Identifying Opportunities for Collaborations in International Engineering Education Research on Problem- and Project-based Learning

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Abstract

We report on the results of a study to examine the global state of engineering education research on problem- and project-based learning (PBL). This paper has two major aims. First, we analyze a large collection of conference papers and journal articles to report on research trends in PBL, including in specific, leading countries. Second, based upon our analysis as well as a literature review of meta-analyses/syntheses of PBL literature, we propose a theoretical model for conceptualizing international research collaborations. Based on this model, we make recommendations for future initiatives, including multinational collaborations for research on PBL in engineering education.

Introduction

Problem- and project-based learning (both using the acronym PBL) are increasingly common in engineering education, especially given the growing recognition of both the benefits of active learning and the importance of engineering students developing robust professional skills. Yet much of the existing research on the effectiveness of PBL has been done in other fields that have a longer history with this teaching method. Further, despite more general internationalization trends within the field of engineering education, no work has yet explored the current status of, and opportunities for, international collaborative research on PBL. This paper represents a step toward filling some of these gaps.

Some accounts locate the origins of problem-based learning in medical schools at Case Western Reserve University and McMaster University in the 1950s and 1960s, respectively, and maintain that it then spread to other universities in the U.S., Canada, The Netherlands, Denmark, Germany, Sweden, Australia, Spain, Mexico, and elsewhere, and into other fields, including architecture, psychology, business, and engineering (Prince &

Felder, 2006). Other accounts emphasize a more concurrent development of PBL in Europe, Australia, and North America (Kolmos, de Graaff, & Du, 2009). Either way, as the original models spread internationally they were adapted to suit the needs of diverse institutions and fields in multiple countries, which has resulted in diverse and fluid definitions of PBL (Savin-Baden, 2007). Savin-Baden presents a detailed history of how PBL spread internationally, first in medical schools and then other fields (Savin-Baden, 2007). Today, PBL continues to grow in popularity worldwide, both within and beyond engineering education. Recent indications of this trend include international PBL conferences, including events in Lima, Peru in 2006, Singapore in 2009, and Sao Paulo, Brazil in 2010.

Engineering education is one field where PBL is growing in popularity. Some of the earliest efforts to develop PBL courses and curricula in engineering can be traced back to the 1970s, at Aalborg University in Denmark. Some recent events notable for their focus on engineering education include the 1st Research Symposium on Problem Based Learning in Engineering and Science Education (held in Aalborg in 2008) and the 2nd International Research Symposium on PBL (held in Melbourne in 2009). Other evidence of a growing interest in PBL in engineering education includes a 2003 special issue of the *International Journal of Engineering Education* (*IJEE*) dedicated to the topic of PBL (de Graaf, Kolmos, & Fruchter, 2003), the Enhancing Project Based Learning Workshop and International Symposium for Research on PBL in Engineering Education and The International Workshop for Research on Problem Based Learning in Engineering Education at Loughborough University (UK) in June 2009, and this special issue of *IJPBL* on engineering education.

The spread of PBL in engineering education around the world has been enabled by factors and motivations that vary significantly across national and institutional contexts (Savin-Baden, 2007; van Barneveld & Strobel, 2009). Evidence suggests that industry demand for professional skills and changes in accreditation procedures have been two primary drivers behind the adoption of PBL at many institutions. Among the papers analyzed in the dataset described below, many of the authors describe their interventions as supporting a variety of professional skills and abilities, including communication, ethics, information literacy, lifelong learning, project management, and teamwork. A growing body of research suggests that PBL is effective at developing such skills (Bielefeldt, Paterson, & Swan, 2009).

Additionally, some engineering educators are motivated by the need to adapt to limited institutional resources (time, space, inflexible and overloaded curricula, etc.), while responding to the rapid evolution of both technology and the traditional engineering disciplines (Al-Abdeli & Bullen, 2005). Others see PBL as a way to market their institution and recruit and retain engineering students (Froyd et al., 2005; Patangia & Mohan, 2006; Simcock, 2008). Still others have adopted PBL as a strategy to overcome national reluctance to establish new engineering schools (de Ureña, Menéndez, & Coronado, 2003).

Interestingly, much of the push for professional or "non-technical" skills in engineering education is coming from outside academia, due to a lack of satisfaction in the professional world with graduates' capabilities. This is in contrast to medical education, where the shift to PBL was more bottom-up and from the inside (van Barneveld & Strobel, 2009). Van Barneveld and Strobel provide a useful summary of the primary drivers of PBL in engineering in various countries (2009).

Changes in accreditation procedures have also driven the implementation of PBL in engineering education. Outcomes-based accreditation is the specification of graduate attributes rather than curricular "inputs," for example, hours or numbers of classes or subjects as requirements for accreditation, staff size, and qualifications. The switch to outcomes-based accreditation also involved the addition of several professional skills to the technical skills which were already valued. The shift to outcomes-based accreditation in Australia, for example, has been one factor in the implementation of PBL in that country (Hadgraft, 2005). Engineering educators from Hong Kong and South Africa have similarly linked their use of PBL to outcomes-based accreditation (Aletta de Wet, Veldman, Bouwer, & Mokhele, 2008; Chau, 2005). As a group of South African authors summarized, "PBL is a learner-centered strategy that can be used to achieve the objectives of Outcomes Based Education (OBE)" (Aletta de Wet et al., 2008, p. 2). An author from Hong Kong added:

> A distinct feature of the civil engineering undergraduate study of Hong Kong Polytechnic University is a major assessment exercise in the form of a problem-based learning (PBL) group project. With the imminent implementation of an outcome-based accreditation assessment by the Hong Kong Institution of Engineers, student performance on this project can become a significant indicator of learning outcomes (Chau, 2005, p. 9).

Growing international interest in PBL may also be attributed to efforts by early leaders to help implement PBL at other institutions, including at home and in other countries. Specifically, the UNESCO International Center for Problem Based Learning (UCPBL) at Aalborg University in Denmark has been active in creating a global PBL network (Du, de Graaff, & Kolmos, 2009a). Notably, research on PBL has been included in these internationalization efforts. Among its objectives, the UCPBL Global Network includes facilitating research on PBL and its membership benefits include "access to research cooperation" (Enemark et al., 2006, p. 13).

At the same time that PBL is growing in popularity in engineering education, engineering education research as a field of scholarship is gaining recognition and visibility in many national and regional contexts. The field has undergone impressive expansion in the United States since the early 2000s, and we observe similar trends in Europe and Australia, as reflected by the formation of research-oriented working groups in those regions (Jesiek, Beddoes, Sangam, & Borrego, 2009; Jesiek, Newswander, & Borrego, 2009). Additionally, the American Society for Engineering Education (ASEE) is actively working to create a global engineering education research community by distributing the *Journal of Engineering Education* (*JEE*) through international partner organizations, and by supporting the Research in Engineering Education Symposium (REES) international conference series (Borrego, Froyd, & Knight, 2007; JEE, 2005; Lohmann, 2008b; Shetty & Melsa, 2008). Furthermore, in 2007 and 2008, representatives from *JEE* and SEFI's *European Journal of Engineering Education* (*EJEE*) partnered on an initiative titled Advancing the Global Capacity for Engineering Education Research (AGCEER): A Year of International Dialog, which involved AGCEER special sessions, held at engineering education conferences in 10 different countries around the globe (Lohmann, 2008a). One of the goals of the initiative was "to encourage and sustain a global community of researchers and practitioners in engineering education research" (Lohmann, 2008a).

Yet despite increasing worldwide diffusions of both engineering education research and PBL implementation, international research collaborations on PBL remain scarce. As discussed below, prior literature has tended to focus on identifying the challenges of PBL and needed areas of research, but without directly connecting these issues to consideration of international research collaboration. This paper is situated at the intersection of the internationalization trends identified above and the challenges identified in prior literature. Our aim is to identify how the challenges can be reframed as opportunities for international research collaborations. To that end, we map out current engineering education research on PBL from a large-scale bibliometric study and propose a theoretical model for guiding international research collaborations focused on PBL. Our literature review, coupled with bibliometric analysis and an associated theoretical model, provide a foundation where researchers may begin to locate their own work within the global engineering education community and consider partnering with their international colleagues.

The benefits of internationalizing research fields, as well as the risks and detriments that come with failing to do so, have been identified, and scholarship from other disciplines points to reasons why such international partnering is desirable. For example, internationalization trends may provide a field with general educational benefits, including through comparative assessments, joint curriculum development, pooling of academic expertise and economies of scale, dissemination of "best practices," and setting and promoting international standards (Shepherd, Monk, & Fortuijn, 2000; Wheeler, Smith, Rydant, & Larin, 2005). Benefits more specific to research include solving local and regional problems, providing new forums for interaction (Shepherd et al. 2000), reducing parochialism, and broadening the perspectives of researchers, students, and faculty (Leong & Ponterotto, 2003; Shepherd, et al., 2000; Thelen, 1992; Yang, 2002). On the other hand, when fields fail to develop an international profile, they run the risk of being populated by isolated scholars working on similar problems using relatively elementary approaches, thus impeding the field's growth and development (Lemaine, Macleod, Mulkay, & Weingart, 1976; McGrath & Altman, 1966).

While recognizing the benefits that come from the internationalization of research, it is equally important to recognize that engineering education research, including on PBL, must also be accountable to local and regional engineering education contexts. In other work, we suggest that engineering educators and engineering education researchers will need to translate research questions, theories, methods, and findings in ways that render them readable and relevant across institutional and national boundaries (Jesiek, Borrego, & Beddoes 2010). Such translation efforts will require an understanding of local cultural and educational differences and a recognition that not all findings will be universally applicable. The goal, then, is to find those aspects of PBL that can be successfully shared across contexts, and that advance engineering education and engineering education research, while at the same time maintaining awareness that some aspects of PBL remain context-dependent.

Research Questions and Methods

This analysis grew out of a larger project to promote cross-national engineering education research by organizing three workshops in 2009 on research areas identified as likely to benefit from international collaborations, namely, The US-Europe Workshop for Research on Gender and Diversity in Engineering Education, in Delft, the Netherlands; The International Workshop for Research on Problem Based Learning in Engineering Education, in Loughborough, UK; and The US-Australasia Workshop for Research on e-learning in Engineering Education, in Adelaide, Australia. Our research and selection process for these workshops is described in detail in other work (Jesiek, Beddoes, & Borrego, 2009). In other papers we analyze select collections of engineering education research publications on the other two research topics, gender/women and e-learning (Beddoes, Borrego, & Jesiek, 2009; Beddoes, Jesiek, & Borrego, 2009). In this paper we focus on PBL and develop a model for conceptualizing collaborations. The questions to be addressed by our research are 1) What is the current global state of engineering education research on PBL? And 2) What collaborative configurations can help support cross-national research on PBL in engineering education?

To address these questions, we conducted an in-depth bibliometric analysis of engineering education journal articles and conference papers published 2005 to 2008 in *Australasian Journal of Engineering Education (AJEE), European Journal of Engineering Education (EJEE), International Journal of Engineering Education (IJEE),* and *Journal of Engineering Education (JEE)* (non-U.S. authors only), *Proceedings of the Australasian Association for Engineering Education Annual Conference (AAEE)*, *Proceedings of the ASEE Global Colloquium on Engineering Education*, and *Proceedings of the European Society for Engineering Education (SEFI) Annual Meeting*. *JEE* articles with non-U.S. authors were excluded because we found that the other publication outlets already included in our database featured a large and representative sample of research from U.S.-based authors. Due to limits of time and expertise, our study is restricted to English-language publications.

Since one of the main goals was to identify potential opportunities for research collaborations, we first systematically reviewed all articles to determine which qualified as systematic engineering education research publications. Given the difficulties inherent in using complex guidelines to determine what counts as scientific research, such as the six criteria proposed by the U.S. National Research Council (Shavelson & Towne, 2002), we developed a simplified procedure to identify all papers that presented and discussed empirical data or evidence, which was most often in the form of surveys or learning assessments. This excluded purely descriptive papers, such as those that discussed the development or content of modules, labs, courses, or curricula, as well as papers that presented only technical data or results. Three researchers used these criteria to evaluate a large initial set of articles. All articles that were not unanimously qualified or disqualified were reviewed and discussed until consensus was reached. As the rate of discrepancies dropped, one researcher took over the evaluation of the remaining articles, and asked the other researchers to review borderline cases on an as-needed basis. Each paper meeting our broad definition for empirical research was entered into an EndNote database. Institutional affiliations of authors were used to record country (or countries) of origin for each article. Author-identified keywords were also added to the database, and papers without keywords were given researcher-generated keywords based on their titles and abstracts. Out of more than 2,000 total papers examined, 885 papers qualified under our broad definition of empirical research.

The collection of articles analyzed in this paper was identified by searching for keywords such as problem (-) based; project (-) based; project(s); and PBL. The list of articles can be found in Appendix 1. This subset of papers includes authors from 54 countries. The PBL articles were categorized based upon their overarching purpose. The lead author developed and applied the coding scheme to every article in the data set. The second author independently applied the same coding scheme to all articles. For any article with coding discrepancies, the lead and second authors reviewed the cases until they reached consensus on the most appropriate codes for that paper. In some instances, full article text was reviewed to clarify the major purposes of a given paper.

As suggested above, definitions of PBL remain debated and contested, and the meaning of the term varies significantly across disciplinary and geographic boundaries. While we give commonly accepted definitions of problem-based and project-based learning below, our principle aim in this paper is not to isolate a precise definition of PBL, but rather to obtain a global picture of research being done by those who self-label their work as PBL. Therefore, our analysis covers a broad spectrum of initiatives, from small, problem-oriented exercises in individual courses to comprehensive project-based curricula.

Literature Review

While a comprehensive review of the PBL literature is beyond the scope of this paper, we draw on the valuable work of others who have already performed large-scale reviews, meta-analyses, and meta-syntheses of the available literature on problem- and project-based learning. In this section we discuss the findings of such studies, focusing specifically on the debates and challenges highlighted within the literature. We then identify gaps in the existing literature and begin to reframe the challenges discussed by these authors as opportunities for collaborative research. As much as possible, we draw on the work of scholars who work in the field of engineering education; however, the meta-analyses and meta-syntheses they have written are not specifically about engineering education research. We note, where applicable, when the literature under review is specific to engineering education. Moreover, this literature review covers both problem- and project-based learning.

Findings

In a meta-synthesis of meta-analyses, the results of which are being published in two different papers, Strobel and van Barneveld examined research on the effectiveness of PBL (Strobel & van Barneveld, 2009; van Barneveld & Strobel, 2009). They posit that research on the assessment of learning outcomes in the context of PBL can be organized in four major categories (non-performance, non-skill oriented, non-knowledge based assessment; knowledge assessment; performance or skill based assessment; and mixed knowledge and skill-based assessment), and that PBL is found to be more effective in each of these categories except "knowledge assessment," which had mixed results for short-term knowledge acquisition but was more effective for long-term knowledge acquisition. Prince also reviewed other meta-analyses of PBL and concluded that the most positive effects are related to skill development gains and how students and faculty respond to PBL (Prince, 2004). In more recent work, Prince and Felder reviewed studies from engineering, as well as other disciplines, and concluded that PBL produced positive effects on professional skill development but unclear effects on content knowledge (Prince & Felder, 2006).

In an earlier study, Thomas reviewed literature that was focused on project-based learning and found that the research fell into four categories: evaluative, to assess the effectiveness of PBL; implementation, to inform the process of planning and executing PBL; assessing the role of student characteristics in PBL effectiveness or appropriateness; and intervention research, used to test a proposed feature or modification of PBL (Thomas, 2000). Other studies have focused specifically on project-based service learning (PBSL). Bielefeldt et al. (2009) produced a report on the state of PBSL in engineering education that describes current approaches to, and impacts of PBSL. They report that while PBSL has not been shown to help recruit students, it has been shown to help with retention of engineering students, particularly minority groups. Their report also reaches conclusions similar to those of Strobel and van Barneveld regarding the effectiveness of PBSL at developing professional skills.

Challenges and Debates

What does the "P" stand for, and what counts as PBL?

The categorization of problem- and project-based initiatives has been a subject of debate (de Graaff & Kolmos, 2007a; Savin-Baden, 2007; Thomas, 2000). The variety of PBL definitions and models in engineering education specifically has been noted (van Barneveld & Strobel, 2009). According to Prince and Felder, problem-based learning "begins when students are confronted with an open-ended, ill-structured, authentic (real-world) problem and work in teams to identify learning needs and develop a viable solution, with instructors acting as facilitators rather than primary sources of information" (Prince & Felder, 2006, p. 128). In contrast, project-based learning "begins with an assignment to carry out one or more tasks that lead to the production of a final product—a design, a model, a device or a computer simulation. The culmination of the project is normally a written and/or oral report summarizing the procedure used to produce the product and presenting the outcome" (Prince & Felder, 2006, p. 130). However, they emphasize that the distinction between project- and problem-based learning is fluid. Generally, project-based learning is characterized as broader in scope than problem-based learning, and is typically directed toward a final product (Prince & Felder, 2006; Savin-Baden, 2007; van Barneveld & Strobel, 2009). Yet such distinctions can vary from country to country and region to region. Additionally, some leading institutions, such as Aalborg University, have developed their own precise definition and format for PBL (Enemark et al., 2006). Therefore, for an international publication analysis such as ours, it is most useful to not impose our own distinctions between problem- and project-based learning.

Assessment

The challenges related to assessing student learning outcomes and skill acquisition in the context of PBL are well documented in the literature (Bielefeldt, et al., 2009; van Barneveld & Strobel, 2009). The need to assess non-technical professional skills instead of relying on students' self-assessment of such skills, and the lack of methods for systematically and precisely assessing those skills, have been noted (Bielefeldt, et al., 2009). The aforementioned PBSL report recommends that researchers should work to share effective methods for assessing professional skills, attributes, and competencies (Bielefeldt, et al., 2009).

Institutional and Instructional Implementation Challenges

Challenges with regard to implementation and execution of PBL are both theoretical and practical. Theoretically, debates remain over the best approach to incorporate PBL and the extent of implementation necessary to benefit students. For instance, some engineering educators argue that the maximum benefits of PBL will not be obtained unless it is implemented across the entire curriculum and all at once (Inelmen, 2003). On the other hand, there are those who argue that due to the significant differences between PBL and traditional methods, it is better for instructors to start with small-scale initiatives so they can incrementally familiarize themselves with PBL (Hansen, Cavers, & George, 2003). These opposing views represent the two models described by Savin-Baden as "pure" and "hybrid." She explains that PBL has historically been conceptualized as one or the other of these two models, but that given the current wide variety of PBL initiatives, conceiving PBL as more flexible is both more accurate and more useful (Savin-Baden, 2007).

Once such theoretical concerns are worked out, practical challenges to implementation remain. The difficulty experienced by students and faculty transitioning from traditional approaches to PBL is a recurring theme in the literature. The changing roles of the teacher and the student are widely recognized as two of the largest barriers to implementation of PBL (Prince & Felder, 2006; van Barneveld & Strobel, 2009). PBL can be difficult for faculty and students "because it challenges them to see learning and knowledge in new ways" and blurs boundaries (Savin-Baden, 2007, p. 24). For instance, students may be hostile to PBL because they are unaccustomed to the level of personal responsibility required and may experience conflicts with team members (Prince & Felder, 2006). And teachers, too, often find it difficult to adjust to PBL (Prince & Felder, 2006; Thomas, 2000). Furthermore, institutional difficulties include resources, program sustainability, scalability, physical facilities, and management (Bielefeldt, et al., 2009).

Future Research Directions

The authors of prior literature reviews have recommended future directions for research on PBL. Thomas, for instance, suggests more research is needed on the effectiveness of PBL in comparison to other methods; the breadth of PBL effects; best practices (procedures for planning, implementing, and managing PBL); implementation challenges extended to instances of teacher-initiated PBL; institutionalization of PBL; and institution-wide PBL-based transformations (Thomas, 2000). Strobel and van Barneveld recommend that research be expanded to PBL in fields and contexts outside of medical education, and that the research focus for PBL should shift from comparison of PBL with traditional methods to studying the effectiveness of specific support structures, including finding successful strategies for implementation. More specifically, they argue that more research is needed on the barriers, drivers, and challenges of PBL (Strobel & van Barneveld, 2009).

Along with these recommendations for future research, however, is a recognition of gaps between research on, and implementation of, PBL. There are individuals who are still opposed to PBL, and those who are interested in implementing PBL but are unable to access related research results or do not find existing research applicable (de Graaff & Kolmos, 2007b; Thomas, 2000; van Barneveld & Strobel, 2009). Thus, we suggest that research collaborations aimed at bridging the research-practice gap will be particularly useful for engineering education, and the findings and discussion are tailored in that direction. Other recent research highlights the desire among engineering educators to more generally encourage the bridging of engineering education research with various domains of practice, including engineering teaching (Jesiek, Beddoes, & Borrego, 2010).

Findings and Discussion

Geographic distribution

Of 885 publications in our engineering education research database, 105 were determined to be about PBL. Information about the individual countries and multinational collaborations represented in this subset of papers is summarized in table 1. The large number of articles from Australia and Denmark is consistent with the fact that those countries have for decades been recognized as leaders in PBL. In Australia, PBL has been widely incorporated into the curriculum of many universities. Problem- and project-based educational

Table 1. Individual Country Counts and Percentage of PBL articles.

Country	Number of PBL articles*	Total number of articles	PBL articles as percent of total articles from that country
Australia	39	205	19%
US	24	317	8%
Denmark	11	20	55%
Spain	4	37	11%
Hong Kong, Japan, Lebanon, Malaysia, Portugal, South Africa, Netherlands, Turkey	2 each		
Belgium, Brazil, Canada, Chile, Denmark, Finland, Germany, India, Ireland, Mexico, New Zealand, Slovenia, Sweden, Taiwan, and Thailand	1 each		

* Total higher than 105 due to papers with co-authors from multiple countries.

practices that are in early stages of development elsewhere in the world have been in place in Australia for more than a decade. We have previously proposed that the shift toward PBL in Australian engineering schools is to some extent linked to the establishment of outcomes-based accreditation criteria and processes (Jesiek, Beddoes, & Borrego, 2009). A significant body of Australian research on PBL emerged in tandem with shifts in accreditation procedures, revealing how shifting accreditation processes are often linked to both educational innovations and changing research trends. As discussed above, engineering educators in other countries have also linked PBL to outcomes-based accreditation.

Similarly, Denmark has a long tradition of PBL that dates back to the early 1970s. Student movements and industry demand for certain graduate competencies contributed to the widespread adoption of PBL (de Graaff & Kolmos, 2007a). PBL has been an important part of Aalborg University since its founding in 1974 and Roskilde University Center since its founding in 1972 (de Graaff & Kolmos, 2007a; Fink, Enemark, & Moesby, 2002). Aalborg University is now the UNESCO Chair for Problem Based Learning (UCPBL) in Engineering Education, as well as the Danish Centre for Engineering Education Research and Development, and they offer an online Masters degree in Problem-Based Learning in Engineering and Science.[1]

In Spain, PBL is slowly but increasingly being used and studied in new universities (de Ureña et al., 2003). Additional research is needed to account for research on PBL in the U.S., although we tentatively point to the relative size of the engineering education enterprise, coupled with a large and active engineering education research community, as contributing factors. In other work, we have also identified PBL as a probable horizon area for engineering education research in the UK and Ireland (Jesiek, Beddoes, & Borrego, 2009).

Purpose

While other analyses have focused on the results and assessment of PBL, as discussed above, here we focus on the major purpose or objective of each paper in our dataset. Each paper was coded based on its primary objective or purpose, as indicated by the authors. In other words, we asked: What did the authors want to achieve in this paper? Coding for objective or purpose, rather than for the specific topic or subject matter per se, aligns with our objective of thinking more broadly about possible collaboration configurations. However, it is worth noting the three most prominent topics we observed in the data set, namely, technology-assisted PBL; teaming and group/teamwork; and generic/professional/portable skills. The major purposes or objectives, along with the number of papers in each category, are summarized in table 2. By far the most common type of research involved the description and evaluation or assessment of an initiative undertaken by the authors. These initiatives range from one project in a traditional course to an entire PBL course or sequence of courses to curriculum-wide initiatives.

Table 2. Frequency of Authors' Purpose/Objective in PBL Research Papers.

Purpose/Objective	No. of articles*
Describe and assess a PBL initiative	70
Present method for evaluating/assessing students	11
Identify challenges and investigate solutions related to PBL Implementation	10
Study student behaviors, beliefs, roles, effectiveness during PBL implementation	10
Faculty/staff development and tools for implementation of PBL	7
Compare PBL outcomes with traditional pedagogy	5
Investigate relationship between learning styles/theory and PBL	3
International transfer/comparison of PBL initiatives	2

* Some papers were coded into multiple categories.

The next most common objective was to present a method for evaluating or assessing students in PBL settings. Those presenting an assessment method were typically focused on assessing student skills and other learning outcomes. The specific assessment concerns in these papers included issues related to individual assessment for teamwork; determining actual outcomes and skills gained; dealing with grading discrepancies (among graders); peer and self assessment; and formative assessment of student progress through problems or projects. Given both this analysis and the preceding literature review, we infer that assessment methods and strategies are one possible avenue for fruitful international research collaborations. Further, seven of these eleven articles were from Australia. Engineering educators in other countries could benefit from Australian knowledge of and experiences with PBL, including in relation to assessment issues.

Several of our other categories align with the implementation challenges identified in our literature review, namely, *Identify challenges and investigate solutions related to PBL implementation*, and *Faculty/staff development and tools for implementation of PBL*. Many of the authors in our dataset are concerned, for instance, with studying the changing roles of students and faculty, intercultural competencies of faculty/staff involved with PBL, "real world" constraints (of PBL implementation), and the logistics of organizing PBL. *Relationship between learning styles or learning theory and PBL* and *Student behaviors, beliefs, roles and effectiveness in PBL contexts* also emerged as categories in our database. The relationship between PBL and constructivist teaching and learning, self-directed learning, and active learning, for instance, were frequently observed, even among those whose primary approach was not to study learning theory. Examples of articles in this category include an examination of what types of learners are most likely to benefit from PBL and what roles students adopt in the context of PBL.

Of particular interest for this study are two articles concerned with the transfer or comparison of PBL initiatives across national borders. One compares problems, solutions, and implementation paths of students in The Netherlands and China in a course titled "Design Methodologies and Innovation Tools," which was originally developed at Delft University of Technology (Kamp & Ravesteijn, 2008). The other paper of this type sought to "evaluate how a design innovation course could be transferred across cultures, disciplines and institutions," specifically by looking at a course that was originally developed in the U.S. and then taught in Switzerland. The authors begin by noting: "The pedagogy of project-based courses is notoriously difficult to transfer but in today's global economy it is crucial to be able to teach innovation" (Skogstad, Currano, & Leifer, 2008, p. 367). Other scholars have also noted the need for studies at the international level and the challenges that different cultural contexts pose to the transfer of PBL (Du, de Graaff, & Kolmos, 2009b; Kolmos, et al., 2009). Yet while both of these PBL implementations were clearly multinational in character, author affiliation data suggests that the associated research activities involved researchers from only one of the participating countries.

Theoretical Model for PBL Research Collaborations

As summarized in table 3, only 4 of the 105 publications (3.8%) analyzed for this study involved multinational collaborations, as revealed by author affiliation data. All of the multinational collaborations in our database appear to be the result of researchers partnering with colleagues at institutions where they formerly worked or studied. The two articles that were explicitly concerned with implementations of PBL in multiple countries did not appear to involve deep international research collaborations. Thus, we conclude there is much untapped potential for promoting cross-national research collaborations around PBL in engineering education.

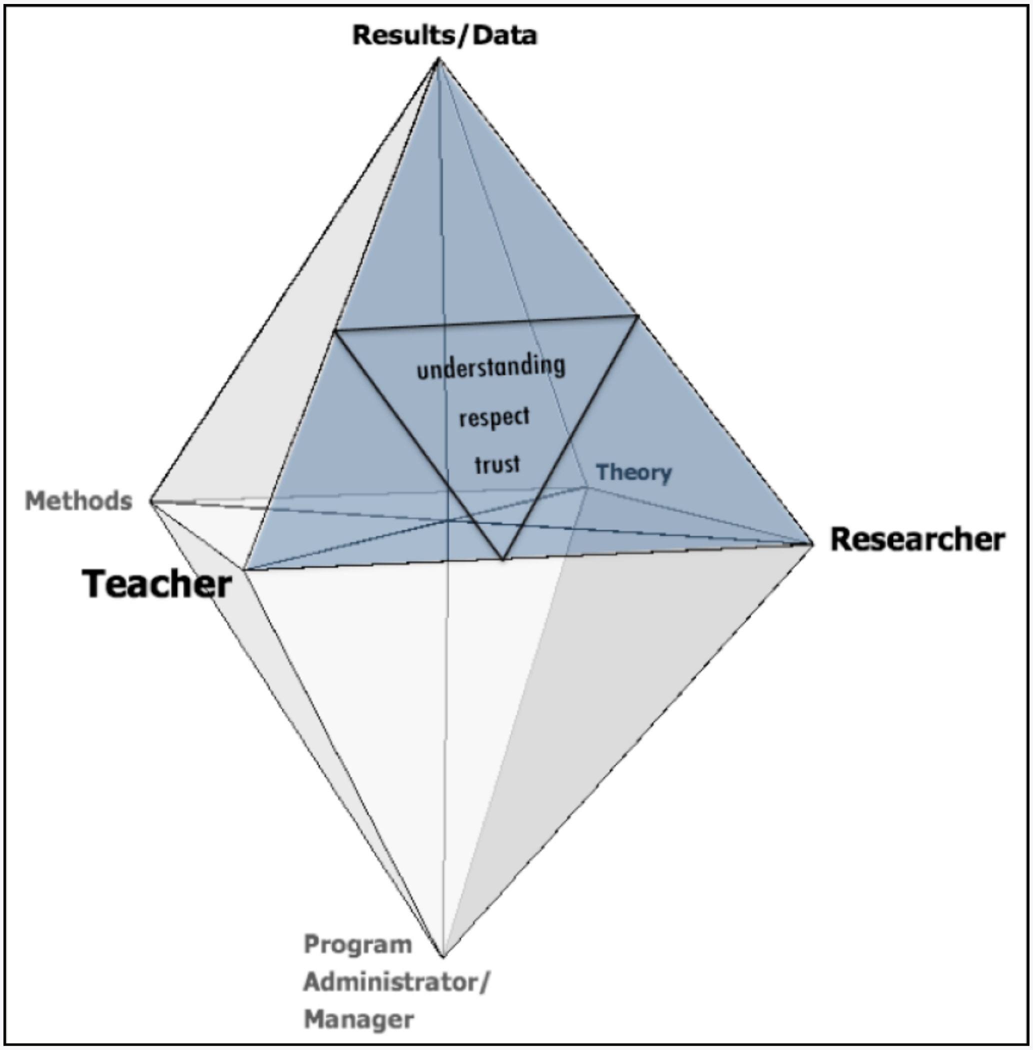
While international research collaborations in engineering education remain scarce, so too does theorizing about collaboration in academia more broadly. Collaboration has been widely under-theorized, including in terms of its associated power dynamics and relations (Durbin, 2009). Durbin has proposed an ecological model that highlights the concepts, actors, and methods that are frequently involved yet largely hidden in collaborative relationships. Graduate students and research subjects are two examples of such actors. He argues that by reflecting on the hidden features when we think about and characterize collaboration, we can become better scholars, citizens, and collaborative partners.

Table 3. Multinational Collaborations.

Co-Author Countries of Origin	Number of articles
Australia + New Zealand	1
Taiwan + US	1
US + Canada	1
Spain + Germany	1

Building on Durbin's work, we have developed a model for conceptualizing cross-national PBL research that highlights both the possible stakeholders and types of research likely to benefit from such collaborations. The model, shown in figure 1, represents a range of possible configurations of actors or stakeholders and research areas that could help bridge research and practice. A geometric portion of this model would represent a possible collaborative configuration. For example, as in the shaded triangle, a researcher with expertise in assessment of PBL could collaborate with a teacher interested in better assessing their students' knowledge or skill acquisition. The model also highlights the importance of trust, respect, and mutual understanding for successful collaborations, a theme which we are currently developing in other work and which has been studied in a variety of collaborative contexts (Child, 2001; Jarvenpaa, Knoll, & Leidner, 1998; Mattessich, Murray-Close, Monsey, & Wilder Research Center, 2001; Vangen & Huxham, 2003).

Figure 1. Model for Possible PBL Research Collaborations in Engineering Education.



Different collaborative configurations may lead to different types of international relationships. For instance, piloting a course or specific intervention in another country may help build interpersonal and institutional relationships, while borrowing theory or citing the work of international colleagues will likely have different—and probably lesser—impacts. Thus, the nature of collaborations and associated networks will shape the ways in which engineering education internationalizes as a field, especially by determining the nature of the relationships and networks that are built.

Tensions between learning theory and accreditation demands may suggest another kind of collaboration. Constructivist pedagogy is emerging in PBL even as calls for systematic benchmarking and accountability increase, and the two may prove difficult to reconcile (Savin-Baden, 2007). Hence, this is one place where researchers with both assessment expertise and knowledge of constructivist learning theories could collaborate with faculty and program administrators or managers who are charged with overseeing accreditation processes or other kinds of program evaluation.

We also suggest that more research is needed on gender and diversity issues in the context of PBL. One author in our dataset who investigated the effects of gender in a PBL environment and elsewhere has argued that multicultural training is needed for PBL staff (Du, Reimann, & Ulsig, 2007). Wolfe and Powell have noted that while collaborative learning and PBL are often assumed to benefit minority students, studies show that women often report negative experiences with team projects (Wolfe & Powell, 2009). Given the highly collaborative and interactional nature of PBL, minority populations are likely to be affected in different ways than in other types of classroom settings. International students in PBL settings can also face unique challenges that teachers, researchers, and administrators should be aware of and might elect to study (Larsen & Fink, 2000).

Conclusion

The various challenges and gaps of existing PBL interventions and research have been well documented, and our analysis supports and extends previous studies. In summary, we find that most of the papers in our data set are primarily or wholly focused on describing and evaluating a specific PBL intervention. Thus, there is much potential for research that moves beyond the first category in table 2 to uncover broader understandings of PBL, especially across a variety of settings. Further, we suggest that new initiatives and studies that strategically and proactively bridge PBL research and practice will likely have the most significant impacts (Jesiek, Beddoes, & Borrego, 2010).

As research in these broader categories both expands and is systematically related to the practice of PBL, it can also greatly benefit from international research collaborations that productively leverage diverse bodies of knowledge and experience. Yet our study finds that multinational research collaborations on PBL in engineering education remain rare.

This dearth of international cooperation could prove detrimental. We therefore propose reconceptualizing current challenges and gaps related to PBL research and practice as important untapped opportunities for international collaborations.

We must acknowledge that PBL, as implemented, is often quite context-dependent. Yet there are reasons to believe that engineering education research on PBL will benefit from internationalization. In addition to prior findings about the productive internationalization of other research fields, our analysis shows that many similar research studies about PBL are already happening around the world. In addition, we find much agreement about the kinds of skills engineering educators want from students and believe they can achieve through PBL. One possible goal of new collaborations could be the development of broader and more nuanced understandings of how PBL is both similar and different across contexts. This can be achieved through various means, including direct international collaboration, or even by simply becoming familiar with and engaging international colleagues' scholarship on PBL.

It has been recognized that we must use caution and not assume that those using the term PBL all conceptualize it the same way (Strobel & van Barneveld, 2009). Yet we suggest that there is much to be gained by considering a broad spectrum of PBL definitions and uses. In this way, we may better learn what questions, theories, methods, and findings are most relevant and applicable across different geographic contexts and implementation scales. The systematic development of such knowledge will help advance engineering education research and practice in productive ways.

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Note

1. http://www.mpbl.aau.dk/.

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Appendix

Articles in Database

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