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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
<i>Author(s)</i>	Neufeld and Barrows (1974)	Barrows (1985); Koschmann et al. (1994)	Neame (1989)	Dolmans and Snellen-Balendong (2000)
<i>Institution of origin</i>	McMaster University, Canada	Southern Illinois University, United States	University of Newcastle, Australia	Maastricht University, The Netherlands
<i>Process description</i>	<p>Sequence of learning activities:</p> <ol style="list-style-type: none"> 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) 	<p>Stage 1: Problem formulation Iterative process of</p> <ol style="list-style-type: none"> 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 <p>Stage 2: Self-directed study</p> <ol style="list-style-type: none"> 1) Resource identification 2) Self-directed study <p>Stage 3: Problem reexamination</p> <ol style="list-style-type: none"> 1) Critiquing/discussing resources 2) Problem reassessment by applying new knowledge <p>Stage 3 can result in new learning issues and self-directed study</p> <p>Stage 4: Abstraction</p> <ol style="list-style-type: none"> 1) Summary and integration of learning <p>Stage 5: Reflection</p> <ol style="list-style-type: none"> 1) Evaluation 	<p>Model for diagnostic decisions:</p> <ol style="list-style-type: none"> 1) Cue recognition 2) Initial formulation 3) Hypothesis generation 4) Hypothesis organization (possible mechanisms) 5) Inquiry strategy with recursive cycles with: <ol style="list-style-type: none"> a) Need to know: patient personal or clinical data b) Need to learn 6) Problem reformulation 7) Final formulation 8) Diagnostic Decision 	<ol style="list-style-type: none"> 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
<i>Author(s)</i>	Schmidt (1983); Schmidt and Moust (2000)	Rienties et al. (2012)	Rohlin et al. (1998)	O'Neill et al. (2002)
<i>Institution of origin</i>	Maastricht University, The Netherlands	Maastricht University, The Netherlands	Lund University, Sweden	University of Manchester, United Kingdom
<i>Process description</i>	<p>First meeting:</p> <ol style="list-style-type: none"> 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 <p>Self-study period:</p> <ol style="list-style-type: none"> 6) Self-study <p>Subsequent meeting:</p> <ol style="list-style-type: none"> 7) Share findings 	<p>Initial discussion of task:</p> <ol style="list-style-type: none"> 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) <p>Postdiscussion of task:</p> <ol style="list-style-type: none"> 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) 	<p>First meeting:</p> <ol style="list-style-type: none"> 1) Define problems 2) Generate hypotheses 3) Formulate learning issues <p>Self-study period:</p> <ol style="list-style-type: none"> 4) Collect additional information outside the group <p>Next meeting:</p> <ol style="list-style-type: none"> 5) Synthesize newly acquired knowledge 6) Test hypotheses 	<p>First meeting:</p> <ol style="list-style-type: none"> 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 <p>Self-study period:</p> <ol style="list-style-type: none"> 6) Self-study privately and gain clinical experience <p>Subsequent meeting:</p> <ol style="list-style-type: none"> 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
<i>Author(s)</i>	Dahlgren and Öberg (2001); Jansson et al. (2015) ^a	Holmberg-Marttila et al. (2005)	Poikela and Poikela (2006)
<i>Institution of origin</i>	Linköping University, Sweden	University of Tampere, Finland	University of Lapland, Finland
<i>Process description</i>	<p>First meeting:</p> <ol style="list-style-type: none"> 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 <p>Self-study period:</p> <ol style="list-style-type: none"> 6) Knowledge gathering: Individual/group work focused on learning objectives <p>Next meeting:</p> <ol style="list-style-type: none"> 7) Reporting: Findings are reported, described, and explained 	<p>First meeting:</p> <ol style="list-style-type: none"> 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 <p>Self-study period:</p> <ol style="list-style-type: none"> 6) Self-study: Searching information to answer learning objectives <p>Next meeting:</p> <ol style="list-style-type: none"> 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 <p>In all phases continuous evaluation and assessment is emphasized</p>	<p>First meeting:</p> <ol style="list-style-type: none"> 1) Problem setting 2) Brainstorming: free association 3) Systematization: structuring 4) Selecting most important categories in problem 5) Learning task: formulation <p>Self-study period:</p> <ol style="list-style-type: none"> 6) Knowledge acquisition <p>Next meeting:</p> <ol style="list-style-type: none"> 7) Knowledge integration: construction 8) Clarification: comparing with original problem <p>In all phases, continuous evaluation and assessment is emphasized</p>

^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
<i>Author(s)</i>	Barrows and Myers (1993)	Torp and Sage (1998, 2002)
<i>Institution of origin</i>	Southern Illinois University and Lanphier High School	Illinois Mathematics and Science Academy's Center for Problem-Based Learning
<i>Process description</i>	<p>Starting a new problem:</p> <ol style="list-style-type: none"> 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 <p>Self-study period:</p> <ol style="list-style-type: none"> 10) Self-directed learning <p>Problem follow-up:</p> <ol style="list-style-type: none"> 11) Critique used resources 12) Reassess the problem (hypotheses, facts, learning issues, and action plan) <p>Performance presentation after conclusion of the problem:</p> <ol style="list-style-type: none"> 13) Knowledge abstraction and summary 14) Self-evaluation (and comments from the group) 	<p>Teaching and learning events:</p> <ol style="list-style-type: none"> 1) Prepare the learner (optional) 2) Meet the problem 3) Iterative cycle of activities: <ul style="list-style-type: none"> ● 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 <p>Instructions and assessment should be embedded within the teaching and learning events</p>

(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 audio-visual 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, & Gale, 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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