7–8
Problem 1: PBL Principles of learning	Track 1: The role of the tutor in PBL (two problems) Track 2: Designing PBL problems & courses (two problems) Track 3: Assessment and organizational aspects of PBL (two problems)	Problem 8: Application of PBL principles

- Track 2: Designing PBL problems and courses. This track focuses on design aspects of PBL, which might be interesting for instructional designers and for more experienced teachers who are taking up the role of PBL problem author or course coordinator.
- Track 3: Assessment and organizational aspects of PBL. This track looks into aspects of PBL at the curriculum level, aligning assessment, implementation, and innovation of PBL curricula. It targets educational managers or experienced staff taking up the role of curriculum coordinator.

For the first and the last 2 weeks participants in all tracks work on the same problems, focusing on the learning principles underlying PBL (first problem) and the application of PBL principles in their own setting. In-between, they work on track-specific problems. Thus, in the middle part the tracks split up (see Table 29.1).

Each problem is divided over 2 weeks, and some basic resources are given in the form of video clips or public booklets or journal articles. Both teacher and student viewpoints are illustrated in short recorded interviews about their experiences with PBL. A larger set of references, some free and some licensed, are provided on a bibliography page. The learning materials include examples from the five different domains of UM: (a) healthy body, healthy mind; (b) economics, business, trade, and management; (c) international relations, politics, and law; (d) arts, literature, and philosophy; and (e) science and technology.

Collaborative learning: Working in small groups

Small-group work is essential to PBL and, therefore, also in this MOOC. In the MOOC one PBL problem takes 2 weeks: in the first week the participants brainstorm within their group, they formulate learning questions together and then start some self-study. In the second week, they complete their self-study and report and discuss with the other group members what they have found. All assignments are group assignments: the groups are asked to hand in their learning questions at the end of the brainstorming phase/prediscussion and a summary of what they have found and discussed at the end of the reporting phase/postdiscussion. The assignments are not graded—only peer reviewed by members of other teams. The peer reviews (see below) are the only individual tasks.

In the first "pre-week" participants are asked to fill out their profile, study the preparation module, and form learning teams (see Figure 29.3). There are three ways to get into a team:

- Start a new team and invite others to join, for example, inviting colleagues or friends, or looking for other MOOC participants who have similar backgrounds or interests (based on their profile).
- Join an existing team, looking for an interesting team (based on the team's name, tagline, or profile) or for other participants with similar interests (based on individual profiles).
- Wait to be automatically assigned to a team at the end of the "pre-week," based on the chosen track and other preferences (only possible if the participant's profile is filled out).

All members of the team have to take the same track. In principle, the teams stay together over the whole course. However, since anyone can enter and the course is free, a significant dropout of up to 95% is to be expected (Devlin, 2013) Therefore, some regrouping is foreseen. The course facilitators encourage teams that become very small (i.e., do not have enough active members to work effectively) to merge with different teams on the same track. (Note that in the original design the idea was to detect small teams automatically and send these teams concrete suggestions of teams they could merge with. Unfortunately, this proved technically impossible in the present implementation.)

Self-directed learning

By nature, MOOCs have a stronger focus on self-directed learning because the participants find the course by themselves and subscribe out of interest (and not because the course is part of a curriculum, for instance). In the absence of formal assessment there is a lot of inherent freedom to decide on what to study, how to interpret the assignments, and also to decide on how much effort to put in. This is in line with the idea to stimulate self-directed learning but differs from the implementation of PBL in an institution-based curriculum where all students are expected to attain the same competencies, and all students have to take the same exams.

The design of "Problem-based learning: Principles and design. Students at the centre!" aims to further stimulate self-directed learning in different ways; for example, by stimulating participants to form their own teams. This option is described as a preferred option in the instructions, and this is stressed by the facilitators during the MOOC execution. In the tasks, a basic structure of the PBL approach is given in the form of steps to take, but the teams formulate their own learning questions. They can also decide for themselves how they want to collaborate and communicate, synchronously or asynchronously, using the tools provided in their team space or others, if they prefer.

The team charter assignment in the "pre-week" is added as a scaffold to help teams to make communication and collaboration plans themselves. In line with 4C/ID, the amount of scaffolding is reduced for later problems (van Merriënboer & Kirschner, 2018). During the MOOC execution, the newly formed teams are asked to fill out and hand in a Team Charter, asking them to divide roles (who will lead, who will plan, who will hand in assignments) and rules for collaboration. In the team charter, the teams are also asked to describe how they intend to communicate (synchronously or asynchronously) and which tools they intend to use. Some open questions at the end ask them to discuss how they plan to deal with unequal participation and lurkers, unwanted behavior, etc. The text of the team charter assignment also gives more elaborate information about the PBL assignments in the course and about what they are expected to do in the course, giving a few examples of how they might want to work, rather than being prescriptive.

During the rest of the course, the teams are asked to formulate their own learning questions for each problem, and this explicitly allows teams to focus on domains or aspects of their interest. Examples of questions related to the example of the problem presented in Figure 29.5 are: What are the characteristics of effective problems? Which types of problems can be designed? Which kinds of formats can be used and what are the advantages and disadvantages of using problems to initiate learning instead of traditional teaching? Teams may, however, decide to focus on only one or two of these aspects or to formulate learning questions more specifically for the domain or the target group of students that they are interested in. Furthermore, participants are stimulated to find and share learning resources within their team and in the general discussion fora.

Finally, self-directed learning is also stimulated by incorporating peer review (between teams) and evaluation of team members (within teams). All the

Track 2: The problem as a starting point for learning (part A)

"As a new teacher in a problem-based curriculum I have been asked to design a problem for use in tutorial groups as a starting point for learning. This is quite different from what I usually do, which is giving students assignments. The problem should be used in a theme-oriented course in the curriculum. The course coordinator told me that the problem should be appropriate to the course and not be too complex. I had much freedom to design the problem and could choose any format. The design of a new problem raised many questions. I started to look at existing problems relevant to my own discipline and wondered how to design a problem and which format to choose."

Assignment

Brainstorming phase:

1. Discuss the problem description presented above in your team. Brainstorm about what you already know and what you do not yet understand about problem design.

2. Formulate questions that need further study.

3. When you have finished, ask one team member to submit a document listing your team's study questions via the 'Get started' button below.

Self-study (may continue into the next week)

4. Study the materials individually. Watch the videos, look at the examples of problems, consult the booklet about problem construction, and the other resources provided. There is a longer list of open and licensed resources in the bibliography.

5. Look for other relevant materials in your own collection or on the Internet. Try to find resources about PBL problem construction that fit your disciplinary background.

6. Share your resources with your team (in the team space) and with all other participants (on Discussions).

7. Write a summary in which you address your questions about problem design.

8. Design or redesign a problem and try to apply principles of effective problem/case design for Problem-Based Learning.

Figure 29.5 Example of a Problem in the Design Track with Instructions for the First Week.

assignments (except for the team charter) are public so that participants can see the assignments of all other teams. The NovoEd platform gives the opportunity to give comments and likes. After each problem, that is, after the reporting phase/postdiscussion at the end of every second week, participants are explicitly asked to peer review the assignments of three other teams using criteria and a grid with the questions: What worked? What was unclear? What could be improved? What other ideas could be considered? The peer reviews are not public, but can be inspected by the team that handed in the assignment. Participants are also be asked to rate their own contribution to the assignment and to rate the contribution of their team mates on a scale from "No contribution" to "Very devoted." These ratings are private and can only be seen by the course facilitators. They can be used by the facilitators to gain insight into who is still active and who is not. Participants whose contributions are rated on average, as "insufficient" by their team members are not awarded a certificate of participation.

Design dilemmas

The inherent differences between the characteristics of MOOCs (open access, no entry requirements, and no formal obligations) and PBL did cause some friction. One of the dilemmas that the design team struggled with was whether group work should be obligatory. The team considered including the option of an individual track with more intensive peer review as the only obligatory interactive activity, but in the end decided against it because this would violate the important principle of collaborative learning. The consequence is that participants who do not want to commit to group work cannot participate in assignments (although the NovoEd platform allows them to subscribe as "auditors" and view all the material). It also means that participants who end up in a team that does not function well or becomes too small due to dropout are expected to look for a different team themselves. The original design did specify some measures to detect inactive teams and propose or enforce merges, but technical limitations made this impossible.

Another threat to group work in a MOOC is the large dropout. In the world of MOOCs dropout is not always seen as a problem: participants are assumed to participate out of intrinsic motivation and when they have learned enough, do not like the course as much as they thought, or cannot free up enough time they leave. However, for effective group work, the building of trust and commitment are important. For this reason, the design team decided to stimulate commitment by encouraging participants to form teams based on shared interests or backgrounds (e.g., based on the domain of interest and the level on experience with teaching and PBL). The NovoEd platform facilitates this by making it possible to search the set of participants based on characteristics in participants' profile. The team charter assignment in the "pre-week" is also aimed at establishing trust and commitment. Nonetheless, substantial dropout is expected and, therefore, the ideal team size at the start is set quite high at 15 participants per team. During the MOOC participants are stimulated to merge teams if their team has become too small.

Another dilemma for the design team was the amount of structure versus flexibility. In general, MOOCs give participants a lot of liberty in what they do and when and how they do it, and this is in line with the principle of stimulating self-directed learning. PBL, however, assumes that structure is important to make groups collaborate. Often a procedure is prescribed in the form of a sequence of steps to take with prescheduled face-to-face meetings, like for example the Seven Jump approach at UM (Maastricht University, 2015; Moust et al., 2014). In the context of online PBL, our experience and the research literature suggest that synchronous discussions might work better than asynchronous discussions (Verstegen et al., 2016), but synchronous contacts might be difficult to arrange with participants who live in different time zones. In the end, the design team chose a middle road for the MOOC of "Problem-Based Learning: Principles and design. Students at the centre!". Each assignment specifies which steps to take but does not prescribe how and when, leaving teams the freedom to communicate and collaborate in their own preferred way. Thus, in line with 4C/ID (van Merriënboer & Kirschner, 2018), guidance is given for the collaborative problem-solving process in a flexible way, and the type of guidance offered is different for different problems.

The fourth topic of discussion concerned the selection of topics and domains for the PBL problems, and the level of difficulty. The MOOC is designed for a wide audience, which means that it should cater for PBL novices and participants with (some) experience with PBL and for participants from different domains. The design team also wanted to show that PBL could be implemented in a variety of ways. Ideally, a large variety of PBL problems should be available, but this was not feasible within the scope and budget of this project. The final design provides three tracks for different target groups, assuming that PBL novices will often start as tutors, and participants with PBL experience will be more interested in the design or implementation track. Within each problem examples of different domains are given, for example, in the tutor track video clips with examples of tutor groups from different faculties.

Execution of the MOOC

This section describes the execution of the MOOC, first in a small-scale pilot study and then in the first large-scale fully open run.

Pilot study

A pilot study with 104 participants (20 subscribed as auditor and 84 as participant) was conducted from May 12, 2015, to July 12, 2015 (9 weeks). Participants were recruited mainly among UM colleagues via newsletters and personal contacts of the project team. The pilot run was executed with three facilitators, two of whom had been involved in the design of the MOOC as well (i.e., Daniëlle Verstegen, Herco Fonteijn, & Geraldine Clarebout). In the pilot run, 30 participants actively joined a team and about half of these finished the course and were awarded a Certificate of Participation (n = 16). During the pilot study, log data were collected on a weekly basis from the NovoEd platform. The assignments and content of the general discussion fora were downloaded at the end of the course. The NovoEd platform does not give course facilitators access to the chat and content of the private team spaces. The participants were invited to fill in two online surveys (after 3 weeks and at the end of the course). Some participants gave additional oral feedback to members of the project team, and an oral evaluation session with the facilitators was conducted by another member of the project team.

The results of the surveys and comments of participants showed that participants were positive about the PBL tasks and the learning materials; participants gave some suggestions for small improvements too. Inspection of the assignments confirmed that the participants had been discussing topics that the task writers had intended them to discuss. The different groups did, however, sometimes choose a slightly different focus and some groups put in more effort than others. This caused some confusion during the peer reviews (which in the pilot run were based on rating scales). The peer reviews were often not very informative because most participants only used the rating scales and give no further comments. Some groups found it difficult to start up because there is no prescribed way of how to collaborate and communicate within the team. Comments during the pilot run and results of the questionnaires also showed that participants had difficulties with keeping an overview of tasks and deadlines and that they were confused by the fact that they had access to the tasks of all tracks.

Based on the results of the pilot study the project team decided to make no major changes in the content of the course. Some small changes in text and layout were made based on suggestions of the participants and experiences of the facilitators. The peer review form was changed to a grid with open questions to stimulate participants to provide more elaborate and constructive feedback. The goal of feedback was also explained more elaborately in the instructions. To support group formation the team charter assignment was added in the "pre-week" (see previous section) and the facilitators were asked to address this topic explicitly during the first weeks by giving more elaborate information about the PBL assignments in the course, about what participants are expected to do, and by giving a few examples of how they might want to work. Unfortunately, the NovoEd platform does not allow offering completely different tracks to different groups of participants. Therefore, the project team decided to provide an explicit schedule for each track and to open up assignments gradually, so that not all of them were visible at the start. Other minor revisions concerned the place of the learning resources and the structure of the general discussion fora.

First run of the MOOC

The first open run of the MOOC "Problem-based learning: Principles and design. Students at the centre!" was executed in 2015, from October 5 to December 12, 2015. The MOOC was advertised using the NovoEd catalogue and newsletter, UM communication channels including newsletters and alumni networks, a press release, and social media like Twitter and LinkedIn, using both personal contacts from project team members and joining groups related to MOOCs. There were four facilitators in the course who were based in educational departments in three different UM faculties (i.e., Geraldine Clarebout, Amber Dailey-Hebert, Herco Fonteijn & Daniëlle Verstegen, see Figure 29.1). Three of the facilitators had also been involved in the pilot study. The facilitators organized weekly Google Hangouts sessions, watched the discussion fora, answered all technical questions, and occasionally reacted to other forum posts.

Log data were collected on a weekly basis from the NovoEd platform. The assignments and content of the general discussion fora were downloaded at the end of the course. The NovoEd platform does not give course facilitators access to the chat and content of the private team spaces. The participants were invited to fill in two online surveys (halfway through and at the end of the course). A focus group discussion with the facilitators was conducted by another member of the project team.

The course started with 2,989 participants, of whom 2,653 subscribed as "students" and 336 as "auditors." Just over a quarter (26%) filled in their profiles and became part of the 111 teams. Of these 111 teams, 49 (44%) finished the course (i.e., handed in the last assignment) and 264 participants received a certificate of participation. There were teams in all the three tracks, but Track 2 was most popular. Questionnaire data show that participants came from all over the world. This is also illustrated by the Google Map that was a voluntary part of the forum "Introduce yourself," see Figure 29.6.

Figure 29.6 MOOC participants came from all over the world.

The majority of teams was formed by the participants themselves (98 teams), and 13 teams were formed automatically (using an algorithm) at the end of the "pre-week" from participants who had filled in their profile but not joined a team yet. Some of the self-formed teams are region-based, or even formed by colleagues from the same institute. Others formed around a certain area of interest, such as professional education or language teaching. These interests were also visible in the heavily used general discussion fora where hefty discussions took place on a variation of topics, ranging from "What does a good tutor do?" to "Can I use PBL for mathematics, primary school children, disadvantaged students, etc."

Some lessons learned

This section briefly describes some of the main lessons learned. For a more elaborate description of all data collected during the MOOC see Verstegen et al. (2016).

The MOOC "Problem-based learning: Principles and design. Students at the centre!" was executed as planned without major problems. Questionnaire results and comments in discussion fora show that most of the active participants were positive about the PBL problems and the learning resources that were provided. Inspection of the assignments showed that the quality of the assignments varied widely. However, the project team members who were responsible for writing the problems were positively surprised by the quality of a large part of the assignments. Some groups developed concept maps in which they explained what they had learned and in which they referred to various literature resources that were consulted.

Both facilitators and participants indicated that the course, which lasted for 9 weeks, was too long. The motivation and enthusiasm of participants seemed to dwindle a bit after 4 weeks. Offering three tracks simultaneously caused some confusion. Due to technical limitations, participants could see the assignments of all tracks, and received reminders of all assignments, also those not on their own track. The NovoEd platform does not support parallel tracks and assumes a strictly linear sequence of tasks ordered by the deadline. This MOOC's design did not fit within those assumptions.

The dropout rate at the individual level was high (around 90%), which is not unexpected for MOOCs (Devlin, 2013). On the other hand, 49 out of 111 teams (44%) completed the course and handed in the final assignment, due to which the dropout rate at the team level was much lower than the dropout at the individual level. It is probable that a large proportion of the dropouts are participants who were not looking for more than a peek at the course and the materials, either because that was the only information they were looking for or because they did not want to commit to active participation in group work (e.g., because of lack of time). However, part of the dropout may have been caused by the fact that some participants were unable to find a team or got frustrated because they ended up in an inactive team. Participants were free to leave a team and join a different team, but this required extra effort. In future, we may further explore ways to support team reformation (e.g., use algorithms to merge teams or form new teams during the course, or by creating explicit spaces on the discussion forum where participants can be helped by facilitators to find or make teams). It is also not clear whether participants would like to regroup halfway through, though. So, maybe another option would be to offer an individual track, for example with more frequent peer feedback, but this would mean a compromise to the principle of stimulating collaborative learning, which is an important aspect of PBL.

Discussions on the fora and inspection of the assignments also showed that teams collaborated and communicated in very different ways and that the quality of the output differs across groups. In general, the teams followed a PBL-like process (brainstorming, formulating learning questions, reporting, and discussing results). Most teams opted for asynchronous interaction, and this may have limited the amount of discussion. For some teams, it took some time to find a good way to collaborate, and some teams clearly struggled. Other teams seemed to have no trouble establishing a way of working and showed great creativity in the tools and methods they used. The project team observed a number of teams in more detail, following the interaction between team members in their team space by joining their team as an observer (after informed consent) (Verstegen et al., 2016).

It proved to be difficult to compose viable groups algorithmically. The majority of the 13 automatically formed teams never really started working on assignments. Self-formed teams appeared to perform better, perhaps because of social cohesion (e.g., a team of teachers working at the same institution in Ukraine) or task cohesion (e.g., a team of English as a second language teachers). Fortunately, most teams managed to collect insights from active team members, despite dwindling numbers of active participants and a large number of participants who were new to MOOCs—and possibly to virtual group work. Participants familiar with face-to-face group work may have experienced that virtuality negatively relates to communication frequency, knowledge sharing, team satisfaction, and team performance, particularly in short-term teams (De Guinea, Webster, & Staples, 2012).

Social equalization, on the other hand, which is also typical of online group work, may have helped to share of information on PBL in culturally diverse groups (cf. Mesmer-Magnus & De Church, 2009). After initial sharing, however, team members quite often seemed reluctant or unable to elaborate on contributions of other team members—although some groups produced impressive infographics and mind maps. Some of the dropout and poor group performance may be explained by social comparison. Rogers and Feller (2016) showed that exposure to exemplary peer performances caused a large proportion of students to quit a MOOC, presumably by causing people to perceive that they cannot attain their peers' high levels of performance. Insufficient digital literacy and teamwork skills could also account for superficial analysis, as well as the absence of a tutor (cf. Ertmer & Koehler, 2015). Tutors in online learning often play an active role in initiating and carrying a discussion forward (e.g., by setting expectations or raising new questions (Nandi, Hamilton, & Harland, 2012). Hence, we feel team members may need more support as they start up team collaboration. In this run, this was stimulated by asking participants to complete a team charter (cf. Mathieu & Rapp, 2009) in the pre-week, in which personalia, self-confessed strengths/weaknesses, norms regarding group successes and failures, and division of roles and implementation intentions (who does what when?) are gathered. However, since some participants dropped out after contributing to the team charter, the teams needed to adapt their process continuously. Incentives to reflect regularly on group processes and outcomes and to update work methods may further enhance co-creation in the absence of a tutor. At the start of the MOOC, teams also need to be made aware of strongly varying digital literacy levels of members. Another option might be to provide more explicit instruction on how to use different online tools.

Discussion

In this discussion, we first reflect on whether this MOOC can be called PBL-based or not. Subsequently, we discuss potential future uses of the PBL MOOC.

Is This MOOC Really PBL?

As described above, the MOOC "Problem-based learning: Principles and design. Students at the centre!" was designed in line with the learning principles that are the basis of PBL: stimulating constructive, contextual, collaborative, and self-directed learning. However, can we call this PBL?

As stated above, PBL is characterized by learning in small groups, a tutor who facilitates learning in the small group, learning initiated by problems and new information to be acquired during self-study (Barrows, 1996). The MOOC "Problem-based learning: Principles and design. Students at the center!" does fit well with most of these characteristics, but there is one large difference: the absence of a tutor to facilitate the learning process. In this respect, the course differs significantly from PBL as practiced in many institutions worldwide. The project team accepted this restriction because of financial and personnel limitations. It would have been impossible to give large numbers of participants free access to this course otherwise. Some of the problems in group formation and group communication and collaboration, however, might have been caused by the absence of a tutor.

Within this MOOC, participants elaborated and actively constructed their own knowledge by discussing authentic, professionally relevant problems. They interacted with each other, discussing complex issues in order to gain a deep understanding. They followed a similar process as in regular PBL: a brainstorming phase in which they collaboratively generated their own learning questions, followed by a self-study phase in which they individually searched resources to study the learning questions, and then a reporting phase in which they collaboratively discussed what they had found. In the complete absence of tutor guidance and feedback, participants learned with and from each other. Inspection of the assignments showed that many groups generated questions and discussed issues that correspond well with the objectives that the problem designers had in mind or even went beyond the intended objectives, (e.g., for the task shown in Figure 29.5 some teams also discussed issues related to review or evaluation of PBL problems). Inspection of assignments handed in after the reporting phase shows that some groups constructed new knowledge, summarizing their main findings in their own words creatively using various formats (text, concept maps, Prezi, poster) and referring to various sources of information. Groups regularly also shared resources that were not listed in our MOOC and referred to related research papers. This seems to indicate that some groups did indeed gain deep insight. The products of other groups, however, demonstrated a lack of deep learning. Their assignments were, for example, very short, consisted only of a list of individual contributions (identified by the name of the contributor), or even only of copy–pasted texts from the resources provided within the MOOC.

Thus, we conclude that the design of the MOOC "Problem-based learning: Principles and design. Students at the centre!" is well aligned with PBL learning principles, but that the envisioned kind of learning was realized in some groups and not in other groups. Further research is needed to investigate ways to support tutor-like support and guidance in the setting of MOOCs. Savery (2015) emphasized that a tutor who guides the learning process is critical to the success of the PBL approach. The tutor promotes in-depth discussions and encourages the use of specific cognitive skills by students (De Rijdt et al., 2012; Dolmans et al., 2002; Norman & Schmidt, 1992). The role of the tutor is to facilitate collaborative knowledge construction (Hmelo-Silver & Barrows, 2006). Given the massive scale (in this MOOC 111 groups) providing an experienced human PBL tutor to each group will not be feasible. There is some experience in face-to-face PBL with PBL groups without tutors or a ratio of one tutor to several PBL groups (e.g., Fonteijn, 2015). It is not yet clear whether concepts like these can be used in the setting of MOOCs, where teams are far more heterogeneous, interact online, and may have no previous experience with PBL.

The future of the PBL MOOC

This project started with the goal of gaining first-hand experience with MOOCs, to explore to what extent PBL and MOOCs are compatible and to gain further insights into the possibilities of online PBL. After the first run of the MOOC, the projected team discussed what other roles the PBL MOOC could have in the future, for example for internal use.

First, there is potential in the area of internal faculty development. At UM, most PBL courses are face to face in tutorial groups that are guided by tutors. Because the role of the tutor is important but also a challenging one, UM pays a great deal of attention to its new tutors. Fresh tutors are trained by professionals in faculty development. For advanced teachers faculty development also offers training in the problem and course design, assessment, and implementation of PBL curricula. Quite a few faculty developers have also been involved in the MOOC project, which resulted in the reuse of some existing materials in the MOOC, but also vice versa: the use of new MOOC materials in internal faculty development.

Regardless of whether it is part of formal faculty development of not, participating in the PBL MOOC can be interesting for UM staff members as a refresher or further elaboration of their competencies in PBL. The interaction with a worldwide audience brings together a wealth of PBL experiences and practices, including resources and innovative formats.

The project team also identified options to use the MOOC to offer internal faculty members development in an innovative and more flexible way; for example, by offering UM staff the opportunity to participate in the MOOC in "special" groups with the guidance of a tutor from faculty development. More experienced teachers might enhance their PBL competencies by designing new PBL problems for the MOOC or by participating as a MOOC facilitator, especially when they are interested in the potential of online PBL. Thus, working on the MOOC could be a form of faculty development too.

Second, the MOOC provided a platform for the exchange of knowledge on PBL across disciplines and cultures. During the design of the MOOC, teachers at UM became aware of the differences in implementation of PBL by various faculties. Once running, the diverse composition of the participant body sparked lively discussions that often focused on constraints on the proper implementation of PBL. Although PBL is often believed to be a signature pedagogy of disciplines like medicine and health sciences in Canada and Europe, discussions were infused with insights from other fields (e.g., science, technology, engineering, and mathematics), cultures (most notably, participants from Brazil, India, and Mexico), and participants with different professional roles (e.g., teacher, educational advisor, manager). These participants highly valued MOOC resources (e.g., video lectures), which triggered as much information sharing on discussion fora as did the PBL assignments. Even in a team where co-construction and elaboration were limited, individual team members could benefit from the intergroup exchange of information through discussion boards. The outcome interdependence (individual certificates were awarded depending on the successful performance of the team) that was implemented via peer assessment provided an additional incentive for sharing knowledge among group members and among groups. Thus, executing this MOOC has certainly contributed to further establishing the university's internal and external network. In the discussions, participants regularly mention that this is for them a follow-up of previous visits or contacts with UM or that they are planning to visit.

Innovation of Education and PBL in Particular

The MOOC project itself has achieved a university-wide discussion about PBL and innovation in PBL within the project team that consisted of 34 people and included representatives from all faculties. Important topics were, for example, variations of PBL, options for PBL online, and limitations of PBL. In future, the PBL MOOC is expected to further promote educational innovation at UM and possibly other institutes for higher education in two ways: innovations in PBL and innovations in MOOCs.

With regard to innovations in PBL, three directions can be distinguished: use of distance teaching, more varied instructional tasks, and a stronger focus on self-directed learning. Until recently, the Maastricht form of PBL was characterized by frequent face-to-face meetings of small educational groups. There is only limited experience with blended and online forms of PBL. The PBL MOOC has shown that fully online versions of PBL are possible but need to be further developed. A second innovation concerns the use of a wider variety of tasks or problems. In traditional PBL most problems describe phenomena for which an explanation can be found in the literature (although some faculties experiment with other types of tasks). The PBL MOOC used different types of tasks (e.g., give an explanation for a particular phenomenon, collaboratively design an artifact, assess solutions offered by others), which might also inspire the use of other tasks in PBL. Third, and probably most important, the PBL MOOC helped us to rethink self-directed learning because (a) groups in the MOOC were working without a tutor, (b) participants in the MOOC could select—part of—the tasks according to their own interests, and (c) groups had a lot of freedom to find their own way of working (rather than using the Maastricht Seven Jump model).

With regard to innovations in MOOCs, the PBL MOOC showed that, at least to some degree, it is possible to realize the learning principles underlying PBL in a MOOC: stimulating contextualized, collaborative, and constructive learning. In the PBL MOOC learners were not primarily studying information (e.g., web lectures, written resources) but the learning was driven by authentic learning tasks that were placed in context. Second, although the first run of the PBL MOOC was still "massive," with over 3,000 participants, they were collaborating in relatively small groups. Third, for several learning tasks participants had to construct tangible products, which they shared within and outside the group. At the start of the project, there was considerable skepticism because many employees of UM viewed MOOCs as conflicting with PBL. After the project, it has become clear that at least some of the PBL principles can be realized in MOOCs, which will stimulate further experiments and innovations with MOOCs in a PBL context.

Other Uses of MOOCs Require Different Designs

Experts reported that organizing MOOCs has increased consciousness of the possibilities of digital education in their institutions, but has also led to a higher appreciation for the profession of teaching, capacity building, and collaborative course design (Salisbury, 2014). This has certainly also been true for our MOOC project. There are, however, many other reasons to organize MOOCs, such as attracting future students or disseminating expertise in a certain domain to a wider public, either in the context of a research project or to reach out to new target groups who do not have easy access to (higher) education. MOOCs serving a different goal would also ask for a different design. For example, if attracting future students for a particular program is the main goal, then it would be advisable to choose a program-specific topic and to make sure that participants have opportunities to connect with future teachers and fellow students.

Conclusion

Many MOOCs fall back on "old-fashioned" information-delivery designs. The example described in this chapter shows that innovative instructional models for MOOCs are feasible. Whether this MOOC can be called PBL remains questionable: it differs from more traditional forms in some important aspects. It does show, however, that it is possible to apply modern learning principles of constructive, contextual, collaborative, and self-directed learning—at least to a large extent—for designing MOOCs. Online collaboration in virtual teams remains a challenge and requires dedicated support. A significant dropout is to be expected, and not all teams will succeed. More research into factors determining team success or failure is required.

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Index

Page locators in **bold** indicate tables. Page locators in *italics* indicate figures.

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