Educational Technology International
2013, Vol. 14, No. 2, 137-166

A Research Review on Major Variables in PBL Designs of Engineering Courses

Sung-Hee JIN
Inha University
Korea

Tae-Hyun KIM*
Chungkang College of Cultural Industries
Korea

Problem-based learning (PBL) in engineering education has been implemented in various ways. The wide range of PBL methods sometimes creates difficulties in implementing PBL. The purpose of this study was to identify the major variables that a teacher considers in PBL designs for an engineering course and suggest specific PBL methods according to the PBL design variables. This study was conducted using a review research method involving 21 studies from a range of engineering education fields. The results showed that the major variables that engineering professors need to consider when applying PBL are the authenticity of the PBL problem and the method of providing knowledge or information that the learners must know to solve the given problem. Based on the two variables identified, the following four types of PBL methods for engineering education are suggested: 1) lecture-based problem, 2) guided problem-based learning, 3) problem-based learning and 4) co-op problem-based learning.

Keywords : Problem-based learning (PBL), PBL design, authenticity, self-directed learning, review study, engineering education

* Dept, of Early Childhood Education, Chungkang College of Cultural Industries
thkim@ck.ac.kr

Introduction

Problem-based learning (PBL) is being applied increasingly in engineering education due to industry demand for professional skills and outcome-based accreditation around the world (Beddoes, Jesiek, & Borrego, 2010; Strobel & van Barneveld, 2009). The industry demands real-world problem solving skills as professional skills because the field feels that the graduates' abilities are less than expected (Strobel & van Barneveld, 2009). Another reason driving the implementation of PBL is the design-related curriculum required by engineering education accreditation to provide students with practical problems where they can collaborate with their peers to find solutions.

The application of PBL also varies in engineering education areas because PBL is a widely used instructional method. The broad range of PBL methods sometimes creates difficulties in implementing PBL. Some PBL cases may fail to achieve the anticipated learning outcomes because of the misapplications of PBL (Savery, 2006). Specifically, PBL can be adopted in a variety of ways depending on the instructors' understanding of PBL. Therefore, it is essential to provide engineering educators with the appropriate guidelines on PBL methods to apply PBL effectively for engineering educators. Some studies have conceptually suggested a PBL classification in engineering education (Gao, Willmot, & Demian, 2009; Graff & Kolmos, 2003) but few have shown how PBL is being implemented in class.

Therefore, this study first identified the major variables that a teacher considers when he/she designs PBL in an engineering course. The paper then presents PBL methods for engineering courses according to the identified PBL design variables, and finally identifies the learning outcomes for each PBL method. The study results are expected to provide the major variables in PBL design and the practical PBL methods for the applications of PBL in engineering education.

PBL in Engineering Education

The general overview of PBL in engineering education is based on a literature review conducted using the following databases: Web of Science (ISI) and Google Scholar, using the keywords 'problem-based learning & engineering' or 'PBL & engineering'. The purpose of this section was to investigate theoretically the potential variables that need to be considered when designing PBL for engineering major courses.

PBL Methods

Barrows (1986) initially introduced six PBL methods according to the problem type and degree of students' responsibility as follows: lecture-based cases, case-based lectures, case method, modified case-based, problem-based, and closed-loop problem-based learning. He examined the teaching and learning sequences as well as the relationship with the particular learning objectives of each method. The PBL methods reported by Barrows are meaningful because they offer an overview of PBL along with guidelines for instructors to choose suitable methods depending on their needs. On the other hand, the problem type, which is the major variable suggested by Barrows in categorizing different PBL methods, reflects the characteristics of medical education, such as clinical problems or cases, and cannot be applied directly to engineering education.

Savin-Baden (2000) suggested the following five PBL models depending on the learning objectives: epistemological competence, professional action, interdisciplinary understanding, trans-disciplinary learning and critical contestability. Savin-Baden's PBL models provide an overview by guiding PBL in an engineering curriculum in conceptual terms. On the other hand, it has a limitation in providing specific guidelines for applying and operating PBL in a single course. Gao, Willmot and Demian (2009) and Graaff and Kolmos (2003) suggested that PBL methods could be classified according to the learners self-directed learning level but specific PBL methods were not stated. Prince and Felder (2006) suggested three models of PBL, medical school model, floating facilitator model and self-directed model. In the medical school model, students work in groups of 7-10 under the supervision of a faculty member or another designated tutor with little, if any, formal class time. In the floating facilitator model, students work on problems in groups of 3-5 during class, while a teacher moves from group to group asking questions and probing for understanding. In the self-directed model, students work in groups that take responsibility for the work. Although it can be assumed that researchers classified the three models based on the level of self-directed learning, they did not explain the specific criteria for such a classification.

Many studies have been performed conceptually to classify PBL because it has been implemented in many ways across many domains (Maudsley, 1999; Prince & Felder, 2006). Previous studies attempted to classify the PBL methods according to the learning objectives, degree of students' responsibility and problem types. The next section briefly examines the properties and types of PBL problems, the tutorial process of PBL and the learning outcomes of PBL, which are variables with the potential to influence the design of PBL in engineering courses

Potential Variables in PBL design

Characteristics and types of PBL Problems

A problem is the key to successful PBL (Jonassen, 2000; Savery, 2006) and developing an appropriate PBL problem is difficult (Weiss, 2003). Complex real world problems that attract the students' interests are used in PBL, including a range of subject fields. Jonassen (2000) derived eleven problem types from highly structured problems to ill-structured problems in the context of problem solving. Within Jonassen's typology of problem types, design problems are normally the most complex and ill-structured problems and the most common type of problem solved by engineers. Design problems have ambiguous goals, multiple solution paths, unstated constraints and incorporate multi-disciplinary knowledge (Jonassen, 2000; Walker & Leary, 2009). The type of PBL problem for Capstone Design courses in engineering education is normally a design problem. Another PBL problem type applicable to engineering courses is a case-analysis problem. The goals are less clear in case-analysis problems, which means the constraints are not likely to be mentioned, procedures for solving the problem are rarely stated and the data available to the problem solving entity is abundant but partial, incorrect or equivocal (Voss, Wolfe, Lawrence, & Engle, 1991). For example, case-analysis problems, such as planning production levels, require the balancing of human resources, technologies, inventory and sales (Jonassen, Privish, Christy, & Stavrulaki, 1999).

The major characteristics of a good PBL problem that scholars have suggested can be organized into the following three categories: ill-structured, authentic and relevant. A good PBL problem is ill-structured (Choi, 2004; Hmelo-Silver, 2004; Weiss, 2003). Such a problem leads the learners to conduct consecutive problem-solving processes, such as problem analysis, information gathering and investigation, and arriving at a solution. The problem needs to be a real-life problem (Choi, 2004; Duch, 2001; Hmelo-Silver, 2004; Uden & Beaumont, 2006; Weiss, 2003). To increase the problem's authenticity, it should contain contextual information as to where the problem occurs. Primarily, the problem should consider the course objectives and learner's competency (Choi, 2004; Duch, 2001; Uden & Beaumont, 2006; Weiss, 2003). A problem can be stated as a PBL problem that enhances higher order thinking skills if it is ill-structured, authentic and relevant to the class goals and learners' competency.

The PBL Tutorial Process

The PBL process begins with the presentation of a problem and ends with student reflection. Dunlap (2005) presented 4 phases of PBL activities referring to

Barrows model: (1) problem analysis, (2) solution design, (3) solution development, and (4) post-development review. Previous research described the details of activities in each phase as follows (Barrows & Myers, 1993; Torp & Sage, 2002; Uden & Beaumont, 2006; Uden & Dix, 2004).

In the first phase of "problem analysis", the PBL problem is introduced and evaluated (Barrows & Myers, 1993; Torp & Sage, 2002), and an action plan for team task implementation is established (Dunlap, 2005; Uden & Beaumont, 2006; Uden & Dix, 2004). At this stage, the students should begin to develop the idea of the final solutions. The students discuss what they already know, what requires further research and any possible solutions. They divide the task of further research into individual tasks assigned to each student.

In the second phase of "solution design", the students carry out their individual tasks and learn by combining their resources to solve the problem according to the action plans (Torp & Sage, 2002; Uden & Dix, 2004). They can share what they have collected and synthesize on a web-based community. During this process, the instructor does not participate directly in the student activity, but rather guides the students to maintain their focus on problem solving.

In the third phase of "solution development", the students in their team reconfirm the problem, deduce a possible solution and implement that solution (Barrows & Myers, 1993; Dunlap, 2005; Uden & Dix, 2004; Uden & Beaumont, 2006). They explain what they have learnt individually and suggest their own opinions to the team. When all learning contents have been shared among team members, the students derive additional learning tasks or a final solution that is essential to solving the problem. When additional task implementation is required, they go back to phase 2 and iterate the individual learning and collaborative learning process until they come up with a final solution. When the final solution ideas have been derived, they implement that solution. Subsequently, each team presents their solution. When needed, the students evaluate the other teams' problem solving processes and results by actively listening to the others' presentation.

In the fourth phase, "post-development review", the instructor organizes and summarizes the contents relevant to the expected instructional objectives through PBL (Steinwachs, 1992; Thiagarajan, 1993) and the students complete their reflection journals. The key learning effects of PBL are likely to be reduced if the instructor does not provide debriefing. Such debriefing can help the students systematize what they have learned through a practical problem solving process. Learning consolidation can also be achieved through a reflection journal (Barrows, 2000; Dunlap, 2005).

Learning Outcomes of PBL

Several important learning outcomes suggested in previous studies as being achievable by adopting PBL include helping the students develop the following: 1) flexible knowledge, 2) effective problem-solving skills, 3) effective collaboration skills, 4) self-directed learning skills (SDL) and 5) intrinsic motivation (Barrows & Kelson, 1995; Hmelo-Silver, 2004). These skills can be taught in separate modules or within a module.

As evident in previous research on PBL, flexible knowledge can be applied to a range of problems and can be enhanced in situations that require certain knowledge (Helmo, 1998; Kolodner, 1993). Previous PBL research also supports this. Hmelo-Silver (2000) reported that students recognized the significance of prior knowledge when gaining new knowledge and made distinctions between the concepts or principles to use when solving certain problems in their problem-based education psychology class. Derry et al. (2000) also suggested that course concepts can be transferred and applied easily using the PBL method. This shows that students identified the appropriate course concepts or principles, and applied them to multiple problems in a PBL environment. Therefore, the cognitive components of problem solving include both knowledge acquisition and knowledge application.

Problem-solving skills include the ability to apply the appropriate reasoning skills to new problems and identify the problem in ill-structured problems (Hmelo-Silver, 2004). A reasoning strategy based on a hypothesis is a learning process (Norman et al., 1998). Patel, Groen and Norman (1993) reported that hypothesis-driven reasoning skills are used increasingly by students in a PBL curriculum than those in a traditional curriculum. In an innovative engineering course applying PBL, Hmelo et al. (1995) showed that the students' problem-solving skills are increased by PBL. Gallagher, Stepien and Rosenthal (1992) also reported that students in PBL could solve unprecedented ill-structured problems. Although research on the effects of PBL on problem-solving is limited, students in PBL can extend their problem solving and reasoning skills to new areas (Hmelo-Silver, 2004).

Problem discussion in PBL is performed mostly in tutorial group sets; students can develop interpersonal skills and learn how to function well as part of a team (Loyens, Magda, & Rikers, 2008). The group function in PBL tutorial groups is a key factor in learning outcomes and intrinsic motivation. Students work together in tutorial groups, but not all groups collaborates well (Hmelo-Silver, 2002; 2004). In-depth research is needed to determine if a PBL environment assists all students to become better team workers.

Self-directed learning (SDL) skills enable autonomous learning. Schmidt (2000, p. 243) defined SDL as "the preparedness of a student to engage in learning activities defined by him- or herself, rather than by a teacher." This indicates not only the motivation and willingness to engage in learning activities, but also their ability to do so. Dolmans and Schmidt (2000) examined which of the instructional elements that students received in PBL classes helped students develop SDL skills, and reported that positive SDL can be achieved the most by discussing the problems and objectives of the course, with tests and lectures having a lesser effect. Hmelo and Lin (2000) also argued that specific PBL features, such as the generation of learning issues, planning for learning and integration of new knowledge, support to foster SDL. In terms of the learning resources, Shikano and Hmelo (1996) reported that engineering students in a PBL course tend to use student-selected resources throughout the course. In particular, poor self-regulated learners can have difficulties in PBL courses, so scaffolding SDL is important (Hmelo-Silver, 2004).

The final goal of PBL is to help the students foster the intrinsic motivation to learn. Intrinsic motivation occurs when the learners work on personally meaningful tasks and have some control of their learning (Loyens, Magda, & Rikers, 2008). These PBL characteristics help increase the learning motivation but there has been little research in this area. A few research reported that PBL students were satisfied with their learning (Dunlap, 2005; Ertmer, Newby, & MacDougall, 1996).

The present study identified the major variables that an engineering teacher considers when designing PBL by analyzing the cases where PBL is adopted in university engineering courses. In particular, this study addressed the following research questions:

a) What are major variables in PBL design of engineering courses?

b) What are the ways to categorize the PBL methods according to the identified PBL design variables?

Review Method

PBL-applied studies were examined using a review study method in the following five-step research procedure: (1) setting the inclusion criteria; (2) selecting the studies; (3) establishing a coding scheme; (4) validating and finalizing the study selection and coding scheme according to an expert validity survey; and (5) analyzing the selected studies and cross-checking.

Inclusion Criteria

The inclusion criteria comprised of the following elements to examine the major variables in PBL design for engineering courses. The empirical or case studies that referred to ‘problem-based learning’ and published after 2005 were selected, whereas those referred to ‘project-based learning’ were excluded. The studies also had to relate to the engineering curriculum applications and included information on the PBL problems, tutorial processes and learning outcomes.

Literature Search

The most commonly used electric database, Web of Science (ISI), was used to find PBL-applied studies that met the inclusion criteria using keywords, such as “problem-based learning & engineering” or “PBL & engineering.” The “snowball” method was used to search additional PBL engineering studies and the references of the selected articles were also reviewed. Initially, 34 studies were identified. Among all research articles found those articles related to engineering curriculum applications with an indication of the PBL problems, tutorial processes and learning outcomes were selected. Seven of them were eliminated because they did not include engineering major courses, such as statistics and physics for engineering students, and six studies deficient in the PBL tutorial process or PBL problems were also excluded. Overall, 21 studies were used in the final analysis.

A systematic literature review of studies on PBL-applied courses in engineering education was undertaken using Garrard (2007)’s Matrix Method. This method, which provides a process and structure, was used to provide the required structure to record the notes on each article in the analysis of the PBL-applied cases. Each study was analyzed using a structured abstracting form with three categories, PBL problem, tutorial process, and learning outcomes.

Table 1 lists the characteristics according to the region and area of PBL application. According to the region, ten, five, four and two studies were from Europe, North America, Asia and South America, respectively. In terms of context, ten, four, four, two and one study was in the electrical, civil, computer, mechanical and chemical engineering fields, respectively.

Table 1. Research contexts, PBL types and authenticity level, tutorial process and learning outcomes

Studies	Context & Course	Problem types and authenticity level*	Tutorial process	Learning outcomes**
S1: Butun (2005)	Electrical Eng. Genetic algorithms Mater level course (Turkey)	Design problem AUL: medium	review of prerequisite knowledge and skill → present a problem with situations → define the problem → team discussion (identify available information and learning issues) → individual study → propose a solution → write a report → presentation & discussion → evaluation	FK, PS & MOT
S2: Dunlap (2005)	Software Eng. Introduction to electronic engineering (USA)	Design problem AUL: high	closed loop PBL present from client a problem → define the problem → set hypothesis → create action plan → self-directed learning → critique learning resources and apply new information to solve the problem → implement a solution and submit it to the client→ reflect on and summarize what students have learned	MOT
S3:Ribeiro & Mizukami (2005)	Civil Eng. Administration theory (Brazil)	Case analysis problem AUL: medium	present a problem → define problem →create action plan → investigate individually the issues→ solve the problem → oral presentation & debate → write a report →(self- and peer-) assessment	FK, TW & PS
S4: Chae & Noh (2006)	Information Management Eng. CAD/ Digital manufacture and laboratory (South Korea)	Design problem AUL: high	present from industry a problem → analyze the problem with team members → solve the problem → write a report & reflective journal → presentation & evaluation by experts from industry	FK, PS & TW
S5: Costa, Honkala, & Lehtovuori (2007)	Electrical Eng. & Telecommunications Eng. Circuit Analysis (Finland)	Design problem AUL: medium	clarify terms → define a problem → analyze the problem → systematic clarification →formulate learning objectives (to obtain additional information)→ self-study → write a report → exam & survey	FK & MOT
S6: Bizjak (2008)	Electrical Eng. Electrical power networks (Slovenia)	Design problem AUL: low	lecture → present a problem → analyze the problem (set and examine hypothesis: calculating the design using the formula given in the lecture and verifying the design) → solve the problem (set prototype) → write a report	FK
S7: Butun, Erkin & Altintas (2008)	Electrical & Electronic Eng. (Turkey)	Design problem AUL: medium	review of prerequisite knowledge and skill →present a problem → define the problem → identify new learning issues → self-directed learning →find a solution → write a report → presentation → test & peer assessment	FK, PS & TW

S8: Ribeiro (2008)	Electrical Eng. Administration theory module (Brazil)	Case analysis problem AUL: medium	present a problem → analyze the problem → create action plans → self-directed learning → share knowledge individually gathered → present solutions → debrief and evaluation	FK, PS, TW & SDL
S9: Lee et al. (2008)	Mechanical Eng. Creative design project (South Korea)	Design problem AUL: low	lecture → present a problem → analyze the problem → solve the problem → write a report and present solutions → debrief	FK & TW
S10: Mantri et al. (2008)	Electronics and Communication Eng. Analog Electronics (India)	Design problem AUL: low	present a problem → set the learning objectives on their (student) own →add supplementary learning objectives (teachers) → determine what they need to study → distribute the work → self-directed learning → discuss solutions → frame similar kinds of problems and identify application areas → presentation → tests & survey	FK, PS & TW
S11: Quinn, Albano & M.ASCE (2008)	Civil Eng. Major Qualifying Project (USA)	Design problem AUL: medium	present a problem → formulate the problem → self-directed learning (synthesize the literature) → solve the problem → write a report and documents→ evaluation	PS & SDL
S12: Montero & Gonzalez (2009)	Electronic Eng. Heat transfer (Spain)	Design problem AUL: low	lecture → present a problem → solve the design problem → write a report → presentation & evaluation	FK
S13: Schaefer &Panchal (2009)	Mechanical Eng. Machine Design, Interactive CG & CAD (USA)	Design problem AUL: medium	present a problem → analyze the problem → self-directed learning → solve the problem → write a report → write a reflect journal	FK
S14: Seo (2009)	Computer Information Laboratory of computer network (South Korea)	Design problem AUL: medium	present a problem → analyze individually the problem and set action plans → analyze collaboratively the problem and supplement action plans → present and discuss the result of the problem analysis → solve individually the problem → solve the problem with team members→ present the solutions→ evaluation and debriefing	FK
S15: Vilonen & Krause (2009)	Chemical Eng. a master level laboratory course (Finland)	Case analysis problem AUL: medium	present a problem (with additional materials)→ plan an experiment → carry out a laboratory work → draw conclusions from the results in the report → laboratory and the report are evaluated → present results and feedback	FK
S16: Ahern (2010)	Civil Eng. Transportation (Ireland)	Case analysis problem AUL: medium	present a problem → define the problem → self-directed learning → present a solution → oral presentation → write a report → make a poster → evaluation	PS & SDL

S17: Hartman & Gindy (2010)	Civil Eng. Structural Engineering Laboratory (USA)	Case analysis problem AUL: medium	present a problem → analyze the problem → discuss what they need to know → independent research → discuss solutions → solve the problem →self-assessment	FK & MOT
S18: Mitchell et al. (2010)	Electronic Eng. Communication Systems II (UK)	Design problem AUL: medium	Not provided directly present a problem → analyze the problem→ group discussion → find new information to solve the problem → self-directed learning →solve the problem → submit a portfolio	FK & TW
S19: Romero (2011)	Computer Engineering Industrial Computers (Spain)	Design problem AUL: low	present a problem (for assignment) → tutorial sessions with groups and individual → find a solution → presentation	FK & PS
S20: Urrestarazu, Salas & Canero (2011)	Engineering Agricultural engineering courses (Spain)	Design problem AUL: low	lecture →present a problem→ analyze the problem →group work to find multiple solutions →discussion for selecting the best option → presentation	FK, TW & MOT
S21: Yadav et al. (2011)	Electrical Eng. Introduction to electronic engineering (USA)	Design problem AUL: medium	self-directed learning (reading materials and taking online quizzes) → present a problem→ solve the problem (in class & out-of-class team work) → evaluation	FK

* AUL: authenticity level
** FK : flexible knowledge, PS: problem solving, TW: teamwork, MOT: motivation & SDL: self-directed learning

Coding Scheme

Among the three major characteristics of PBL problems, an ill-structured problem was analyzed according to Jonassen's (2000a) typology of problem types and the design problems or case-analysis problems were assumed in most engineering education papers. In terms of the authenticity level of the problems, it was coded as high if real problems from industry were used, medium if scenario problems that can be encountered in a future workplace were used, and low if task problems related directly to achieving the learning objectives were used. On the other hand, in the present study paper, the level of relevance, which is one of the three characteristics of the PBL problem, regarding how the problems are related to the respective learning objectives and the ability of the students could not be analyzed. The PBL tutorial learning process was analyzed with the intervention described in each study. Finally, the PBL learning outcomes were coded with the following six development skill sets, as suggested by Hmelo-Silver (2004): flexible knowledge, problem-solving skills, self-directed learning skills, teamwork skills and motivation.

Analytic Method

The research selection and coding scheme were verified by a survey conducted by three experts with a doctorate degree in educational technology and research experience in PBL. An expert validity survey was designed for the experts to evaluate the analysis criteria using a four-point Likert-type scale (strongly invalidated/strongly validated). The survey measured the suitability of the research selection as well as the validity of the coding scheme. In statistical analysis, an inter-rater reliability of $r > 0.74$ was excellent, 0.60–0.74 was good, 0.40–0.59 was fair and <0.40 was poor (Yang & Chan, 2008). The inter-rater reliability for the case selection and coding scheme was 0.92 and 0.88, respectively, which indicates a good condition.

Subsequently, three educational experts including the author analyzed the selected studies according to the coding scheme and documented the grounding resources. Although any disagreement was settled by discussion, a cross-validation check revealed 0.94 proportional agreement between the analysts involved.

Results

Two major variables in PBL design of engineering courses

The authenticity level of the problems used in PBL was the first major variable analyzed. According to the authenticity level of the problem, three problem types used in engineering major courses were identified: real problems from industry, scenario problems with contextual or situational information that might be encountered in a future workplace, and task problems closely related to students' future profession without any background information. If a real problem has not solved by a company was used in a PBL class, an instructor should have a prior consultation with the company and obtain a clear understanding of the problem offered by the company. The PBL outcomes presented by each team can also be evaluated or reviewed by the company experts.

An ill-structured PBL problem was also analyzed according to Jonassen's (2000a) typology of problem types. The results showed that PBL problems in engineering courses are relatively ill-structured, complex problems, and case-analysis or design problems depending on the characteristics of the course content. Nevertheless, there was no direct relationship found between the types of problem by the ill-structure and PBL tutorial process or learning outcome.

The example of a design problem is as follow: *You are a member of InstruConsult*

Corporation, a conglomerate that designs instrumentation devices for use in a wide range of scenarios. InstruConsult is making you responsible for a biomedical instrumentation design project. The client, a corporation that manufactures hospital equipment, wishes to upgrade its paper-based electrocardiographs (ECG) to a digital ECG system. Your job is to design the system. You must produce a block diagram and specify all components. You must also demonstrate its function using the double "rapid prototyping" system that InstruConsult has made available to you, which consists of: (1) virtual acquisition chain implemented in LabVIEW (2) a modular hardware acquisition chain that can be customized, including datasheets for all components.

The example of a case-analysis problem is as follow: *You work as a summer trainer in a company producing esters. The company has lately expanded its butyl acetate production line to increase capacity. Now there is a plan to utilize the old equipment for the production of propyl acetate. Your group's job in the team is to estimate the possibilities of re-use of the old esterification reactor.*

The level of self-directedness of the learners was found to be another major variable in designing a PBL course. Self-directedness in PBL refers to the level of learner initiative in searching for and understanding information or knowledge to solve a given problem. Although PBL courses involve a student-directed tutorial method, the result from the analysis showed that the PBL methods implemented in engineering courses requires different level of self-directedness. More specifically, three types were identified: when an instructor delivers the information required to solve a problem through lectures, when the necessary information is provided by an instructor or a tutor as reading material, or when students select, find and learn information on their own.

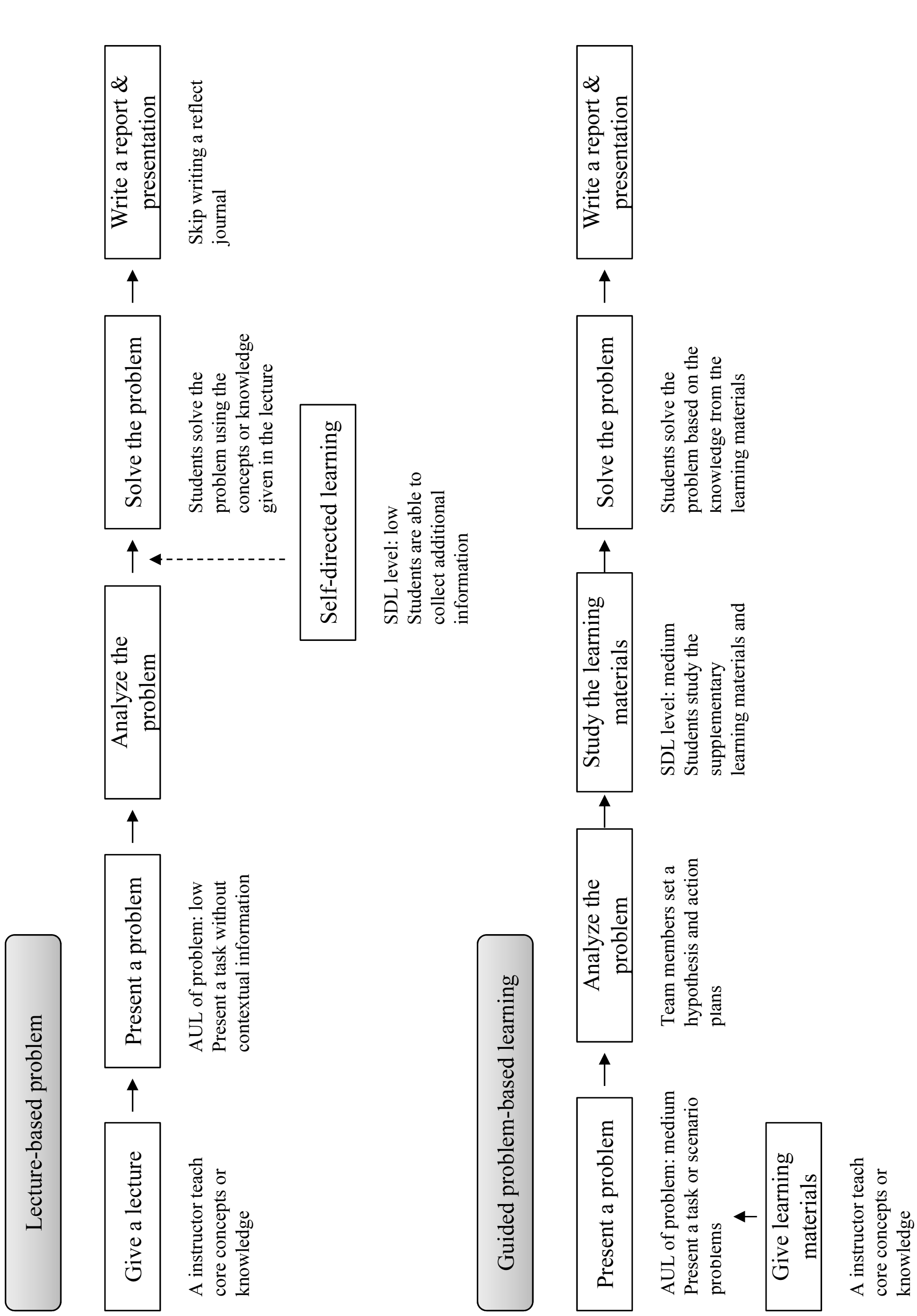
PBL Methods Applied to Engineering Education

After reviewing the selected studies for their tutorial processes according to two major variables in PBL design, these processes were categorized into four groups depending on the authenticity of the PBL problem and the learners' self-directing level. PBL problems were analyzed according to the authenticity level as a real problem from industry, possible scenario problems with contextual information, or task problems without background information. The learners' self-directed learning level was analyzed according to the process for obtaining the required information or knowledge for solving a problem: teacher lectures, resources that the teacher or tutor provided, or students' self-directed learning. Various combinations of these design variables in PBL are possible. Four PBL types were recognized from this review study.

Lecture-based problem (AUL of problem: low, SDL level: low). This is where a lecture is presented before the PBL approach is applied. The PBL approach is applied by giving students the opportunity to understand the core concepts or knowledge through lectures so that they can apply their knowledge to a practical problem to assure knowledge acquisition. In identifying the problem, some hypothesis-driving reasoning and limited decision-making might be needed to solve the ill-structure problem presented. The students might be able to collect additional information or obtain additional knowledge to solve the problem but fundamentally, the necessary information or new information is provided by the initially presented lecture. Examples of this tutorial type are S6, S9, S12 and S20. The PBL problems used in these examples are potential design problems that can be encountered in a future workplace presented as tasks without contextual information.

Guided problem-based learning (AUL of problem: medium or low, SDL level: medium). The students are provided with the resources that contain the necessary information for the given problem to guide their self-directed learning. Before or when the problem is presented, additional materials that contain the necessary information are provided. The students engage in problem identification and setting a hypothesis in teams but they basically analyze the problem based on the materials given by the instructor or tutor. They also need to learn the materials provided by the instructor to solve the problem. Therefore, the self-directed learning skills are higher than in the lecture-based problem methods, but this might appear to be self-directed learning guided by the instructor. Examples of this tutorial type include S1, S5, S10, S15 and S21. The PBL problems used in the examples are potential case-analysis or design problems that can be encountered in a future workplace presented mostly as scenario problems with contextual information, but sometimes as tasks without contextual information.

Problem-based learning (AUL of problem: medium, SDL level: high). In this PBL tutorial type, the necessary information or knowledge is obtained through self-directed learning to solve the problem given to the students (S3, S7, S8, S11, S13, S14, S16, S17, S18, and S19). This method is the same as those generally used in other academic fields. The PBL problems used in the examples are potential case-analysis or design problems, except for S19, which are presented as authentic problems with scenario and contextual information. The specific PBL tutorial process is as follows: 1) the ill-structured problem is identified by the team, 2) the hypothesis is set up based on prior knowledge, 3) the action plan is laid out, 4) the additional learning is progressed through self-directed learning, 5) the hypothesis is revised and the solution is devised, and 6) a presentation is made and an evaluation is performed. Therefore, the highest level of hypothesis-driven reasoning and decision making activity may be required from the students along with self-directed learning ability to obtain new information. The solution design and solution development steps can be revisited repetitively to derive the best solution according to the complexity of the problem. The students can move on to the next step when they agree that they have reached the best solution after analyzing that problem, shared the acquired information through self-directed learning and verified their hypothesis. On the other hand, when students in a team agree upon a deficiency of collected information to solve the problem, they can decide on what type of additional information is further required and return to the self-directed learning


Lecture-based problem
Give a lecture
A instructor teach core concepts or knowledge
Present a problem
AUL of problem: low
Present a task without contextual information
Analyze the problem
Self-directed learning
SDL level: low
Students are able to collect additional information
Solve the problem
Students solve the problem using the concepts or knowledge given in the lecture
Write a report & presentation
Skip writing a reflect journal
Guided problem-based learning
Present a problem
AUL of problem: medium
Present a task or scenario problems
Give learning materials
A instructor teach core concepts or knowledge
Analyze the problem
Team members set a hypothesis and action plans
Study the learning materials
SDL level: medium
Students study the supplementary learning materials and
Solve the problem
Students solve the problem based on the knowledge from the learning materials
Write a report & presentation

step. When the students agree that they have collected all the information necessary to solve the problem, they decide on a solution and present it for evaluation. PBL is then finalized by the instructor's debriefing.

Co-op Problem-based learning (AUL of problem: high, SDL level: high). Similar to previous PBL methods, this PBL method requires the students to search for the information and knowledge needed to solve the presented problem in self-directed manner. The only difference is that the co-op problem-based learning uses real problems from a company. Examples of this problem type are S2 and S4. PBL problems that correspond to the learning objectives are received from a company before the course begins. Prior consultation is also done to discuss how the PBL class will be run in cooperation with the company. The subsequent steps of the co-op PBL tutorial process are similar, but when the student teams deliver final presentations on their solutions, experts might be invited in person, to review and evaluate the final solutions. The advantages of this method is that it can provide practical field experiences as the students try to solve the real problems of the industry, analyze the needs of the client and suggest solutions.

Discussion

Theoretical contributions: Co-op PBL

This study empirically supports the previous suggestion that PBL methods can be classified according to the degree of a learner's self-directed learning (Gao, Willmot & Demian, 2009; Graaff & Kolmos, 2003; Prince & Felder, 2006). Although previous studies suggested that PBL methods can be categorized according to the level of students' self-directed learning, they did not provide any specific guidelines for designing a PBL course. From the review study presented in this paper, the self-directed learning in PBL classes refers to the students' self-directedness in acquiring the knowledge or information necessary to solve a given problem. Moreover, it is this self-directedness that distinguishes one PBL method from another.

On the other hand, Barrows (1986) provided PBL methods for medical education according to problem types. As design problems are used most of the time in engineering education, the problem type was not considered to be one of the major variables affecting the design of PBL course. In engineering education, the authenticity of the problem was the significant variable. Such a disparity is due to the different characteristics of two academic fields. Medical education deals with PBL problems according to the level of ill-structure, whereas engineering education deals with PBL problems according to the level of authenticity. Therefore, the variables for designing a PBL course depend on the specific characteristics of the discipline.

Moreover, the co-op PBL suggested in this study is a PBL method that reflects the characteristics of engineering, which is clearly distinct from the PBL methods used in other academic areas. In particular, the method can provide opportunities for practical experience that the field emphasizes. The existing PBL methods originated from medical education, and were adopted in other areas in similar ways. This particular method is suggested as a PBL method for engineering.

Practical contributions: Two major variables in engineering PBL designs

The results of this study provide practical implications for engineering professors when preparing and operating PBL engineering courses by suggesting the major variables they need to consider; the authenticity of the problem assigned to students and the method of providing knowledge or information required for solving the given problem. In addition, it offers useful guidelines for designing a PBL course by practically demonstrating the process of a PBL tutorial according to the two major variables. In particular, the study is expected to be useful for engineering professors who are new to using PBL in their course.

Limitations and Future Directions

In this review paper, the differences in learning outcomes for different PBL methods were not examined because the number of cases using PBL methods was dissimilar and limited. Therefore, future research should investigate the learning outcomes for each PBL method by conducting an experimental study. In addition, to provide more detailed guidelines for applying and managing PBL in engineering education, future research should examine PBL methods for different types of engineering courses. For example, it was assumed that lecture-based problems can be used for courses that teach disciplinary knowledge, guided PBL for general design courses that foster both knowledge acquisition and design skills, and PBL or co-op PBL for capstone design courses that enhance the creative problem-solving skills by solving real problems using what students have learned over the past four years of college. On the other hand, there is a need for empirical research to provide more solid evidence because it is based only on theoretical assumptions.

References

Bandura, A. (1997). *Self-Efficacy: The Exercise of Control*. NY: Freeman.

Barrows, H., & Kelson, A. C. (1995). *Problem-Based Learning in Secondary Education and the Problem-Based Learning Institute* (Monograph 1). Springfield, IL: Problem-Based Learning Institute.

Barrows, H. S. (1986). A taxonomy of problem-based learning methods. *Medical Education, 20*, 481-486.

Barrows, H. S. (2000). *Problem-based learning applied to medical education*. Springfield, IL: Southern Illinois University School of Medicine.

Barrows, H. S., & Myers, A. C. (1993). *Problem-based learning in secondary schools*. Unpublished monograph. Springfield: Problem-Based Learning Institute, Lanphier High School and Southern Illinois University.

Beddoes, K. D., Jesiek, B. K., & Borrego, M. (2010). Identifying Opportunities for Collaborations in International Engineering Education Research on Problem-and Project-based Learning. *The Interdisciplinary Journal of Problem-based Learning, 4*(2), 7-34.

Choi, J. (2004). A study on the problem design principle for Problem-Based Learning through the case analysis. *Journal of Educational Technology, 20*(1), 37-61.

de Graaff, E., & Kolmos, A. (2003). Characteristics of Problem-Based Learning. *International Journal of Engineering Education, 19*(5), 657-662.

Derry, S. J., Levin, J. R., Osana, H. P., Jones, M. S., & Peterson, M. (2000). Fostering students' statistical and scientific thinking: Lessons learned from an innovative college course. *American Educational Research Journal, 37,* 747-773.

Dolmans, D. H. J. M., & Schmidt, H. G. (2000). What directs self-directed learning in a problem-based curriculum? In D. H. Evensen and C. E. Hmelo. (Eds.), *Problem-Based Learning: A Research Perspective on Learning Interactions* (pp.251-262). Mahwah, NJ: Erlbaum.

Duch, B. (2001). Writing problems for deeper understanding. In B. Duch, S. E. Groh, & D. E. Allen (Eds.), *The power of problem-based learning: A practical "how to" for teaching undergraduate courses in any discipline* (pp.47-53). Sterling, VA: Stylus Publishing.

Dunlap, J. C. (2005). Problem-based learning and self-efficacy: How a capstone course prepares students for a profession. *Educational Technology Research and Design, 53*(1), 65-85.

Ertmer, P., Newby, T. J., & MacDougall, M. (1996). Students' responses and approaches to case-based instruction: The role of reflective self-regulation. *American Educational Research Journal, 33,* 719-752.

Gallagher, S. A., Stepien, W. J. & Rosenthal, H. (1992). The effects of problem-based learning on problem solving. *Gifted Child Quarterly, 36,* 195-200.

Gao, M., Willmot, P., & Demian, P. (2009). Gauging the effectiveness of design projects in engineering education. In X. Du, E. de Graaff, and A. Kolmos. (Eds.), *Research on PBL Practice in Engineering Education* (pp.71-83). Sense Publishers.

Garrard, J. (2007). *Health sciences literature review made easy: The matrix method.* Sudbury. MA: Jones & Bartlett.

Hmelo-Silver, C. E. (2000). Knowledge recycling: Crisscrossing the landscape of educational psychology in a Problem-Based Learning Course for Preservice Teachers. *Journal on Excellence in college teaching, 11,* 41-56.

Hmelo-Silver, C. E. (2002). Collaborative ways of knowing: Issues in facilitation. In G. Stahl. (ed.). *Proceedings of CSCL 2002* (pp.199-208), Hillsdale, NJ: Erlbaum.

Hmelo-Silver, C. E. (2004). Problem-based learning: What and how do students learn?. *Educational Psychology Review, 16*(3), 235-266.

Hmelo, C. E. (1998). Problem-based learning: Effects on the early acquisition of cognitive skill in medicine. *Journal of the learning science, 7,* 173-208.

Hmelo, C. E., & Lin, X. (2000). The development of self-directed learning strategies in problem-based learning. In D. Evensen, and C. E. Hmelo. (Eds.).

Problem-Based Learning: Research Perspectives on Learning Interactions (pp.227-250). Mahwah, NJ: Erlbaum.

Hmelo, C., Shikano, T., Bras, B., Mulholland, J., Realff, M., & Vanegas, J. (1995). A problem based course in sustainable technology. In D. Budny, R. Herrick, G. Bjedov, & J. B. Perry (eds.), *Frontiers in Education 1995*. Washington, DC: American Society for Engineering Education.

Jonassen, D. H. (2000*). Design Methods*. Jone Wiley & Sons Ltd.

Jonassen, D., Prevish, T., Christy, D., & Stavurlaki, E. (1999). Learning to solve problems on the Web: Aggregate planning in a business management course. *Distance Education: An International Journal, 20*(1), 49-63.

Kolodner, J. L. (1993). *Case-Based Reasoning*. San Mateo, CA: Morgan Kaufmann.

Loyens, S. M. M., Magda, J., & Rikers, R. M. J. P. (2008). Self-Directed Learning in Problem-Based Learning and its Relationships with Self-Regulated Learning. *Educational Psychological Review, 20,* 411-427.

Maudsley, G. (1999). Do we all mean the same thing by "problem-based learning"? A review of the concepts and a formulation of the ground rules. *Academic Medicine, 74*(2), 178-85.

Norman, G. R., Brooks, L. R., Colle, C., & Hatala, H. (1998). Relative effectiveness of instruction in forward and backward reasoning. *Paper presented at the Annual Meeting of the American Educational Research Association*, San Diego, CA.

Patel, V. L., Groen, G. J., & Norman, G. R. (1993). Reasoning and instruction in medical curricula. *Cognition and Instruction, 10,* 335-378.

Prince, M. J., & Felder, R. M. (2006). Inductive Teaching and Learning Methods: Definitions, Comparisons, and Research Bases. *Journal of Engineering Education, 95*(2), 123-138.

Savery, J. R. (2006). Overview of Problem-based Learning: Definitions and Distinctions. *The Interdisciplinary Journal of Problem-based Learning, 1*(1), 9-20.

Savin-Baden, M. (2000). *Problem-based learning in higher education: Untold stories*. Berkshire: The Society for Research into Higher Education & Open

University Press.

Schmidt, H. G. (2000). Assumptions underlying self-directed learning may be false. *Medical Education, 34,* 243-245.

Steinwachs, B. (1992). How to facilitate a debriefing. *Simulation* & *Gaming, 23*(2), 186-195.

Strobel, J. & van Barneveld, A. (2009). When is PBL More Effective? A meta-synthesis of meta-analyses comparing PBL to conventional classrooms. *The Interdisciplinary Journal of Problem-based Learning, 3*(1), 44-58.

Thiagarajan, S. (1993). How to maximize transfer from simulation games through systematic debriefing. In F. Percival, S. Lodge & D. Saunders. (Eds.), *The Simulation and Gaming Yearbook* (pp.45-52). London: Kogan Page.

Torp, L., & Sage, S. (2002). *Problems as possibilities: Problem-based learning for K-16 education*. VA: Association for Supervision and Curriculum Development.

Uden, L., & Beaumont, C. (2006). *Technology and Problem-based Learning*. London: Information Science Publishing.

Uden, L., & Dix, A. (2004). Lifelong Learning for Software Engineers. *International Journal of Continuing Engineering Education and Life Long Learning, 14*(1-2), 101-110.

Walker, A., & Leary, H. (2009). A Problem Based Learning Meta Analysis: Differences Across Problem Types, Implementation Types, Disciplines, and Assessment Levels. *The Interdisciplinary Journal of Problem-based Learning, 3*(1), 12-43.

Weiss, R. E. (2003). Designing problems to promote higher-order thinking. In D. Knowlton and D. Sharp(Eds.), *Problem-Based Learning in the Information Age* (pp.25-31). CA: Jossey-Bass Publishers.

Yang, Y. C., & Chan, C. (2008). Comprehensive evaluation criteria for English learning websites using expert validity surveys. *Computer* & *Education, 51*, 403-422.

References: Studies included in the review study

Ahern, A. A. (2010). A case study: Problem-based learning for civil engineering students in transportation courses. *European Journal of Engineering Education, 35*(1), 109-116.

Bizjak, G. (2008). Load flow network analysis with problem-based learning approach. *International Journal of Electrical Engineering Education, 45*(2), 144-151.

Butun, E. (2005). Teaching genetic algorithms in electrical engineering education: a problem-based learning approach. *International Journal of Electrical Engineering Education, 42*(3), 223-233.

Butun, E., Erkin, H. C., & Altintas, L. (2008). A new teamwork-based PBL problem design for electrical and electronic engineering education: a systems approach. *International Journal of Electrical Engineering Education, 45*(2), 110-120.

Chae, S., & Noh, S. (2006). The Development and the Application of Problem Based Learning Linked to Industry Field Training. *The Journal of Curriculum Studies*, *24*(4), 131-151.

Costa, L. R. J., Honkala, M., & Lehtovuori, A. (2007). Applying the Problem-based Learning Approach to Teach Elementary Circuit Analysis. *IEEE Transactions on education, 50*(1), 41-48.

Dunlap, J. C. (2005). Problem-based learning and self-efficacy: How a capstone course prepares students for a profession. *Educational Technology Research and Design, 53*(1), 65-85.

Hartman, D. J., & Gindy, M. (2010). Comparison of Lecture- and Problem-based Learning Styles in an Engineering Laboratory. *Transportation Research Record, 2199,* 9-17.

Lee, J. Min, B., Yoon, W., Hahn, J., & Jung, H. (2008). A Basic Course of Creative Mechanical Engineering Design Emphasizing Experience Based Learning. *Journal of Engineering Education Research, 11*(2), 32-41.

Mantri, A., Butt, S., Gupta, J. P., & Chitkara, M. (2008). Design and Evaluation of a

PBL-based Course in Analog Electronics. *IEEE Transactions of education, 51*(4), 432-438.

Mitchell, J. E., Canavan, B., & Smith, J. (2010). Problem-Based Learning in Communication Systems: Student Perceptions and Achievement. *IEEE TRANSACTIONS ON EDUCATION, 53*(4), 587-594.

Montero, E., & Gonzalez, M. J. (2009). Student Engagement in a Structured Problem-based Approach to Learning: A First-Year Electronic Engineering Study Module on Heat Transfer. *IEEE TRANSACTIONS ON EDUCATION, 52*(2), 214-221.

Quinn, K. A., Albano, L. D., & M.ASCE, P. E. (2008). Problem-based Learning in Structural Engineering Education. *Journal of Professional Issues in Engineering Education and Practice, 134*(4), 329-334.

Ribeiro, L. R. C., & Mizukami, M. G. N. (2005). Student assessment of a problem-based learning experiment in civil engineering education. *Journal of Professional Issues in Engineering Education and Practice, 131,* 13018.

Ribeiro, L. R. C. (2008). Electrical engineering students evaluate problem-based learning. *International Journal of Electrical Engineering Education, 45*(2), 151-161.

Romero, J. A. (2011). Problem-based Learning in an Industrial Computers Course. *International Journal of Engineering Education, 27*(1), 146-154.

Schaefer, D., & Panchal, J. H. (2009). Incorporating research into undergraduate design courses: a patent-centered approach. *International Journal of Mechanical Engineering, 37*(2), 98-110.

Shikano, T., & Hmelo, C. E. (1996, April). Students' learning strategies in a problem-based curriculum for sustainable technology. Paper presented at *American Educational Research Association Annual Meeting,* New York.

Seo, D. (2009). The Design and Implementation of Problem-based Learning for Computer Network. *Journal of Engineering Education Research*, *12*(1), 17-23.

Urrestarazu, L. P., Salas, A. F., & Canero, R. F. (2011). Multidisciplinary Education for New Landscape Engineering Concepts using Problem-based Collaborative

Learning. A Case Study in Spain. *International Journal of Engineering Education, 27*(1), 138-145.

Vilonen, K. M., & Krause, A. O. (2009). Problem Based Laboratory Work in Industrial Chemistry: Acquisition, Integration and Applying Knowledge. In X. Y. Du et al. (Eds.), *Research on PBL Practice in Engineering Education* (pp.125-137). Sense Publishers.

Voss, J. F., Wolfe, C. R., Lawrence, J. A., & Engle, R. A. (1991). From representation to decision: An analysis of problem solving in international relations. In R. J. Sternberg (Ed.), *Complex Problem Solving*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Yadav, A. Y., Stubedi, D., Lundeberg, M. A., & Bunting, C. H. (2011). Problem-based learning: Influence on Students' Learning in an Electrical Engineering Course. *Journal of Engineering Education, 100*(2), 253-280.

Sung-Hee JIN

Research Professor, Innovation Center for Engineering Education, Inha University

Interests: Appropriate Teaching Methods, Creativity (TRIZ), PBL, Design Education, Visual Display

E-mail: sungheejin13@inha.ac.kr

Tae-Hyun KIM

Professor, Dept, of Early Childhood Education, Chungkang College of Cultural Industries

Interests: Instructional Design, e-Learning contents design and development

E-mail: thkim@ck.ac.kr

Received: July 29, 2013 / Peer review completed: October 6, 2013 / Accepted: October 29, 2013