# Problem-Based Learning in Engineering

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## Overview

Problem-Based Learning (PBL) is an educational approach that is learner focused. The focus shifts from a method of instruction that is teacher driven and led to one where the student is empowered to conduct self-directed learning. The learner is mentored and encouraged to conduct research, integrate what is learned, and apply that learning to develop a viable solution to an ill-defined problem. PBL, according to Savery (2006), originated in North American over 30 years ago to help medical students to become self-directed and multidisciplinary learners. From its beginning, the effectiveness of PBL in comparison with traditional approaches has been questioned. Newman (2003) concluded from his analysis and review of literature on the effectiveness of PBL in health related programs that there were insufficient high quality evidence to provide a conclusion on its effectiveness. However, use of PBL in medical programs is widespread.

Despite clear evidence for the effectiveness of PBL, the approach has been adopted in many other disciplines to include engineering. The engineering field, which continues to rely primarily on traditional teacher driven methods, Mills (2003), has looked to PBL to help fill the gap reported by industry in entry level engineers. The new employees were “book smart” but generally lacked practical and people skills. PBL is currently used in many of the top engineering programs such as Rose-Hulman Institute of Technology, Carnegie Mellon, and here at the United States Military Academy. Effectiveness of PBL in engineering education, however, is also debatable. Comparisons of programs that heavily favor PBL to programs that heavily favor traditional approaches are mixed, Fink (1999). Programs that extensively use PBL graduate students with strong design and team skills while students from traditional programs are better grounded in the fundamental engineering sciences and mathematics.

The newest trend in engineering education may be a hybrid approach. In the early years, students are taught the foundational knowledge and skills required in engineering. In the final years, PBL is favored to help integrate knowledge, reinforce self-directed learning, teach people and group skills, and apply the design process.

## Origin of PBL

PBL was developed in the 1960s and 1970s in medical and health related education. Educators suggested that teaching content such as anatomy, psychology, and pharmacology separately in a teacher driven classroom did little to improve the practical application or diagnosis skills required by medical doctors. Adding to this problem was the nature of modern medicine where the discipline was rapidly evolving requiring its practitioners to be lifelong learners. Therefore

in the 1980s and 1990s, many of the medical programs adopted PBL even though studies did not find clear evidence that PBL was more effective. However, anecdotal evidence from educators suggested that students were more engaged and preferred the PBL method even though both methods produced similar test scores, Torp (2002).

**Characteristics of PBL**

PBL is a learner focused educational approach where the student extends previous knowledge to new problems through self-directed reflection, research and practice in solving a problem. According to Savery (2003), for PBL to be effective, the selection of the problem is critical to the success of the approach. It must be ill-defined, multidisciplinary, and guided by a knowledgeable mentor. Students learn through problem solving where there is usually no single right answer.

A good website, www.pbli.org, lists the characteristics of PBL:

1. Students must have the responsibility for their own learning.
2. The problem used in PBL must be ill-structured and allow for free inquiry.
3. Learning should be integrated from a wide range of disciplines.
4. Collaboration is essential.
5. What students learn during their self-directed learning must be applied back to the problem with reanalysis and resolution.
6. A closing analysis of what has been learned from work with the problem and a discussion of what concepts and principles have been learned are essential.
7. Self and peer assessment should be carried out at the completion of each problem and at the end of every curricular unit.
8. The activities carried out in PBL must be those valued in the real world.

**PBL in Engineering Education**

Studies in the 1990s suggested that the engineering curricula and its graduates was generally deficient in addressing the concerns of the modern society, Mills (2003). Industry, accreditation boards, academia, and students echoed these concerns. Some of the key concerns, as listed in Mills (2003), included the following:

1. Engineering curricula are too focused on engineering science and technical courses without providing sufficient integration of these topics.
2. Programs do not provide sufficient design experiences.
3. Graduates lack communication skills and teamwork experience.
4. Programs need to develop more awareness amongst students of the social, environmental, economic and legal issues.
5. Faculty lack practical experience.
6. Teaching and learning strategies or culture in engineering programs is outdated and needs to become more student-centered.

With acceptance of these concerns, engineering programs starting in the 1990s realized a need for curricular change. PBL was adopted by many engineering programs as an approach to help graduates learn the skills required by their employers and to address many of the concerns listed above. In most cases the implementation of PBL, however, is at the course level within a traditional engineering program. Only a handful of programs integrate PBL across the program because it requires the cooperation and integration of faculty from multiple departments. Additionally, it is unclear that a fully integrated PBL approach is the best approach to achieving success in the above listed concerns.

**Appropriateness of PBL in Engineering Education**

Perrenet (2000) argues that while PBL is effective in medical education because of its "encyclopaedic structure," it may be more challenging in engineering because of its hierarchical structure. In medicine, the order in which various concepts are learned generally are not critical. In contrast, mathematics, physics, and in much of engineering, the order in which the knowledge is gained is critical. For example, a solid foundation is algebra must be achieved before moving to calculus. Perrenet suggests that because of this hierarchical structure, a fully integrated engineering program may not produce the "right" knowledge at the right time. Another difference is in problem solving. In medicine there is usually only one correct diagnosis which can be made relatively quickly. In engineering, an authentic problem could extend over long periods of time with multiple solutions.

**Example of PBL**

Many universities report in literature its use of PBL in individual courses but only a handful integrate PBL throughout its program. Aalborg University in Denmark uses PBL throughout its multiple engineering programs. All engineering programs at Aalborg uses a common first year curriculum that includes courses in mathematics, physics and computer science taught in a traditional teacher-driven approach. In the remaining two to four years of study, half the course work is projects, quarter fundamental knowledge and the final quarter is knowledge that supports the projects. The problems are usually industry driven and new problems are assigned each year. Student groups range from 5 to 7 with their own group office space. Projects are carefully selected by the faculty with common themes and students are allowed to pick from a list of projects.

Evaluation of Aalborg University's approach is described in Fink (1999). Fink compares Aalborg with the Danish Technology University (DTU) which uses a traditional approach. The evaluation consisted of interviews of industry leaders, students, and graduates together with site visits to both schools. The findings were mixed. Aalborg graduates were stronger in team skills, communication, project management, and more flexible at graduation. Aalborg students were, therefore, more employable upon graduation. DTU students were stronger in the fundamentals but required more practical training at graduation. The Aalborg dropout rate was 20-25% while it was 40% at DTU.

## Conclusions

PBL starting with medical education in the 1960s have had widespread appeal in engineering education. The efficacy of a fully integrated PBL program such as the one at Aalborg University is debatable in part for the lack of conclusive evidence and in part for the hierarchical structure of engineering education. Key concerns raised in the 1990s about engineering education stands as the impetus for change. A program that utilizes a hybrid mode where the early part of the program is taught in a traditional setting to lay the foundation followed by a culminating year where the learned knowledge can be extended to a yearlong authentic problem may be optimal.

## References

Barrows, H. S. (1996). Problem-based learning in medicine and beyond: A brief overview. In L. Wilkerson & W. Gijselaers (Eds.), *Bringing problem-based learning to higher education: Theory and practice*. New Directions For Teaching and Learning Series, No. 68 (pp. 3-11). San Francisco: Jossey-Bass.
This paper describes the limitations of the traditional medical education and the impetus for the development of PBL for medical education. It describes the PBL method and its characteristics. The author argues that PBL strengthens a doctors ability to diagnosis problems through a combination of reasoning and integration of knowledge. Teaching discipline specific content such as psychology or anatomy without an integrative experience and application of what is learned in medical practice did not provide the right developmental experience.

Duch, B. J., Groh, S. E., & Allen, D. E. (2001). Why problem-based learning? A case study of institutional change in undergraduate education. In B. Duch, S. Groh, & D. Allen (Eds.), The power of problem-based learning (pp. 3-11). Sterling, VA: Stylus.
This book describes the work of the authors at University of Delaware to design and implement PBL in courses across a range of disciplines. The book provides information about how PBL was implemented at University of Delaware. It provides examples of how PBL was implemented by various programs and all of the related issues from institutional down to course level. It finally provides the benefits of using PBL to promote creative life-long learners.

Fink, F.K., (1999), Integration of engineering practice into curriculum - 25 years of experience with problem based learning. In 29th ASEE/IEEE Frontiers in Education Conference, November 10-13, 1999, San Juan, Puerto Rico. Available at http://fie-conference.org/fie99/.
This paper presents the results of the 1998 evaluation of all Electronic and Electrical Engineering programs in Denmark. The international board of evaluators concluded that the universities that employed PBL over traditional methods were generally more effective. However, the results suggest that programs that employ PBL had stronger team and design skills while the students from traditional schools had a better foundation in the fundamentals of engineering.

Mills, J. (2003) Engineering Education – Is Problem-Based or Project-Based Learning the Answer? Australasian Journal of Engineering Education, Online Publication at http://www.aaee.com.au/journal/2003/mills_treagust03.pdf
This paper discusses the use of PBL in engineering education. It describes the differences between its use in medical and engineering education. It provides examples of universities in North American and Europe that use PBL. It provides results of studies that compare these universities with similar universities that only use traditional approaches. The paper concludes that each method has some strengths and weaknesses and perhaps a mix mode would be optimal.

Newman, M. (2003). A pilot systematic review and meta-analysis on the effectiveness of problem-based learning. from http://www.ltsn-01.ac.uk/docs/pbl_report.pdf.
This study concludes that despite the volumes of published work in PBL, there is very little quality evidence to provide a definitive assessment of the efficacy of PBL. The paper reports on the meta-analysis on the efficacy of PBL by an international group of educators and researchers.

Perrenet, J.C., Bouhuijs, P.A.J. & Smits, J.G.M.M. (2000). The suitability of problem-based learning for engineering education: theory and practice. Teaching in higher education, 5, 3, 345-358.
This article describes the characteristics and purpose of PBL. The article describes the employment of PBL at both Maastricht University and Technische Universiteit Eindhoven in number of engineering and medical programs. The authors study the suitability of PBL in engineering education and compare it against the employment of PBL in medical education. The authors conclude that because of the longer duration of engineering projects and hierarchical structure of engineering education The article concludes that PBL has certain limitations for engineering education that makes it less desirable as an overall strategy in comparison to its more successful employment in medical education.

Savery, J.R. (2006), "Overview of Problem-based Learning: Definitions and Distinctions," The Interdisciplinary Journal of Problem-based Learning, Vol. 1, No. 1.
The paper provides an overview of problem-based learning starting with the history of the origin of problem-based learning. It discusses the characteristics of problem-based learning. It compares problem-based learning to other experiential approaches.

Torp, L., & Sage, S. (2002). *Problems as possibilities: Problem-based learning for K-16 education* (2nd ed.). Alexandria, VA: Association for Supervision and Curriculum Development.
This book provides an overview of PBL. Describes its benefits and weaknesses in learning from kindergarden through undergraduate education. The book provides details on development of a PBL curriculum and its assessment. Finally the book provides an overview of relevant efficacy studies.

Website developed by Southern Illinois University School of Medicine, www.pbli.org
The website provides information about PBL, resources, workshops, implementation and assessment of PBL. The site states that even though their application is in medical education, the methods and processes do extend to many other areas.

**Annotated Readings:**

Boutin, N. et al (2002), "Bringing First-year Engineering Students to Reflect on their Learning Strategies," American Society of Engineering Education Annual Conference and Exposition.
This paper presents a case study of electrical engineering and computer science freshmen at the Universite de Sherbrooke, Quebec, Canada. The curriculum was radically changed to follow the PBL methods with small groups that learned knowledge motivated by the needs of the projects. The authors provide students' end of term self-assessment essays as qualitative evidence to support their claim that students, even in their early years of training, have the capability to reflect on their own learning strategies and improve their learning through this reflection.

Dennis, N. (2001), "Experiential Learning Exercised Through Project Based Instruction," American Society of Engineering Education Annual Conference and Exposition.
This paper describes the use of PBL at the University of Arkansas Civil Engineering Department's Foundations Course. The paper details the selection of the student design team to ensure success. The design teams are selected so that students with practical experience are made team leaders. The paper provides as evidence the quality of design submissions to the open-ended design problem as supporting data to suggest that teaming is important in the PBL process. The student composition at University of Arkansas includes a large percentage of non-traditional students. Leveraging their experience on the design teams have proven to be very positive in their PBL approach.

Esche, S., and Hadim, H. (2002), "Introduction of Project-based Learning into Mechanical Engineering Course," American Society of Engineering Education Annual Conference and Exposition.
The paper describes the introduction of PBL in two courses, Mechanics of Solids and Mechanisms and Machine Dynamics, at the Stevens Institute of Technology. Student groups of 3 to 4 where assigned six different projects that would cause the team to synthesize the material taught at the beginning of each module. The topics covered in the new course was similar to that of the previous traditional course, however, the amount of homework was reduced by half to compensate for the increased project work. Based on student surveys at the end of the course, the faculty concluded that student motivation and interest improved. Analysis of student performance on exams showed improvements under the PBL approach especially in design work.

Felder, R., Felder, G., and Dietz, E.J. (1998), "A Longitudinal Study of Engineering Student Performance and Retention versus Comparisons with Traditionally-Taught Students," Journal of Engineering Education, 87(4), 469-480.
This paper presents a five consecutive semester longitudinal study conducted at North Carolina State University in the chemical engineering program. The study compared the outcome of the students taught using cooperative, active, and various other techniques with the outcome of students taught under a traditional approach. The authors conclude that the students taught using the non-traditional methods outperformed the traditionally taught students in knowledge retention, graduation rate, and motivation to pursue graduate degrees

Mills, J. (2002), "A Case Study of Project-based Learning in Structural Engineering," Proceedings of the 2002 American Society for Engineering Education Annual Conference & Exposition.
Author proposes PBL to promote the integration of knowledge in structural engineering. She states that the traditional "chalk and talk" techniques remain the dominant form of instruction in engineering. It is proposed that PBL help students to understand the synthesis of structural analysis, material behavior, constructability and economic reality that is essential in professional practice. A case study of the structural engineering program at the University of South Australia is presented to provide the analytics for her observations and conclusions.

Miner, S., and Tyler, T. (2001), "A Project Based Introduction to Mechanical Engineering," American Society of Engineering Education Annual Conference and Exposition.
The paper describes the newly formed introductory course in mechanical engineering at the United States Naval Academy. The course uses PBL to help meet the three course objectives. The paper finally provides the results of the first two course offerings in subjective terms. Student interest and motivation increased with the hands-on approach.

Newsletter, W., and Benkeser, P. (2002), "Learning Assessment in Problem-based Learning for BME Students," American Society of Engineering Education Annual Conference and Exposition.
This paper presents the assessment tools used to evaluate the students in a PBL course in biomedical engineering at Georgia Institute of Technology. The authors state that this is a challenge because the learning objectives in a PBL course may not be aligned with a course of similar content in a traditional setting. The paper describes the instruments used to conduct the assessment such as concept maps, problem response, group interviews and tutor evaluation. Exams were used to determine what they learned but other techniques helped them assess how they learned. (This is my favorite paper.)

Palmquist, S. (2005), "Benefiting Professional Practice using Engineering Mathematics: A Project-based Learning Approach," American Society of Engineering Education Annual Conference and Exposition.
A case study of a sophomore level engineering statics course that employs PBL is presented in this article. The instructor uses a steel truss bridge project to teach students to develop generalized mathematical techniques and applied engineering mechanics. The course assessments and evaluation indicated that the students preferred the traditional methods over the PBL methods that the instructor employed. The instructor concluded that regardless of the assessment results, PBL methods should be used. (This paper is an example of how not to employ PBL.)

Riddell, W. et al (2008), "Communication in a Project Based Learning Design Course," American Society of Engineering Education Annual Conference and Exposition.
Rowan University's College of Engineering students take eight PBL courses called clinics during their four year program. In year two students focus on technical writing and oral presentations of their projects. The faculty presents the student assessment results to suggest that students better understand the importance of communication in the design process because of the methods used in their programs.

Wilson, S., and Cambron, M. (2005), "Creation of an Assessment Plan for a Project Based Electrical Engineering Program," American Society of Engineering Education Annual Conference and Exposition.
An electrical engineering course that employs PBL is presented in this paper. The course is taught by faculty from Western Kentucky University and University of Louisville. The newly formed Department of Engineering at Western Kentucky University primarily uses PBL in their programs. The paper describes in detail its assessment plan that is nested in the ABET evaluation processes. The assessment includes FE exam results, advisory boards, faculty and student assessments, and several other methods. The paper does not provide conclusions about the efficacy of PBL based on their assessment techniques. However, the detailed assessment techniques described in this paper is useful.

Veljanovski, R., and Stojcevski, A. (2007), "Online Role Paying in a New Problem Based Learning Curriculum in Electrical Engineering," American Society of Engineering Education Annual Conference and Exposition.
In 2006 the School of Electrical Engineering at Victoria University initiated on-line role playing as part of their e-learning to support PBL methods. Authors report that one of the challenges with PBL is the selection of an authentic problem that also maintains the interest of the students. The faculty introduced on-line role playing as a way to make the projects more interesting. The on-line role playing platform was powered by Fablusi. Fablusi simulations model human interactions in a flexible environment. The students perform their roles in an anonymous fashion to act out the social, political, and environmental aspects of their designs. Student survey results showed that the on-line approach improved student interest and motivation.