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Problem-Based Learning

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Problem-based learning (PBL) represents a major development in educational practice that continues to impact both courses and disciplines worldwide (Schmidt, van der Molen, te Winkel, & Wijnen, 2009a). The chapter first outlines what PBL is and when, why, and how it developed. Next, it discusses what PBL aims to establish. The key elements of PBL are reviewed, followed by empirical research on the effects of PBL. Finally, it concludes the chapter with critical remarks and final notes.

Why and How Did Problem-Based Learning Develop?

The roots of PBL go back to the mid-1960s at the McMaster University Medical School in Hamilton, Canada (Neufeld & Barrows, 1974). A common problem in medical education was that students had difficulty with first-year courses such as anatomy, biochemistry, and physiology. They struggled with these topics and became less motivated because they did not see the relevance of the issues discussed in these courses for their professional future (Barrows & Tamblyn, 1980; Schmidt, 1983). McMaster University Medical School came up with an instructional format that used realistic medical problems that physicians have to deal with. Introducing 'problems' in a course was not the innovative element here, but rather the moment that students were presented with these problems, namely as the starting point of the learning process before any other curriculum input (Barrows, 1996). It is assumed that Donald Woods of McMaster University Medical School was the first to use the term *problem-based learning* (PBL; for a detailed discussion see Savin-Baden & Major, 2004). Since then, PBL has been implemented in numerous programs across many domains and at many educational levels on a world-wide scale (Barrows, 1996). Therefore, PBL can be considered as "one of the few curriculum-wide educational innovations surviving since the sixties" (Schmidt et al., 2009a, p. 2).

What Happens in PBL?

Learning in PBL begins with a complex, ill-structured problem that describes one or more observable phenomena or events (Schmidt, 1983). Students need to discuss these problems before they receive other curriculum input and therefore, need to rely on their prior knowledge. In a group, they try to construct understanding of the problem and discuss possible explanations or solutions (i.e., pre-discussion or brainstorm). Since their prior knowledge is limited, they formulate issues that form the basis of their self-directed learning. Subsequently, they need to select relevant literature about the topic, plan their study activities to optimally prepare themselves for the next group meeting, and assess whether their self-study activities were sufficient to fully understand the subject matter introduced in the problem.

Students engage in knowledge construction (Hmelo-Silver, 2004; Schmidt, 1983) during pre-discussion, self-study, and when sharing and critically evaluating their findings after self-study. Prior knowledge is triggered during the initial problem discussion and new findings are interpreted in light of this prior knowledge. Ideally, any misconceptions are also resolved here. The PBL process is depicted in Figure 1.

Insert Figure 1 about here

Initial discussion of the problem-at-hand as well as evaluation of self-study findings happen in small groups of students (i.e., tutorial meetings), which can also be labeled as collaborative learning (Loyens, Rikers, & Schmidt, 2007; Slavin, Volume 3).

These meetings are guided by a tutor - sometimes called facilitator or coach - whose role is to stimulate discussion, make sure that relevant content information is discussed (e.g., by asking questions), evaluate progress, and monitor the extent to which each group member contributes to the group's work (Schmidt, Loyens, Van Gog, & Paas, 2007).

Why PBL Was Designed

As mentioned, the prevailing goal preceding the development of PBL was to show students the relevance of the subject matter by putting it in a realistic context. Also, PBL was designed to foster several other desirable learning outcomes, namely to help students (1) construct an extensive and flexible knowledge base, (2) become effective collaborators, (3) develop effective problem-solving skills, (4) become intrinsically motivated to learn, and (5) develop self-directed learning (SDL) skills (Barrows, 1985, 1986; Norman & Schmidt, 1992).

An extensive and flexible knowledge base should enable students to retrieve and use information when needed. Activating prior knowledge through problem discussion in the group is seen to set the stage for the to-be-learned information, facilitating elaboration and increasing retention.

By working together in groups, students are expected to develop interpersonal skills and learn how to become good collaborators, learning to contribute to the discussion in an open and clear way, come to agreement about the learning issues and their answers, and resolve possible inconsistencies in their findings (Hmelo-Silver, 2004).

Since the problem is the starting point, students are expected to learn to develop problem-solving skills. In medical education, students usually encounter problems that need to be solved (e.g., diagnose a sickness and determine subsequent treatment based on the information in the problem). In other domains, however, the problem does not need to be or cannot be solved. Here the goal is to explain or understand the problem in terms of its underlying mechanisms. Either way, PBL aims to learn students how to analyze the problem at hand, to assess the importance of various pieces of information, and to decide which information should be used to understand, explain, or solve the problem and plan subsequent study actions.

With regard to PBL's goal to foster intrinsic motivation to learn, working on problems is believed to be engaging and interesting for students since they present realistic situations, usually related to future professional practice. Besides working on meaningful tasks, it was also assumed that the control students have over their learning would also motivate (Bandura, 1997).

The notion of control prefaces the final goal, namely developing SDL skills. SDL refers to "the preparedness of a student to engage in learning activities defined by him- or herself, rather than by a teacher" (Schmidt, 2000, p.243).

Though all of these goals are valued within PBL, some have been emphasized more than others in different PBL curricula. This resulted in different 'types' of PBL, namely one stressing construction of flexible knowledge bases (Type 1), one emphasizing development of inquiry skills (Type 2), and one that sees PBL primarily as a tool for 'learning how to learn' (Type 3; Schmidt et al., 2009a). This chapter will mainly focus on the Type 1, while acknowledging the importance of inquiry and learning-to-learn skills.

The Key Elements of Problem-Based Learning

Despite the different implementations of PBL, several key elements can be distinguished (e.g., Barrows, 1985) which can be categorized in three levels: 1) curriculum level, 2) group level, and 3) individual student level. PBL elements at the curriculum level are identical for all students in a specific PBL course or module. For example, the problems used are the same for all students. The instructor who coordinates a specific course (i.e., course coordinator) determines curriculum aspects such as problems, learning objectives, and learning resources. In contrast, PBL elements at the group level may play a role in a specific tutorial group, but not necessarily in all groups. Influences of a tutor on, for example, the group discussion only operate within his or her tutorial group. Finally, several PBL elements, such as students' SDL-activities, come to the fore at the individual student level.

The Curriculum Level: Problems, Collaboration in Small Groups, Learning Objectives, and Multiple Learning Resources

Key features of PBL at the curriculum level are the use of problems as the starting point of students' learning, small-group collaboration as the central curriculum format, learning objectives that guide students' self-study, and learning resources that are employed during self-study.

Problems.

The problem is the first input that students encounter. Often (e.g., in medical education), these problems originate in professional practice; in other cases, they relate to problems or events typical for a particular domain of study (Barrows, 1996; Norman & Schmidt, 1992). Since these problems need to be understood in terms of their underlying theoretical explanations, they need to have several characteristics that ensure sufficient scaffolding for the brainstorm, the formulation of learning issues, and students' self-study activities. To optimize the work of problems, a number of central features for problem construction in PBL have been proposed (Dolmans, Snellen-Balendong, Wolfhagen, & Van der Vleuten, 1997; Majoor, Schmidt, Snellen-Balendong, Moust, & Stalenhoef-Halling, 1990). These features can be narrowed down to five "rules" for effective problems, namely that PBL problems must build on prior knowledge, elicit discussion, stimulate SDL, encourage knowledge integration and transfer, and be relevant for the students' future profession.

Building on prior knowledge.

Research in cognitive psychology has shown that prior knowledge influences the quantity and quality of new knowledge acquired (e.g., Anderson, 1990). Students need to be acquainted with at least part of the knowledge necessary to solve or understand the problem. If not, the brainstorm is impossible. Problems that are too difficult (i.e., where prior knowledge is minimal or non-existent) can frustrate the student and decreases motivation. Problems that are too easy will be perceived as boring and insufficiently challenging. Therefore, problem complexity needs to be tuned to prior knowledge (F. Kirschner, Paas, & Kirschner, 2009a, 2009b; Otting & Zwaal, 2006). An implication of this is that a PBL curriculum needs to have a balanced structure. A specific problem about diabetes, for example, can only be presented to medical students after they have knowledge of human anatomy and physiology (Dolmans et al., 1997).

Eliciting discussion.

Problems also must be constructed so that learners can retrieve their prior knowledge and subsequently elicit discussion. Prior knowledge retrieval is crucial for relating new information to it. Problems can elicit discussion when they contain cues such as opposing viewpoints, allowing students to generate arguments for and against each view and discuss which view is best. The extent to which a problem can elicit discussion is indicated in the literature by the distinction between well-structured and ill-structured problems (King & Kitchener, 1994). *Well-structured problems* are demarcated problems that lead to one solution by applying one or a limited set of rules. A mathematical equation where one has to 'determine the value of x' is an example of a well-structured problem. In contrast, *ill-structured* or *ill-defined problems* can lead to multiple solutions and can be solved in multiple ways. Often, an ill-structured problem does not contain sufficient information to solve it or it cannot be solved at all. In that case, it is often called a *wicked problem* (Rittel & Webber, 1973; Van Bruggen & Kirschner, 2003) where one can only try to understand the underlying mechanisms. The question "What is the best bridge between two shores?" can be categorized as an ill-structured problem. Because of their multiple solutions and/or multiple ways to reach a solution, ill-defined problems are especially appropriate for eliciting discussion (Otting & Zwaal, 2006). Furthermore, ill-structured problems often better represent problems encountered in daily life and are, thus, more realistic than well-structured ones.

Stimulating SDL.

Third, PBL problems need to be constructed so as to ensure the formulation of learning issues (Majoor et al., 1990) because PBL students determine themselves what they find relevant for their learning based on the learning issues (Barrows, 1996). Learning issues are questions that are generated in the tutorial group and that guide students' self-study activities (e.g., Hmelo-Silver, 2004). The self-study activities for dealing with the learning issues are assumed to prepare students for autonomous problem solving later in life (Dolmans et al., 1997). An ill-structured problem can stimulate the formulation of learning issues and further SDL because it can involve multiple solutions which generates discussion in the tutorial group, while possibly also causing cognitive conflict within the student (Dolmans, Wolfhagen, Van der Vleuten, & Wijnen, 2001). Learners experience conflict because they may have had certain ideas about the problem that no longer seem to hold (either in part or as a whole) or that are questioned in the group discussion. Students become puzzled and - ideally - become motivated to find out more during self-study. In this process, the tutor is expected to stimulate students' identification of knowledge gaps (De Grave, Dolmans, & Van der Vleuten, 1999).

Encouraging knowledge integration and transfer.

Problems need to encourage students to integrate their acquired knowledge in their already available knowledge schemas so that they can apply this information in subsequent, new situations. In other words, a problem needs to stimulate knowledge integration and transfer. To accomplish this, information needs to be presented in a broad context so that students can better understand the purpose of the problem. A description of somebody, who hurt herself and feels a throbbing pain around the wound a few days later, can stimulate students to discuss topics such as the natural healing process of a wound, infection, and characteristics of inflammation (Dolmans et al., 1997). These single processes and features become meaningful in the context of the story. Knowledge acquired in a meaningful context can promote transfer.

Relevance for future profession.

Finally, PBL problems should be relevant for students' future profession as such problems are considered to be more motivating for students (Loyens, Magda, & Rikers, 2008; Otting & Zwaal, 2006). They are also thought to narrow the gap between the learning situation and praxis, since learning and praxis become more similar. Presenting medical students with a patient's file is a good example in this respect.

An example.

> "You work as a school psychologist and your task is to diagnose possible learning disorders in the children attending the school, consult parents or guardians about their children, and give them advice about possible treatments. On a Monday morning, you see Harry (7 years old) in your office. Harry seems to be an intelligent and spontaneous child. Harry's teacher told you that Harry has no trouble understanding things. He is good at mathematics and does not seem to have any problems in his social contacts, either at school or at home. An ophthalmologist has determined that Harry has no vision problems. But Harry has great difficulty learning to read. He often confuses the letters b and d, reverses words while reading, and even writes some words backwards. The teacher told you that Harry has some trouble with his speech as well, but she could not give you any specific examples."

This example of a problem about dyslexia is meant for first-year PBL psychology students after they have studied how children learn to read, and thus is intended to build on their prior knowledge of the normal reading development. The problem is presented in a context of a school psychologist at work and is, thus, considered to be relevant for some of the students' future profession. It contains different relevant diagnostic elements such as language understanding, making social contact, and Harry's vision. This might lead to a discussion about Harry's possible problem, its signs and symptoms, and, most importantly, how it can be treated, since this is the school psychologist's task. There are multiple options possible and students need to determine and explore these options during self-study based on the formulated learning issues (e.g., "What is dyslexia?" "What are possible treatments for dyslexia?").

Collaboration in small groups.

A second key element of PBL at the curriculum level is small-group collaboration in tutorial group meetings. Tutorial groups typically consist of 6 to 10 students who meet for 2 to 3 hours per session, usually twice a week (Schmidt et al., 2007). These meetings are guided by a tutor and, in addition, two students in the group assume the roles of chair and scribe. The chair leads the discussion, makes sure it proceeds in a structured way, and encourages group members to participate. The scribe summarizes the contributions on a white board (e.g., Wood, 2003) or, if available, SMART board (i.e., interactive whiteboard). All group members alternately function as chair and scribe throughout a course.

In addition to tutorial meetings, lectures can be part of the curriculum, but their occurrence is intended to be limited (Schmidt et al., 2009a) and not compulsory. They are typically comprehensive, rather than transmissive. For the dyslexia example, a school psychologist might be invited to talk about his/her job and would explain what occurs when a child is referred to him/her. By organizing the curriculum around tutorial meetings and giving lectures an optional status, PBL students have ample time for self-study (Schmidt et al., 2009a). In a study comparing the quantity of instruction (i.e., lectures, small-group tutorials, practical sessions, and self-study) of eight Dutch medical schools, time available for self-study appeared to be the only significant determinant of length of study (i.e., number of years to graduate) and graduation rates. In addition, lectures were negatively related to self-study time and graduation rate, and positively related to the length of study. These findings led the authors to conclude that in higher education, students learn more by being taught less and that curricula should provide sufficient room for students' self-study instead of increasing the number of instructional moments (Schmidt et al., 2009b).

Research shows that collaborative learning can stimulate discussion and task involvement. For example, an analysis of verbal interactions during a PBL group discussion revealed that the great majority of interactions were learning-oriented in nature. Students engaged primarily in exploratory questioning (e.g., open, critical, and verification questions), cumulative reasoning (i.e., statements, arguments, judgments), and handling conflicts about knowledge (i.e., counter arguments, judgment negotiation, disagreement, evaluation), with cumulative reasoning accounting for most of the interactions. These results suggest that students' task involvement during tutorial sessions is high (Visschers-Pleijers, Dolmans, De Leng, Wolfhagen, & Van der Vleuten, 2006a). A recent study looked more closely into why students benefit from group discussion and determined that actively providing explanations during a discussion was crucial, yielding benefits for long-term memory (Van Blankenstein, Dolmans, Van der Vleuten, & Schmidt, 2009).

Nevertheless, it should be mentioned that non-participation in a tutorial group does not always mean not learning. Feelings of being insufficiently prepared, whether justified or not, and the resulting reticence to speak can lead to a lack of verbal participation in PBL groups together with contextual and cultural constraints (Remedios, Clarke, & Hawthorne, 2008).

Learning objectives and multiple learning resources.

Learning objectives and using multiple learning resources constitute a final PBL characteristic at the curriculum level. Learning objectives are goals a course coordinator has determined for all students in a specific PBL course or module. For example, 'Study the research literature about treatments for dyslexia' can be a learning objective of an educational psychology course. Students work their way towards achieving these objectives by generating and subsequently dealing with the learning issues (see the following section). The course coordinator communicates the learning objectives to the tutors and, at least globally, to the students at the beginning of the course. The way in which these objectives are communicated (i.e., how detailed and elaborate) influences students' strategies for using the objectives in their learning process (Dahlgren, 2000).

Within the context of the learning issues, PBL students are free to select and study relevant literature resources (i.e., articles, books, book chapters) in the library and/or in electronic databases. Searching for literature and other resources is an important constituent skill for professionals and is one of the SDL skills students must master. However, successfully identifying relevant literature also requires domain knowledge. To this end, scaffolding is provided for novice students via a restricted set of resources from which they can select. More advanced students are expected to increasingly rely on their own SDL skills to find relevant resources (Jeong & Hmelo-Silver, 2010; Schmidt et al., 2007). Because of the emphasis on selecting one's own learning resources, it is not surprising that PBL students use learning resources more actively and visit libraries more frequently and for longer periods of time than students in lecture-based programs (Marshal, Fitzgerald, Busby, & Heaton, 1993). Furthermore, with educational experience, students gain efficiency in using learning resources (Williams, Saarinenrahikka, & Norman, 1995).

The Group Level: The Tutor and Learning Issues

There are two key PBL elements at the group level: the tutor and student-generated learning issues.

The tutor.

The role of the tutor is to facilitate and stimulate group discussion, ensure that problem content is considered in-depth, and evaluate group members' contributions to unraveling problems (Barrows, 1985). Hence, whenever needed, the tutor is expected to ask open-ended questions such as "Explain in your own words what this article says about the learning issue?" when students are primarily summarizing instead of discussing or "How does this article differ from the other?" or "What do you think?" By asking such questions and catalyzing group progress, the tutor helps support knowledge building.

Ideally, tutor interventions should diminish over time as students become more knowledgeable in the PBL process and more self-directed in their learning, although empirical evidence on this is scarce and not decisive (Hmelo-Silver & Barrows, 2008). According to Barrows (1985), a tutor primarily facilitates the process, but also possesses relevant subject-matter knowledge.

The issue of whether facilitation skills or content expertise carries the most weight and, more generally, which characteristics a good tutor should have, is the subject of many PBL studies. One of the first in this respect was an investigation by Schmidt, Van der Arend, Moust, Kokx, and Boon (1993), on the influence of tutor expertise on student achievement, self-study time, and tutor evaluations. They concluded that both subject-matter expertise and process-facilitation skills are necessary for effective tutoring.

In a subsequent study, Schmidt (1994) investigated the circumstances under which the tutor's expertise is most prevalent and concluded that all PBL students need a minimum level of structure. This structure can be provided by their own prior knowledge or by cues in the learning environment (i.e., learning objectives and/or available learning resources). When this structure is insufficient, students rely on tutors for this and in those cases, students benefit the most from tutors with subject-matter expertise.

These findings led to the formulation of what constitutes a good tutor (Schmidt & Moust, 1995). In their view, effective tutors possess cognitive congruence, social congruence, and expertise. *Cognitive congruence* refers to the ability to "frame his or her contributions in a language that is adapted to the level of the students" (Schmidt & Moust, 1995, p.709). *Social congruence* refers to the tutor's willingness to be involved with students' life and learning. A tutor also needs a suitable knowledge base of the topic being studied (i.e., *subject-matter expertise*; Schmidt & Moust, 1995, 2000).

A study by Dolmans and colleagues (2002) found that both congruence and expertise are needed. Four dimensions constitute an effective tutor: stimulating elaboration (i.e., ensuring the depth of the brainstorm, stimulating identification of prior knowledge gaps), directing the learning process (i.e., stimulating learning issue generation), stimulating knowledge integration, and stimulating interaction and individual accountability (e.g., by stimulating explanations in one's own words instead of reading notes; De Grave et al., 1999).

A study of student perceptions of the tutor showed that students saw effective tutoring as stimulating active learning. Students distinguished between poor and excellent tutors along three dimensions, namely the degree of direction (i.e., not too directive, but not too passive), degree of content knowledge, and being able to adequately evaluate both content and process (Dolmans, Janssen-Noordman, & Wolfhagen, 2006; Maudsley, Williams, & Taylor, 2008).

While these studies made use of ratings in determining the role of the tutor, another line of research used video observations of tutor performance to abstract tutor characteristics. Similar to studies using ratings, the tutor was found to be particularly involved in both advancing PBL discourse (e.g., by paraphrasing) and scaffolding learning (Hmelo-Silver & Barrows, 2006).

Learning issues.

After the initial problem discussion, students generate learning issues that guide their self-study activities. Learning issues are typically formulated as questions (e.g., "What is dyslexia?"). Although there is always room for personal interests related to the topic, learning issues need to cover the subject matter underlying the problem and are hence related to the learning objectives. Research shows that students value three characteristics of learning issues, namely: whether they contain useful key words for a literature search, are concise, and are clear (van den Hurk, Dolmans, Wolfhagen, Van der Vleuten, 1998). Veale (2007), however, found that students' learning issues corresponded only moderately with a course's learning objectives.

Research on self-generation of learning issues demonstrated that student-generated learning issues, as opposed to receiving predefined learning issues, positively affected the amount of materials studied, the self-study time, and the time allocated to report the literature (Verkoeijen, Rikers, te Winkel, & van den Hurk, 2006). On the other hand, Dolmans, Schmidt, and Gijselaers (1995) reported discrepancies between learning issues and literature resources studied, suggesting that students do not exclusively rely on learning issues for their self-study activities. Other influences such as tutor guidance, interest, prior knowledge, and the nature of the available resources also play a role.

The Student Level: Self-Directed Learning - SDL

In PBL, learning is initiated by the student. The most prevalent PBL feature at the student level is, therefore, self-directed learning (SDL). Silén and Uhlin (2008) pointed out that the feeling of being in charge and having an impact on the learning situation is the key element in SDL. It should be mentioned here that SDL can be both a learner characteristic and a design feature of the learning environment, since the environment should provide room for student autonomy (Loyens et al., 2008). Also, both perspectives are intertwined as shown in a study on the influence of learning resources on students' self-study time and achievement. Students in courses providing more learning resources and hence more freedom of choice, had higher achievement scores. Also, there was also a tendency towards more self-study time in these courses (Te Winkel, Rikers, Loyens, & Schmidt, 2006). Similarly, Dolmans and Schmidt (1994) found that students' SDL was also determined by curriculum elements, such as discussions in the tutorial group, content tested, and course objectives.

Nevertheless, SDL is treated here as a student level variable, stressing the specific learning activities students can undertake as self-directed learners (e.g., formulating learning issues, time planning and self-monitoring, and information-seeking behavior). A review of research on SDL in PBL revealed mixed results on the impact of PBL on SDL as well as great discrepancies in how SDL is measured (Loyens et al., 2008).

However, it is most desirable that students continue to exhibit SDL behavior after graduation. A study carried out by Shin, Haynes, and Johnston (1993) investigated how well PBL graduates versus graduates from traditional, lecture-based medical education kept up to date with current clinical practice guidelines for hypertension. To that end, graduates' knowledge about the management of hypertension was tested, five to sixteen years after graduation. PBL graduates obtained significantly higher scores on this test.

Of course, students vary in their willingness or readiness to engage in SDL (Miflin, Campbell, & Price, 2000). Some longitudinal research demonstrates that more advanced students report more self-management, more desire for learning, and more self-control (Kocaman, Dicle, & Ugur, 2009). Another study, however, did not find an improvement in students' self-assessment ability over time (Lew, Alwis, & Schmidt, 2010).

Evidently, numerous other student characteristics influence students' learning such as prior knowledge, motivation, learning approach, and self-efficacy beliefs. Recently, Araz and Sungur (2007) linked several cognitive and motivational characteristics of students in a PBL environment. However, these factors are not key elements of PBL and influence learning regardless of the learning environment. As mentioned earlier, prior knowledge is an important aspect during initial problem discussion and PBL aims at making students intrinsically motivated to learn. Similar to SDL, these elements are both features of the learning environment as learner characteristics. The learning environment should be designed in a way that prior knowledge and motivation are ideally triggered, but the learner still needs to bring these aspects to the fore. In sum, we acknowledge the role of other student factors, but consider

SDL as the most prevalent student feature within the PBL context.

Integrating Three Levels

All three levels determine the quality of the tutorial group. Several studies have modeled the PBL process to determine the decisive factors. Gijselaers and Schmidt (1990) tested a model with prior knowledge, the PBL problem, and tutor functioning as input variables on student study time and the tutorial group functioning (i.e., process variables). Self-study time was related to achievement, while group functioning determined self-study time as well as the outcome variable of student interest. Results demonstrated that the problem and the tutor were the most decisive factors for group functioning. Prior knowledge did not affect the process variables, but was significantly related to the outcome variables of achievement and interest.

In a subsequent study, the causal PBL model was refined (Schmidt & Moust, 2000). Again, the model assumed that group functioning depends on the amount of prior knowledge, problem quality, and tutor functioning, with group functioning influencing student interest in the subject matter as well as study time. Finally, it was hypothesized that study time affects achievement in the proposed causal model. Similar to the results of Gijselaers and Schmidt (1990), prior knowledge only affected achievement and interest in the subject matter directly and not via group functioning. Furthermore, the problem quality influenced group functioning as hypothesized, but also determined self-study time and interest. Tutor functioning was only significantly related with group functioning, stressing the relative importance of the problem compared to the tutor (Schmidt & Moust, 2000).

PBL and Its Siblings: Project-Based Learning, Case-Based Learning, and Inquiry-

Based Learning

PBL, a student-centered educational format, has spawned a number of offshoots that often differ considerably from it. Barrows (1986) identified three important variables that can vary in student-centered approaches, namely: the design and format of the problem, project or case; the degree to which learning is teacher-centered or learner-centered; and the sequence in which problems are offered and information is acquired.

In Project-Based Learning or Project-Centered Learning, students have a significant voice in selecting the content areas and nature of the projects that they carry out. A project can address a specific problem, but this is not necessary. Students in Project-Based Learning investigate the topic collaboratively and create end products (e.g., a computer animation, website, presentation, or report) that serve as the basis for discussion, feedback, and revision (Blumenfeld et al., 1991). Project-Based Learning and PBL are both student-centered, work with authentic (i.e., simulating and realistic situations) ill-structured tasks (either a project or a problem in which students have to explore multiple learning resources), and rely on collaborative learning with teacher or tutor facilitation. However, Project-Based Learning relies more on student input, since students can come up with their own projects. Therefore, Project-Based Learning can be considered more student-centered than PBL.

Another instructional approach related to PBL is Case-Based Learning. This is also a form of collaborative learning where learners are presented with a problem. However, the sequence in which the problem is discussed and information about the problem is gathered is different. In PBL, the problem is the starting point. Students do not receive any other curriculum input before they receive the problem. In Case-Based

Learning, students need to prepare for the group session and can ask questions during the session, when the case is discussed under the guidance of a facilitator (Srinivasan, Wilkes, Stevenson, Nguyen, & Slavin, 2007).

Inquiry-Based Learning is yet another student-centered approach, often found in science education (Savery, 2006). Students, here, are confronted with an open-ended question or puzzling situation that allows several responses or solutions. Students can ask the teacher questions about this problem situation and formulate their own hypotheses. Here, the teacher often also acts as an expert, which is different from PBL. Students seek evidence for the hypotheses by gathering and processing data in order to finally reach conclusions that are evaluated (Kahn & O'Rourke, 2005; see Loyens & Rikers, in press, for a discussion of the effectiveness of these approaches).

Apart from the fact that there are many forms of student-centered learning using different labels, differences may also exist within these separate approaches, primarily in terms of implementation and focused elements (Lloyd-Jones, Margetson, & Bligh, 1998). This can be ascribed to various reasons such as modifications because of the target group (e.g., K-12 versus higher education), but also because of the so-called coverage virus; the fear of teachers that subject-matter is insufficiently covered, leading to the incorporation of more teacher-centered practices and less student autonomy in PBL (Moust, van Berkel, & Schmidt, 2005). In addition, hybrid forms of PBL have emerged throughout the years, combining PBL with teacher-led formats (e.g., Kwan, 2008).

PBL in the 21st Century: The Addition of Technology

Over the last 40 years PBL has evolved. Not surprisingly, many innovations in PBL have coincided with the increased use of technology in education. In 2002, Barrows discussed several papers introducing technology in PBL, noting "It is truly possible to have such a thing as dPBL?" where "d" stands for "distributed". In his article, he stated: "I have been involved in a number of attempts to carry out dPBL and, although there have been some attractive results, the technology that was available was cumbersome and not designed for the authentic PBL process" (Barrows, 2002, p.120). Since then, numerous attempts to integrate information technology and PBL have been documented, ranging from using video cases in tutorial groups (De Leng, Dolmans, Van de Wiel, Muijtjens, & Van der Vleuten, 2007), virtual patients (Poulton, Conradi, Kavia, Round, & Hilton, 2009), internet access in the tutorial rooms (Kerfoot, Masser, & Hafler, 2005), to using avatars (Omale, Hung, Luetkehans, & Cooke-Plagwitz, 2009). Several of these studies follow, acknowledging that this is by no means an exhaustive list.

Lau and Mak (2004) implemented an *Interactive Multimedia E-Learning System* (IMELS); e-learning courseware for industrial engineering adopting a PBL approach. IMELS presents students with problems in a simulated virtual business environment. Within this environment, students can find information about the company and company structure definitions. In addition to the virtual company, there is a knowledge base with subject matter content. Students can ask each other and ask the teacher questions on an online discussion forum and pre-scheduled discussions among students and teacher can take place in the chat room. Similarly, Nelson, Sadler, and Surtees (2005) reported on a virtual reality package for nursing education where virtual reality scenarios were used as problems, enabling students to explore different aspects of a case (e.g., students can tour a patient's neighborhood as well as the interior of the patient's house). Students worked collaboratively on the problems in the virtual reality and a nurse educator facilitated.

Liu (2004) investigated whether hypermedia technology could provide scaffolding to support sixth graders' learning in PBL. The PBL hypermedia program *Alien Rescue* was used in a science class in which students need to find a new location for various species of aliens with different needs (i.e., the problem situation). Hence, they have to research the aliens' needs as well as the solar system. Several tools are built in to scaffold the problem-solving process (e.g., concept database and expert modeling). The amount of available information is, however, elaborate, forcing students to sift through the different pieces of information to decide what is relevant and important and what is not. Students of different ability levels worked together in groups of two or three. The teacher acted as facilitator, redirecting students' questions to the class and adding comments when appropriate. Results demonstrated positive effects on students' knowledge gains on a science test. However, more scaffolding was needed for slow readers because of the large amounts of information.

Another study looked at dPBL as a method for medical students to continue PBL during clinical placements. More specifically, students' approaches to learning were investigated in dPBL. Participants first received training in *ClassFronter*, a learning management system. Every student in a PBL group was at a different hospital location and accessed the learning management system via a personal computer with internet connection. The majority of the sessions were carried out synchronously, meaning that students were all behind the computer at the same time, having discussions with each other. The PBL process was similar to regular PBL formats, as was a tutor, who guided the process. Results demonstrated an increase use of web-based resources and less reliance on textbooks. In addition, students valued group activity as well as the role of the tutor less after their experience with dPBL (Strømsø, Grøttum, & Hofgaard Lycke, 2004).

Yet, based on log files, another study did show increased communication among students during self-study in a blended PBL (bPBL) environment (i.e., a virtual learning environment combined with face-to-face tutorial meetings). This study demonstrated that a bPBL environment was preferred by students over a regular PBL environment, although this view was not shared by tutors (Woltering, Herrler, Spitzer, & Spreckelsen, 2009).

With respect to effective use of learning resources in an online PBL environment, several factors need to be taken into account. Students need to develop an understanding of the resources and learn how to access them efficiently, they need to learn how to meaningfully process resources and how to integrate different resources, and they need to learn to collaboratively use resources. This imposes a challenge for students, especially for low-achieving students (Jeong & Hmelo-Silver, 2010).

In sum, although some technology innovations in PBL look promising in terms of user evaluations, caution is needed. First, many of the studies are only descriptive. Second, technology implementations often differ in the degree to which the PBL process is really an e-PBL process. In some studies, the role of technology is limited to a vivid multimedia presentation of the problem. Finally, technological innovations should serve *all* learners, and perhaps especially the lower-ability ones. Some studies report challenges for slow readers (Liu, 2004) and lower-achieving students (Jeong & Hmelo-Silver, 2010) while using technology-based learning environments. Future developments and research are needed to optimize the use of technology for all PBL learners.

Problem-Based Learning and its Effectiveness

The introduction of new educational methods goes hand in hand with research scrutinizing the effectiveness of the method as a whole or elements of that new method. The body of research on specific elements of PBL such as problem characteristics, tutor, and learning issues was highlighted earlier in this chapter when the key elements of PBL were discussed. These studies target the development of 'the ideal PBL format', but are less concerned with the effectiveness of PBL as a whole. With respect to the effectiveness of PBL, two lines of research can be distinguished, namely perceptions of and experiences with PBL and PBL's effects on knowledge and competency acquisition.

Perceptions of and Experiences with PBL

The first line of research can be described as *exploratory research* on student and instructor perceptions of and experiences with the implementation of and/or shift towards PBL as well as on whether specific study objects are suitable for PBL. Examples of this line of research are perceptions of primary school children about PBL (Azer, 2009); experiences of staff with learning to teach with PBL (Spronken-Smith & Harland, 2009) and with using online PBL (Kiernan, Murrell, & Relf, 2008); experiences implementing PBL in specific programs such as physiotherapy and nursing (Dahlgren & Dahlgren, 2002), in clinical internships (Macallan, Kent, Holmes, Farmer, & McCrorie, 2009) or in specific courses such as qualitative research methods (Wiggins & Burns, 2009).

As mentioned, the focus in these studies is on experiences of students and instructors, mostly using qualitative research methods and (satisfaction) questionnaire data. Therefore, these studies do not address the effectiveness of PBL as such, but they do contribute to the general picture of PBL in that they deal with perceptions that constitute an attitude towards PBL and on experiences which can advise users on how to overcome possible challenges and difficulties with PBL or its implementation.

Perceptions of PBL.

The image that emerges from several studies within this line of research is that students and instructors are enthusiastic about PBL (e.g., Barman, Jaafar, & Rahim, 2007). Severiens and Schmidt (2009) showed that PBL students were more satisfied with the quality of formal and informal contacts with their instructors as well as with the quality of formal - but not informal - contacts with their peers compared to students in conventional and mixed (i.e., lectures with some forms of active, small group learning) curricula. PBL students also reported that instructors more often attempted to get to know them, took them more seriously, and invited them into the profession (i.e., academic integration).

Students' appreciation of the integration of knowledge with practice is also evident (Coleman, Collins, & Baylis, 2007; Smith & Coleman, 2008). White (2007) interviewed PBL students and students in traditional education at three different points in a medical program. PBL students reported problems transitioning into medical school, but as they got further, they appreciated the responsibility that PBL required and reported more intrinsic motivation to learn, making the transition to internships less problematic. Traditional students had less difficulty adjusting to medical school, but reported a rougher transition into internships. They felt insufficiently prepared to deal with the independence and self-directedness expected from them there.

The integration of knowledge was also noted as an advantage of PBL in a study on student perceptions of useful elements of the group discussion. This study noted the prominent role of explanations during group discussion. The students indicated that they felt that the subject matter became clearer and that they felt that they were better able to integrate it after the tutorial group discussion. They appreciated that they could ask for, give, and receive explanations. Furthermore, they valued the discussion of differences with respect to the subject matter in the tutorial group (e.g., conflicting theories) and the way the discussion process was guided and monitored (Visschers-Pleijers et al., 2006b).

Studies have also compared PBL and non-PBL graduates on their perceptions of competence acquisition. Prince, Van Eijs, Boshuizen, Van der Vleuten, and Scherpbier (2005) questioned PBL and non-PBL students 18 months after graduation about how well their undergraduate medical training had prepared them for practice with respect to 12 capabilities: expert knowledge, profession-specific skills, computer skills, communication skills, teamwork skills, planning and organization skills, leadership skills, independence, creativity, initiative, dealing with change, and accuracy. PBL graduates came from a Type 1 PBL medical curriculum (Schmidt et al., 2009a) and the non-PBL graduates from lecture-based medical curricula. Participants had to indicate on a 5-point Likert scale how frequently they used these capabilities in their work and where they primarily had acquired them (i.e., medical school, workplace or elsewhere). Both groups indicated that expert knowledge, profession-specific skills, communication skills, teamwork skills, independence, and accuracy were used most. PBL graduates indicated that they acquired communication skills primarily in medical school, whereas non-PBL graduates reported having learned those skills on the job or elsewhere.

A similar study where students rated their competence in different domains (e.g., communication skills, clinical knowledge, and scientific skills) showed higher self-rated competencies for PBL graduates (Cohen-Schotanus, Muijtjens, Schönrock-Adema, Geertsma, & Van der Vleuten, 2008). Similarly, in a study of graduates from two Dutch medical schools (one PBL, one traditional), Schmidt, Vermeulen, and Van der Molen (2006) reported an overall medium to large positive effect for PBL graduates with respect to self-rated communication skills, with the largest effect for interpersonal skills. Moreover, a study by Tiwari, Lai, So, and Yuen (2006) where students were randomly assigned to a lecture-based versus a PBL nursing therapeutics course over one academic year examined self-perceptions of participants' critical thinking skills. Each tutorial group consisted of 10 students facilitated by a tutor. For the PBL treatment, each group had 3 to 6 hours of PBL tutorials each week for a total of 28 weeks over 2 semesters. Critical thinking was measured by means of an inventory and was administered four times (i.e., prior to the first semester, at the end of the second semester, and follow-ups after one and two years). The groups did not differ on self-reported critical thinking prior to the semester, but PBL students showed significantly greater improvement in critical thinking over time. Effects, however, were small.

Challenges with Implementing PBL.

One challenge to implementing PBL is instructors taking on the role of facilitator (Spronken-Smith, & Harland, 2009), as they are typically used to being a lecturer. In a study on technology enhanced PBL (Park & Ertmer, 2008), lack of shared vision, good feedback, and effective communication of expectations were found to be factors related to teachers' hesitance to implement the environment.

Another challenge is students' uncertainty due to PBL's emphasis on personal responsibility and self-directedness (e.g., Nel et al., 2008). Maudsley and colleagues (2008) reported that students found the lack of a syllabus to be a disadvantage of PBL because they experienced feelings of uncertainty about whether they had studied the appropriate literature. Lack of guidance in literature resources is also mentioned by Moffat, McConnachie, Ross, and Morrison (2004) as a source of stress in a first-year student population.

Another study reported PBL students experiencing confusion because of the responsibility and control given to them. Students experienced this confusion differently with some finding it stimulating and challenging, while others feeling seriously hindered in their learning process to the extent of developing feelings of anxiety (Duke, Forbes, Hunter, & Prosser, 1998). Uncertainty about what was required from them and related anxiety was also the reason for students' negative appraisals of a technology-based PBL approach to health informatics (Green, Van Gyn, Moehr, Lau, & Coward, 2004).

In sum, both positive and negative views have been found in exploratory research on PBL.

Effects of PBL on Knowledge and Competencies

The second line of research comprises studies investigating the effectiveness of PBL curriculum as a whole (i.e. graduation rates, length of study) or effects of PBL on specific outcomes, often categorized in terms of knowledge, skills or competencies, and affective variables (e.g., motivation). Often, these studies employed a comparative approach, contrasting PBL with traditional, lecture-based curricula. The following overview mainly focuses on knowledge and skills/competencies, since those are often considered most revealing in terms of effectiveness.

The review is limited review to studies published in the period 2004-2010. This is because of the publication of several meta-analyses and review articles on the effects of PBL (Dochy, Segers, Van den Bossche, & Gijbels, 2003; Gijbels, Dochy, Van den

Bossche, & Segers, 2005; Hmelo-Silver, 2004) which give a clear overview of the PBL effect studies carried out before this period.

Strobel and Van Barneveld (2009) summarized the findings of all meta-analyses on PBL effects conducted before 2005 in two trends; one trend on the effects on knowledge acquisition, the second trend referring to the acquisition of competencies or skills.

With respect to the first general trend, students in traditional curricula tended to perform better on assessment of basic science knowledge. However, differences between PBL students and students in traditional classrooms on knowledge tests tend to diminish over time, suggesting that PBL students remember more of the acquired knowledge (Dochy et al., 2003). In general, comparative findings with respect to knowledge have been labelled as non-robust (e.g., Dochy et al., 2003), also evidenced by a recent meta-analysis of Schmidt and colleagues (2009a). They performed a meta-analysis of curricular comparisons, using a single, Type 1 PBL medical school in the Netherlands. This school was compared with traditional medical schools in the Netherlands. Medical knowledge was one of the outcome variables in this meta-analysis and was measured by medical students' scores on the so-called 'progress test' consisting of 200 to 300 questions dealing with medicine as a whole. The comparisons involving the PBL curriculum under study and various Dutch medical schools demonstrated a small, positive effect.

A second trend noted was that a PBL approach tended to produce better outcomes for clinical knowledge and skills. If outcome measures make a strong appeal to the application of knowledge, PBL students tend to perform better compared to students in conventional curricula (e.g., Gijbels et al., 2005).

For this chapter, studies that were not part of the just-mentioned articles were selected, since the goal was to provide a state-of-the-art overview. In trying to avoid comparing apples and oranges, the authors will be as specific as possible in describing the PBL features as well as the dependent variables under study.

Effects on knowledge acquisition.

In a within-subjects design, Capon and Kuhn (2004) examined students' learning of two concepts. Each class learned one concept in a PBL format and the other in a lecture combined with discussion format. The unique features of the PBL approach were a) addressing the problem in small groups of 2 tot 3 students and reporting back and b) a group's assigned task of utilizing the concept to solve the problem followed by reporting. In the lecture/discussion condition, students discussed more examples and related concepts. All other elements were identical in both conditions. Learning was assessed after six weeks via an unannounced quiz and after twelve weeks through one question on the final, open-book examination. This question required integration of the knowledge learned and not recall since learning resources could be used. After six weeks, the lecture/discussion group outperformed the PBL group on one concept, but both groups obtained similar quiz scores on the other concept. After twelve weeks, however, each group showed superior understanding of the concept for which they had acquired via PBL. The first assessment, thus, failed to demonstrate superior acquisition or recall of the relevant material for PBL, but the second assessment showed a better understanding for PBL. This is in line with Dochy and colleagues (2003) who stated that differences between PBL and traditional students on knowledge tests diminish over time. PBL students tend to remember more of the acquired knowledge, which could imply a better organization of the knowledge learned.

In contrast, no effects in favor of PBL students on knowledge acquisition were found in a study by Şendag and Odabaşi (2009). Forty participants were randomly assigned to an online PBL course or an online teacher-led course. Students' content knowledge about the topic at hand (i.e., computers in education) was tested both prior to and after the course. All students had to take a 40-item multiple choice content knowledge test. Both groups obtained higher scores on the posttest compared to the pretest, but no significant differences were found between both groups.

Effects on competencies and skills.

A substantive number of studies have been carried out on the effects of PBL on competencies and skills used with university graduates as participants. This allows for making claims about potential long-term, post-graduation effects of PBL and possible beneficial effects of the curriculum in the students' later career.

In a recent, systematic review of studies investigating physician competencies after graduation, advantages were found for social skills for physicians who had completed PBL curricula (Koh, Khoo, Wong, & Koh, 2008). Thirteen studies were included in this review based on three inclusion criteria: PBL was the instructional format in the medical school, physician's competencies were assessed after graduation, and a control group of graduates of traditional curricula was included. A distinction was made between self-assessed and observed (i.e., by a supervisor) competencies. Competencies were categorized into eight dimensions: 1) overall, 2) technical (e.g., diagnostic skills or accuracy), 3) social (e.g., communication, teamwork skills), 4) research (e.g., writing reports or articles), 5) teaching, 6) cognitive (e.g., continuing learning, understanding evidence-based medicine), 7) managerial (e.g., time management), and 8) knowledge (both possession and use). Significant differences in favor of the PBL graduates were found primarily for the social and cognitive dimensions with strongest evidence (both self-assessed and observed) for the appreciation of legal and ethical aspects of health care and the ability to cope with uncertainty.

A Canadian peer assessment program was used to examine the competencies of medical education graduates from McMaster PBL and non-PBL Ontario curricula. This program is a peer review mechanism, initiated by the College of Physicians and Surgeons of Ontario in 1980, which examines 400 to 500 randomly selected practicing doctors per year. A trained doctor peer assessor visits a doctor's office, reviews patient records, produces a detailed summary, and interviews the doctor to be assessed. The outcome is a rating on a 5-point scale ranging from serious concerns (1) to excellent (5). A quality assurance committee and not the assessor, makes the final judgment. Multiple regression analysis was used to examine predictors of ratings. Certification by family medicine or a specialty, gender (in favor of females), and younger age were all predictors of practice assessment, school of graduation was not (Norman, Wenghofer, & Klass, 2008).

Another study focused on critical thinking skills. Critical thinking refers to reflective judgments in response to observations and experiences and implies inquisitiveness, analytical ability, and comprehensive interpretation and evaluation (e.g., Şendag & Odabaşi, 2009). In the aforementioned study of Şendag and Odabaşi (2009), critical thinking skills were also assessed using a critical thinking skills test consisting of items addressing inference, recognition of assumptions, deduction, interpretation, and evaluation of arguments. Again, both a pre- and a post-test were administered. Both groups scored higher on the post-test, but the PBL group showed larger gains in critical thinking skills.

A study contrasting medical graduates from before (conventional) and after (PBL) a curriculum shift investigated students' clinical competence measured by their clinical clerkship scores. Another dependent variable was career development, which was measured by the amount of time between graduation and the start of their postgraduate training. No differences in clinical competence were found. With respect to career development, graduates from the traditional curriculum took 3 months less to find the post-graduate placement of their choice (Cohen-Schotanus et al., 2008). The same approach was adopted by Hoffman, Hosokawa, Blake, Headrick and Johnson (2006) who compared students' residency evaluations, given by program directors, before and after the curriculum shift. In contrast to Cohen-Schotanus and colleagues (2008), significantly higher evaluation scores for students' residency were found for after the transition to PBL.

Curriculum as a whole.

Because "a curriculum is a potpourri of individual components, making it difficult to establish links between specific aspects of the curriculum and student behavior" (Norman et al., 2008, p. 795), some studies have focused on the effects of the curriculum as a whole and have introduced length of study and graduation rates as dependent variables. Study delays and inadequate graduation rates are seen as problems within higher education (Van den Berg & Hofman, 2005) as they increase the costs of the study for both the student and the institution (i.e., longer study duration) and decrease the income for the institutions (i.e., less tuition, lower government premiums).

Analysis of graduation rates and time needed to graduate was performed on ten generations of medical students from medical schools in the Netherlands. It was investigated whether medical schools that emphasized active, small group learning (e.g., a PBL format) produced a higher graduation percentage as well as less delaye in the study. Data from eight medical schools were included; three active learning and five conventional lecture-based curricula. Graduation rate data were obtained from the Association of Dutch Universities (VSNU). On average, 8% more students graduated from active learning curricula and these students graduated five months earlier than their fellow students following traditional curricula (Schmidt, Cohen-Schotanus, & Arends, 2009). Another study measured study progress in terms of credit points obtained after one study year in a conventional curriculum, a PBL curriculum, and a mixed curriculum. PBL students earned more credit points compared to the other groups (Severiens & Schmidt, 2009). Similarly, attrition and graduation rates were compared within a South African medical school before and after implementation of a PBL approach. The student cohort after the curricular shift showed lower levels of drop-out, had shorter throughput periods, and a significant greater percentage of them were able to graduate within six years (Iputo & Kwizera, 2005). Similar results with respect to higher retention rates for PBL students were found in another South African sample (Burch, Sikakana, Yeld, Seggie, & Schmidt, 2007).

Some Critical Remarks about PBL

Finally, some critical remarks need to be made about PBL. Those remarks also serve as points of attention when reading about or investigating PBL. First, researchers often mean different things when they refer to and study PBL. This was already addressed earlier. Despite many attempts to clarify the PBL process and philosophy in theory and practice, a 'conceptual fog' continues to surround practice, which can color the views of both proponents and opponents (Maudsley, 1999; Taylor & Miflin, 2008).

Another point deserving attention is that practice can significantly differ from theory. Moust and colleagues (2005) highlight 'signs of erosion' that have crept into PBL after three decades such as increasing numbers of students in tutorial groups, skipping pre-discussion of the problem, and anxious course coordinators with the aforementioned 'coverage virus' handing out literature references to the students. In a way, it is positive that these signs are not left unnoticed, but signaling them alone is insufficient. Steps need to be taken to return to the original PBL format, if one still holds that philosophy.

Finally, the great majority of studies on PBL have been conducted in higher education. The effects of PBL could be different for younger learners. This issue of the learner's level and its implications for instructional design is further discussed in the section on PBL, human cognitive architecture, and cognitive load theory.

Methodological Comments: A Claim for More Controlled Experiments

Some methodological comments have already been made when the PBL effect studies were described. Demonstrating the effectiveness of an instructional format requires a control group equivalent to the PBL condition. This implies curriculum comparisons, which are often problematic because of the influence and interplay of many variables (Schmidt et al., 2009a). Even within the same institution, a shift to a new curriculum often implies a shift to an updated curriculum, possibly with new content and modeled on new professional practices. Although resulting in a lower ecological validity, controlled experiments can unravel the puzzle to a certain extent. In this respect, Kirschner, Sweller, and Clark (2006, p.79) stated, “none of the arguments and theorizing would be important if there was a clear body of research using controlled experiments” indicating that PBL was more effective than other forms of instruction.

Another aspect of curriculum comparisons is that many different variables are altered at the same time. For example, the use experimental designs where one group of students receives PBL while another group receives lectures or other forms of more conventional instructions makes it problematic to identify the cause of changes in the outcome variables. This also applies to research comparing student outcomes before and after a curricular change to PBL. Carrying out randomized, controlled experiments can be used to directly test the consequences of a specific instructional format.

Randomized, controlled experiments could also overcome the self-selection effect prevalent in PBL studies. This effect or bias refers to the fact that PBL students have deliberately chosen to enroll in a PBL curriculum. While this might also be the case for some students in traditional classrooms, it undermines randomization of participants.

Finally, as stated earlier in this chapter, much of the research comparing PBL to other forms of education make use of self-report measures. Cook and Campbell (1979) were one of the first to question the reliability and validity of self report noting that respondents (a) tend to report what they believe the researcher expects to see, or (b) report what reflects positively on their own abilities, knowledge, beliefs, or opinions. Self-report is known to have ‘issues’ with respect to ‘problems of over-reporting and underreporting’, though one cannot be sure when one or the other occurs (Huizinga &

Elliott, 1986). Caution, thus, should be taken when using and reporting on self-report measures and when basing conclusions or policy on it.

PBL, Human Cognitive Architecture, and Cognitive Load Theory

With respect to PBL and human cognitive architecture, a recent debate has emerged in the literature, initiated by an article of Kirschner and colleagues (2006). They argued that while one of the basic premises behind PBL is that learning is achieved by working on problems, there is much evidence that for novice learners, working with problems is not a good instructional method (see van Merrienboer & Sweller, 2005; Sweller, van Merrienboer, & Paas, 1998 for overviews of this research). According to Kirschner and colleagues (2006), the main problem with this approach is that it ignores human cognitive architecture and specifically the limitations to human working memory. Human cognitive architecture is concerned with the manner in which our cognitive structures (e.g., memory) are organized (Sweller, Volume 1). For example, our working memory is extremely limited in capacity (Baddeley, 1992; Swanson & Alloway, Volume 1). However, it is not only this limited processing capacity; the interactions between working memory and long-term memory are even more important (Sweller, Volume 1). These limitations only apply to new, yet to be learned information not yet stored in long-term memory. When dealing with previously learned information stored in long-term memory, these limitations disappear.

In response to the critical view on PBL by Kirschner and colleagues (2006), Schmidt and colleagues (2007) argued that PBL's underlying principles, if correctly applied, are compatible with the manner in which our cognitive structures are organized. In contrast to Kirschner et al.'s argument that PBL can be considered an unguided or minimally guided instructional approach, Schmidt et al. (2007) argued that PBL can incorporate extensive guidance structures that can be flexibly adapted to the level of learner expertise and the complexity of the learning tasks. The guidance structures of PBL that can be used to manage the high cognitive load that is typically associated with working on relatively unfamiliar tasks comprise the training of group collaboration skills, learning tasks, tutorial groups, group discussion, tutor, and resources for individual learning.

With regard to the group collaboration process it was argued that when an instructional technique is used that is in itself unfamiliar, it is important to train students in it before instruction starts, in order to reduce the additional ineffective cognitive load that engaging in this technique or with this technology would bring along (cf. Clarke, Ayres, & Sweller, 2005). Therefore, in order to minimize this cognitive load associated with the communication and coordination of knowledge between the group members, students in a PBL curriculum will typically be trained in group collaboration skills before instruction starts. This training focuses on (a) mastering a standard procedure to translate problems into learning issues for individual study and (b) structuring of the group communication process by learning the various roles required for optimum group performance.

With regard to the learning tasks, simple-to-complex whole task sequences are used in the design of problem-based instruction, such that students start with the easiest problem and progressively proceed to more complex or expert-like problems. Simple-to-complex sequences make optimal use of the reduction of intrinsic load with increasing expertise, allowing students to acquire knowledge in the simpler tasks that reappear in the more complex tasks along with new information, stimulating elaboration (Van Merriënboer & Kirschner, 2007).

Human cognitive architecture, and in particular the limitations of working memory capacity at the individual level (Cowan, 2001), is an important reason to assign learning tasks to tutorial groups rather than to individuals. Within the theoretical framework of cognitive load, exploiting the expanded working memory capacity that becomes available in groups of collaborating learners has been identified as an alternative way of dealing with working memory limitations at the individual level (F. Kirschner, et al., 2009a, b). It is believed that the more complex the task (i.e., the higher the intrinsic cognitive load), the more efficient it will become for individuals to cooperate with other individuals in a fashion that this load is shared. Here, the group discussion plays an important role.

The group discussion in PBL is intended to reach two goals: Activating whatever prior knowledge is available and sharing expertise. The assumption is that by activating and sharing prior knowledge among group members, intrinsic cognitive load decreases, thereby decreasing the necessity of omitting interacting elements and enabling students to deal with more complex tasks.

If a learning task, despite being carefully designed and having been discussed in the group, turns out to be too complex or if an essential knowledge element for the group's learning process was not activated during discussion, the tutor is instructed to share this knowledge with the group, thereby reducing intrinsic load. In line with the claims of cognitive load theory, that the advantage of guidance begins to recede only when learners themselves have sufficient expertise, research has shown that tutor effectiveness depends on tutor subject-matter expertise, prior knowledge of the student, and the amount of structure present in the instruction.

Searching for literature and other resources is considered an important constituent skill that is mastered by successful professionals. However, successfully searching for literature is highly dependent on domain knowledge. Hence, novice learners are likely to engage in irrelevant literature search activities, which impose a high extraneous load (Paas, van Gog, & van Merriënboer, Volume 3). Therefore, novice students in PBL need to be provided with a restricted set of resources (e.g., book chapters, articles) to choose from for individual study. With increasing expertise students are provided with less and less specified resources to stimulate them to search for relevant literature themselves.

Conclusion

What can we conclude from this chapter? Or, to put it into PBL words: If you were an educational psychologist who had to inform the director of a school whether he or she should implement a PBL format, what would you recommend?

A close look at the effect studies shows a puzzling picture for PBL's effects on knowledge with some studies finding effects, although small, and others failing to find effects. However, for skills, it seems warranted to conclude that graduates of curricula that employ PBL have some advantages in social skills compared to graduates from traditional curricula. There is some evidence for beneficial effects on medical skills, although not all studies endorse this. For critical thinking skills, the conclusion seems positive, but caution here is also needed, given that there only was one recent study in this area.

With respect to graduation and retention rates and speed of study progress, all studies indicated positive effects for PBL curricula. Interestingly, an often heard critique of PBL is that it requires large initial investments, financial and otherwise (e.g., training instructors and tutors and creating areas for group work). Higher retention and graduation rates, however, are exactly those components that can bring in financial resources for programs.

Future Issues

Possibly the most important conclusion that can be drawn from all of this is that for the implementation of PBL communication of clear objectives, guidelines, and expectations to students, teachers and tutors is indispensable. Studies reporting challenges with the implementation of PBL have led to studies on how they can be overcome. For example, Ertmer and colleagues (2009) described specific planning, implementation, and assessment strategies for adopting PBL in middle school. Similarly, Vardi and Ciccarelli (2008) proposed strategies to better prepare students for PBL (e.g., providing online resources), participation (e.g., training critical discussion), group functioning (e.g., critical evaluation of group discussion and student preparation), and efficient time use (e.g., identifying central issues of the problem before class and sharing and discussing them in class) in PBL.

Future PBL studies should also take the learner's level of knowledge and cognitive/social development more into consideration. Although Schmidt et al. (2007) have shown that the elements comprising PBL allow for management of cognitive load by flexibly adapting guidance to the complexity of the tasks and the expertise of the learners, it remains an interesting research question whether students should always start to work in group or that it might be more effective to start learning individually in a more didactic way and proceed with group learning only after sufficient prior knowledge has been acquired. Studies investigating this issue can build a bridge between cognitive load and human cognitive architecture theory on the one hand and instructional approaches such as PBL on the other hand as well as making PBL more tuned to its audience: the learners.

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