AC 2012-4147: TENSIONS WITH PBL IMPLEMENTATION IN UNDERGRADUATE ENGINEERING EDUCATION: RESULTS FROM TEACHING PRACTICE

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Tensions with PBL Implementation in undergraduate engineering education – results from teaching practice

Introduction
Engineering educators are facing high demands as they are challenged to create learning environments that can not only better teach technical skills, but also incorporate process skills and foster other graduate attributes. Problem-based learning, known as PBL, and its variants have been deemed adequate for meeting the needs of educators and society in preparing the engineers of the 21st century. With pedagogical innovations like PBL, however, comfortable routines related to the structure and flow of classroom activity are disrupted for both educators and students. In addition to having to manage changes within their classroom processes and routines, engineering educators must also interact and operate within the larger systems in which their classrooms are embedded, the university. The structure and culture of the university system may facilitate or hinder the teaching intentions and goals of educators, as this larger system can impose its own set of tensions.

Purpose of study
The purpose of this study was to describe, based on interview data, the variation in engineering educators' ways of experiencing tensions in PBL implementations, as well as how they managed the tensions. In the specific context of the first two years of undergraduate engineering education, the research questions were:

1. What are the qualitatively different ways in which engineering educators experience tensions with a PBL implementation in their teaching practice?
2. How do engineering educators manage these tensions?

Perspective and theoretical foundations
In PBL learning environments, learners are placed in authentic situations where knowledge and skill acquisition (technical and process) is self-identified and directly relevant to the presenting problem derived from the real world, thus bridging the gap between theory and practice, and enhancing the opportunity for transfer of skills to real-world settings (Barrows, 2002).

In engineering education, PBL is often implemented in later years so that students have the opportunity to apply the foundational engineering and basic science knowledge that they acquired earlier in the curriculum (Brodie, Zhou, & Gibbons, 2008; Mitchell & Smith, 2008; Nasr & Ramadan, 2008). However, engineering faculty have recognized and acknowledged the need to implement problem-based pedagogies earlier in the program (Lima, Carvalho, Flores, & van Hattum-Janssen, 2007) to provide early opportunities to develop and integrate technical skills, process skills (e.g., problem solving skills, communication and team work skills) (Simcock, Shi, & Thorn, 2008; Town & McGill, 2008), to demonstrate linkages between course content and real life engineering (Güzeliş, 2006), to prepare students to understand the role of engineers in society (Hsieh & Knight, 2008), to support deep learning and transfer of knowledge and skills (Janowski, Lalor, & Moore, 2008; Montero & Gonzalez, 2009), and to increase student retention in engineering programs (Froyd et al., 2006; Savage, Chen, & Vanasupa, 2007).
The introduction of an innovative pedagogy such as PBL brings with it a set of tensions (Hung, Bailey, & Jonassen, 2003) and compounds the tensions already identified in engineering education reform efforts (Crawley, Malmqvist, Östlund, & Brodeur, 2007). Barriers that impact adoption of innovations can reportedly be structural or cultural. Structural barriers (Yidana,

2007) are related to the status and priorities of faculty, while cultural barriers are related to the basic values of teaching and research within the institution (Schneckenberg, 2009; Tang & Chamberlain, 2003). Tensions exist between the desired outcomes of education and the affordances that actually exist within the institutional system.

Through a review of the PBL research literature, Hung et al. (2003) identified and described five tensions of PBL. These were (1) depth versus breadth of curriculum; (2) higher-order thinking versus factual knowledge acquisition; (3) long-term effects versus immediate learning outcomes; (4) students' initial discomfort versus their positive attitudes; and (5) traditional role of instructor versus role as facilitator.

While Hung et al. (2003) identified PBL tensions in general, other researchers identified and described tensions specific to engineering education reform. These were (1) individual versus organizational value assigned to teaching (Crawley et al., 2007; Wright, 2005); (2) theory versus application/practice (Mills & Treagust, 2003; Town & McGill, 2008); (3) classroom problems versus real-world problems (Crawley et al., 2007; Holt, Radcliffe, & Schoorl, 1985); (4) single-disciplinary versus interdisciplinary content (Froyd et al., 2006; Olds & Miller, 2004); and (5) problem solving versus design (de Graaff & Kolmos, 2007; Holt et al., 1985). How engineering educators conceptualize and manage these tensions remains largely unexplored.

Methods

With this qualitative study, we endeavored to describe the variation in engineering educators' ways of experiencing tensions in PBL implementations (through a phenomenographic framework), as well as how they managed the tensions (through thematic analysis). Phenomenography is a methodology "where the focus of interest is the variation in ways people experience phenomena, or aspects of phenomena, they meet in the worlds they live in" (Booth, 2001, p. 171). The outcomes represent the different ways and levels of understanding a given phenomenon (i.e., the tensions encountered) and a level of awareness (Åkerlind, 2008). The emphasis is on understanding and describing not only the commonalities, but more so the variation in the individuals' ways of seeing and experiencing the phenomenon (Marton & Tsui, 2004).

The target population for this study was US engineering educators who implemented PBL in the early years of an undergraduate engineering program – Year 1 and/or Year 2. The rationale for this choice of context was that PBL has less of a presence in the early years of the engineering program than in later years, when project-based capstone courses are widely adopted. Despite advocacy for learner-centered pedagogies like PBL in engineering education, implementations are fraught with tensions.

Design of study

This qualitative study contained two phases of research. The first was a survey that provided descriptive data about respondents (engineering educators) and their experiences with problem-based learning implementations. The purpose of this phase was to select a smaller subset of engineering educators for interviews. The second phase was a qualitative, phenomenographic (explained in next section) study that, through the use of cases, explored the experiences, conceptions, and practices of engineering educators who have implemented problem-based learning within their classroom practices. For this study, the phenomenon studied was the conceptualization of tensions in a PBL implementation in engineering education, and the unit of analysis was the individual educator's conception of the phenomenon.

Data collection

The online survey served as a first step for sampling strategy. Of the 313 survey respondents, 91 agreed to be interviewed. Email invitations were sent to the first 45 of 91 respondents to initiate the interview process as soon as possible. Twenty-eight engineering educators responded to the invitation. Of the 28 interviews conducted, 14 met the inclusions criteria which consisted of (1) PBL implementation in one's own course; (2) PBL implementation in Year 1 and/or Year 2 of undergraduate engineering programs; (3) at least two consecutive implementations of PBL, not necessarily in the same course; and (4) hold faculty positions in degree-granting institutions in the Unites States.

The semi-structured interview protocol consisted of 21 questions divided into four sections – teaching practice (5 questions); outcomes (6 questions); process/implementation of PBL (6 questions); and concepts (4 questions). The purpose of the interviews was to capture the experiences and conceptualizations of the engineering educators as they addressed and managed the tensions encountered in their teaching practice of educating engineering students.

Interview participants

Twenty-eight engineering educators responded to the invitation for an interview. Fourteen made use of PBL in the first two years of the engineering program. Male educators made up 57% (n=8) of the sample while female educators made up 43% (n=6) of the sample. The average age of the participants was 48.63 years (SD=13.05 years) for male educators and 42 years (SD=7.21 years) for female educators.

The participants represented 11 different states – California, Indiana, Kansas, Massachusetts, Missouri, New Jersey, and Oklahoma each had one participant, while Connecticut, Michigan, and Texas each has two participants

With regard to faculty role, participants (n=14) held the following ranks: full professor (4 or 29%), associate professor (6 or 42%), and assistant professor (4 or 29%). The engineering domains represented were Mechanical (6 or 42%), Civil (4 or 29%), Materials (2 or 14%), and Biological, Chemical, and Environmental/Ecological (each with 1 or 7%). The majority of interview participants (50%) came from large research universities.

Data analysis

Analysis of the transcripts served to develop pools of meaning, seeking to identify the variations in the experience of the phenomenon (Marton & Booth, 1997). This was accomplished through a combination of deductive and inductive coding. Deductive coding is the process of assigning pre-determined codes when coding transcripts, while inductive coding is process of allowing codes to emerge from the transcripts during analysis (Fereday & Muir-Cochrane, 2006).
In order to represent the variation in how engineering educators experienced and understood the predominant tensions that they encounter in their teaching practices with PBL implementations, a phenomenographic analysis was conducted (see Figure 1).

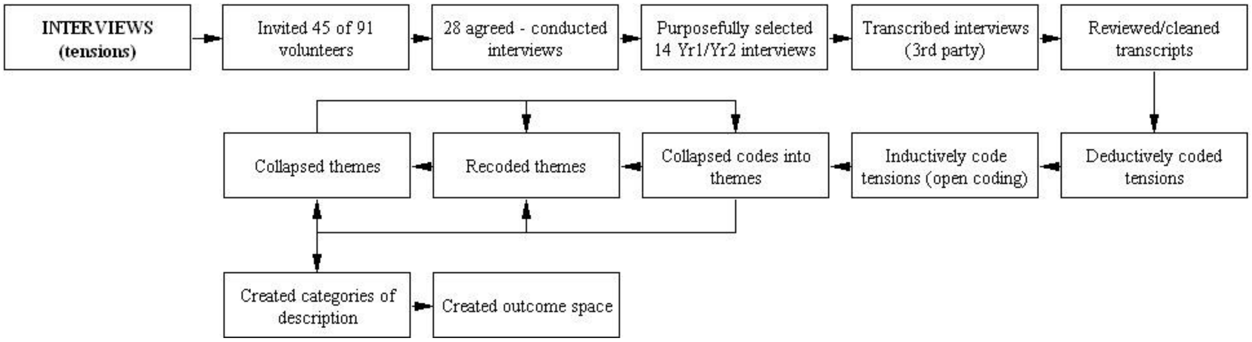

Figure 1: Process of phenomenographic data analysis.

To address the research question related to the management of tensions, a thematic analysis (Braun & Clarke, 2006) was performed on the transcripts (see Figure 2).

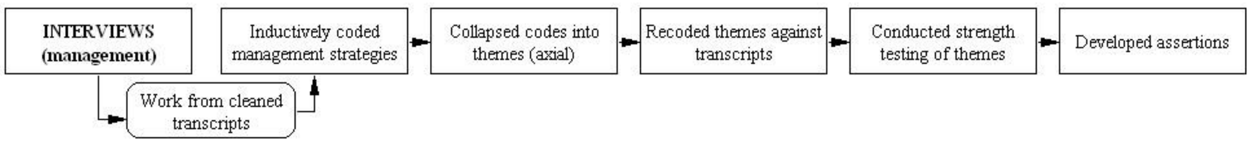

Figure 2: Process of thematic analysis.

Credibility was established with the use of triangulation. Specifically, multiple sources of data, represented by the collection of data (via interviews) from various people in different places, with various perspectives and experiences with the phenomenon under study, additional data coders, and member checks to validate researcher interpretations were used to ensure the internal validity of the study (Merriam, 2009).

Results and discussion

While all tensions were touched upon to some extent by interviewees, three tensions elicited the greatest amount of conversation from the engineering educators: student discomfort with the initial transition to PBL, the role of the educator as facilitator rather than teacher, and the value assigned to teaching by the individual and the organization.

Tension 1: Student discomfort

Educators in this study conceptualized the tension of students' initial discomfort with the transition to PBL as (1) a lack of readiness with regard to knowledge, skills, and attitude as part of their entry into the program from high school, (2) dissonance in student expectations between their old learning environment and their new learning environment, and (3) the transition to the new learning environment (PBL). See Figure 3.

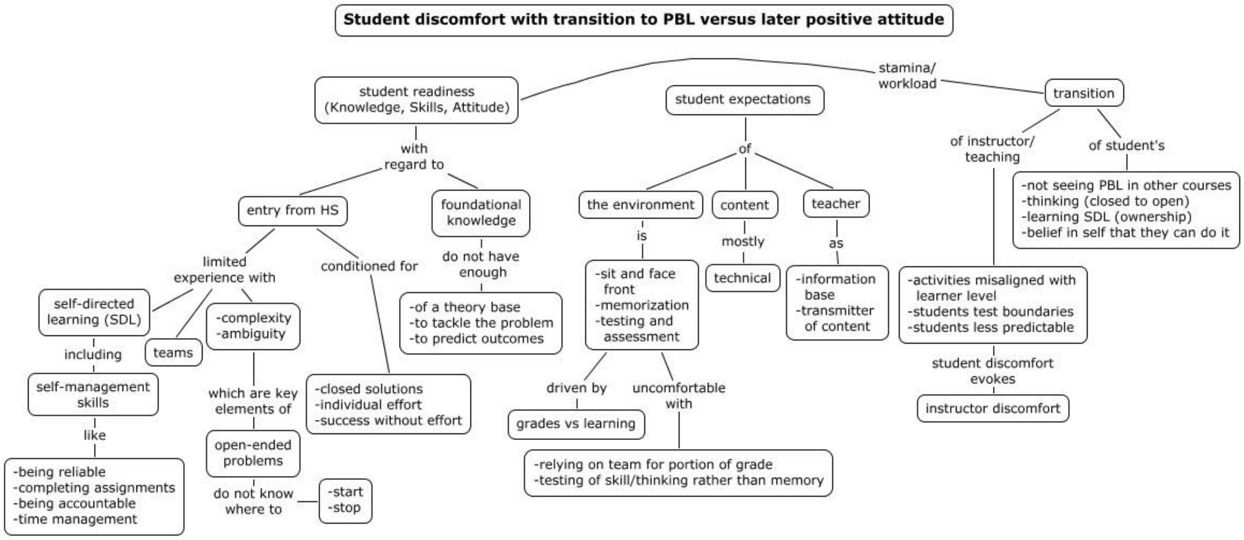

Figure 3: Engineering educators' conceptualizations of the tension of students' initial discomfort with PBL.

Student readiness: Category 1 depicts the conceptualization of this tension as one of lack of student readiness with regard to entry skills from high school and foundational knowledge for engineering. Limited experience with self-directed learning (Savage, Chen & Vanasupa, 2007), working in teams, and dealing with open-ended problems (Hasna, 2008) were key attributes related to entry skills from high school, as was the attribute of being conditioned to be a learner in the high school learning environment (Sheppard, Macatangay, Colby & Sullivan, 2009).

Expectations: The conceptualization of tensions now moved from the readiness of the student before he/she gets to the program to their engagement in the engineering program where student expectations and contextual reality of being an engineering student may be dissonant. The student expectations may be, in essence, a product of their old learning environments - sit and face front and memorize technical content, all in a very teacher-centered setting (Sheppard et al., 2009). While this may be the case in more traditional approaches to engineering education, the PBL learning environment is more student-centered and focuses on both content and process skill development (Felder & Brent, 2003).

Transition: Student discomfort is now conceptualized as a transition into the PBL learning environment. For the student, the process of transitioning required time and effort to modify one's thinking, accept greater ownership for one's own learning, and establish a belief in one's ability to learn in this new environment. Interestingly, the conceptualization of this tension also seemed to encompass the educator's transition and there was the suggestion that the student discomfort may evoke instructor discomfort, seemingly due to the unpredictability of behavior and of questions.

Tension 2: Value assigned to teaching

Educators conceptualized the tension of the individual versus organizational value assigned to teaching as (1) indifference to his/her innovative efforts on the part of others with regard to the use of PBL, (2) skepticism about PBL on the part of fellow faculty and administration, and (3) a misalignment within the system. See Figure 4.

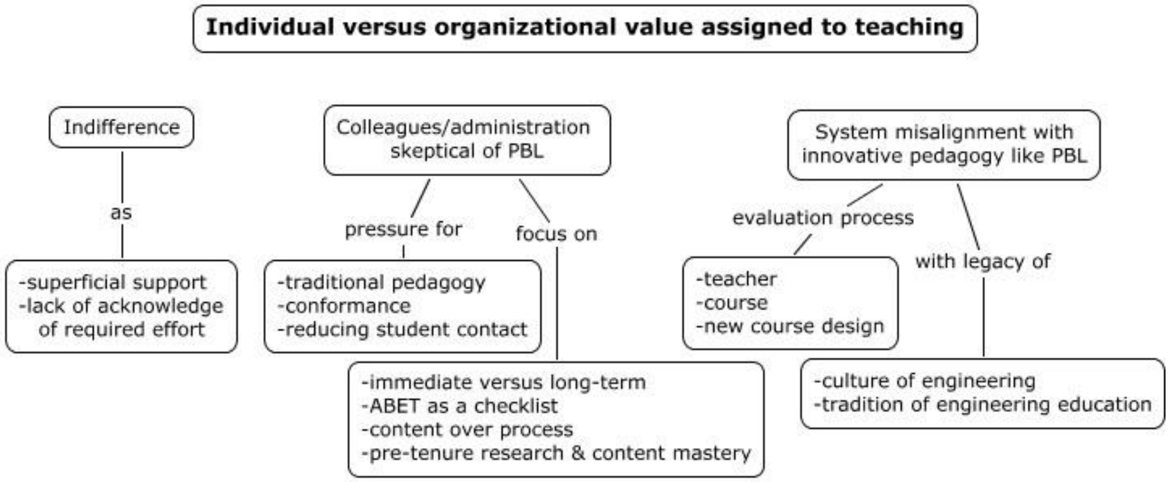

Figure 4: Engineering educators' conceptualizations of the tension of the individual versus organizational value assigned to teaching.

Indifference: Educators' conceptualization of this tension as indifference to his/her innovative efforts on the part of others with regard to the use of PBL. The key attributes of this category included the perception of superficial support and a lack of acknowledgement of the time and effort required to implement PBL. The implementation of PBL was on the educators' own time and, as reported below, usually without acknowledgement or recognition (Hora & Millar, 2008).

Skepticism: This category evidenced the engineering educators' conceptualization of the value assigned to teaching as skepticism of fellow faculty and administration about PBL. Included here is a focus on maintenance of the traditional educational setting, and pressure to conform to established teaching methods by colleagues who questioned why things need to change.

Misalignment: This category encompasses more than the individual (indifference) and the faculty (skepticism) value assigned to teaching, and moves it into the systemic level, making it a more complex conceptualization of the tension. The focus on research over teaching remained strong, while traditional processes for teacher and course evaluation were perceived to be ineffective to capture the innovative approach to teaching used by the educators in this study. The educators in this study seemed to propose that the evaluation processes were not only misaligned with PBL and more aligned with lecture-based teaching, but were superficial at best. An interesting finding in the work of Wright (2005) was that the tension of the individual instructor value assigned to teaching and the instructor's perception of the organization's value assigned to teaching was more evident in large research universities than it was in two or four-year institutions where the research agenda was less aggressive.

Tension 3: Instructor role

Finally, educators in this study conceptualized the tension of traditional role as instructor versus the role as facilitator as (1) content provider, (2) process advocate, and (3) learning (re) constructivist. See Figure 5.

Content provider: In some cases, the educator may understand his/her role as controller of content as well as deliverer of content. The focus seemed to be not only on the imperative of content or subject matter mastery of the instructor, but also on being able to give the content to the student. This perspective aligns with Prosser, Martin, Trigwell, Ramsden, and Lueckenhausen (2005) who indicated that where the conceptualization of teaching was more teacher-oriented, the discussion seemed to be more focused on delivery of content and gravitated towards information transmission. This category appeared to reinforce the '*what I know*' aspect of the conceptualization of this tension.

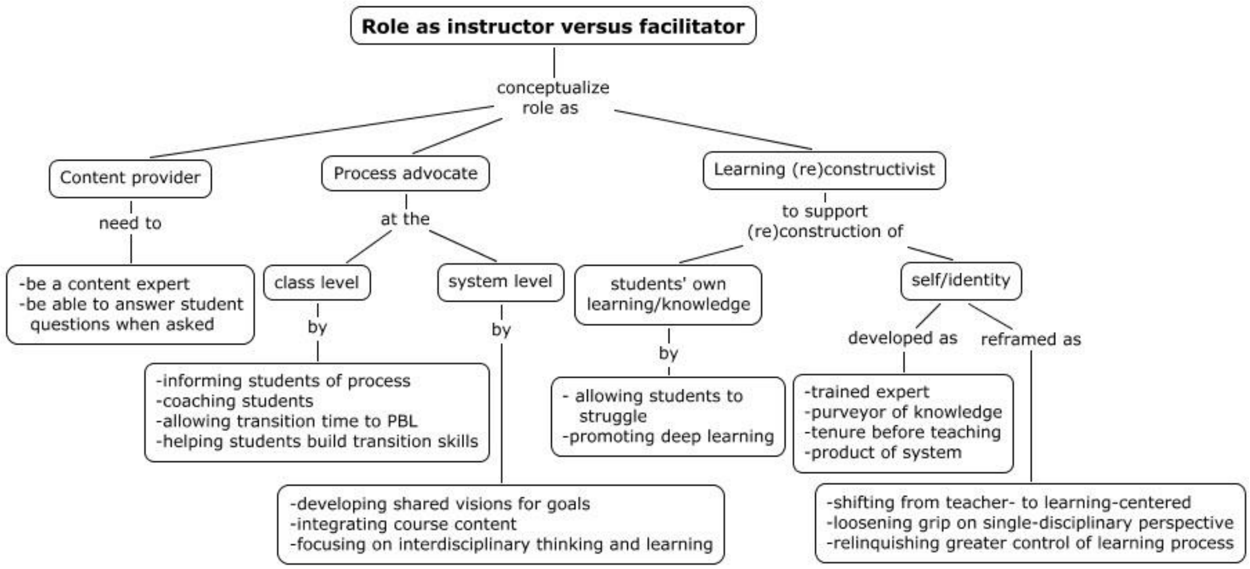

Figure 5: Engineering educators' conceptualizations of the tension of their role of instructor versus facilitator.

Process advocate: This category was different than the previous one in that the focus moved beyond instructor content knowledge and delivery being a requirement and now included pedagogical knowledge as a critical aspect of the role. At the classroom level, educators continued to inform, coach, and support students in the PBL process, but also helped the students to build transitioning skills (for the transition from non-PBL experiences into a PBL-centered class). This category reinforced the '*what I do*' conceptualization of the role, moving the educators' understanding of their role from the more static knowledge giver to a more active and engaged advocate of the PBL process with students and faculty. This conceptualization of process advocate and student-centeredness aligns with Prosser et al. (2005) who found that educators who had a more holistic view of their subject matter content tended to focus their role as educator on helping students acquire conceptual knowledge rather than just having students be recipients of content delivered in a didactic format. It also aligns with Åkerlind's (2005) work that revealed that, in their development, educators experienced an increased sophistication of their understanding of their field by acquiring a greater comprehension of a particular teaching method. In this case, the commitment to working within a PBL environment and the perspective of student-centeredness seemed to be a co-evolution of the conceptualization of the role of instructor versus facilitator.

Learning (re)constructivist: The conceptualization of the role was now focused on transformative aspects of instructor versus facilitator. The role of learning (re)constructivist aligns with Kember and Kwan's (2000) view that a more sophisticated view of the instructor-facilitator role was that of facilitating students in becoming independent learners. The reframing of the educators' identity may reflect the change of perspective that being an educator goes beyond the content provided to or the concepts acquired by students. This category reinforces the '*who I am*' conceptualization of the role where the essence of the engineering educator is not confined by how much they know and how much they can control the students and the learning environment, but embraces a transformed perspective of learning and of self and how he/she can be of service in supporting the students to construct their knowledge.

While the outcome spaces of the three conceptualizations of the tensions stand on their own, there is also a relationship between them that could inform a final, integrated outcome space. Two of the conceptualizations are PBL tensions (student discomfort and instructor role), while the third is a system (engineering education reform) tension (value assigned to teaching). The key attributes of this outcome space were conceptualizations of the PBL implementation as (1) content-centered, (2) student-centered, and (3) learning centered. The final outcome space (see Figure 6) depicted not only the variation in conceptualizations of the PBL tensions, but also the influence of the system-level tension of value assigned to teaching. To describe this influence further, the words of Kegan (2000) are appropriate in that each of the three attributes are "…honorable, valuable…each can be enhancing, necessary, and challenging for the teacher to facilitate. In given moments or contexts, a heavier weighting of one or the other may be called for" (p. 51).

Tensions	PBL Implementation		
	Content-centered	**Student-centered**	**Learning-centered**
Instructor-facilitator	Content provider	Process advocate	Learning (re)constructivist
Student discomfort-satisfaction	Student readiness	Student expectations	Student transition

Figure 6*: The final outcome space of the variation in engineering educators' conceptualizations of the predominant tensions encountered with the implementation of PBL in their teaching practice in the early years of the program.*

Category 1: PBL implementation as content-centered.
The key attributes in this category included the educators' conceptualization of their role as a content provider and more of a focus on filling the knowledge and theoretical gaps educators reported with regard to student readiness. This may be considered a traditional conceptualization of the interaction between educator and student within a PBL implementation, focused on information and content acquisition on the part of the student.

Category 2: PBL implementation as student-centered.
The key attributes in this category included the educators' conceptualization of their role as process advocates and their awareness of the need to address the students' expectations with

regard to the new PBL learning process. This category differs from Category 1 in that, while content remained critical, the focus was more complex than simply *what* was to be acquired by the student and the educator oriented and supported students on *how* the concepts were to be acquired by them.

Category 3: PBL implementation as learning-centered.
The key attributes in this category included the educator's conceptualization of their role as a learning (re)constructivist and the students' transition into the PBL learning environment. This category differs from Category 2 in that the interaction between the educator and the student is more focused on shaping the students' thinking, not only giving them more responsibility for the construction of their own knowledge, but also through the facilitation of and for deep learning. This moves the focus of this category to an even more complex level beyond the *what* and the *how*, and creates learning experiences for students to integrate the *why*, and the *why not*.
While the conceptualizations of the tensions showed variation, where an educator actually finds him/herself on the continuum may be influenced by the system level tension of the value assigned to teaching. As stated by Light and Calkins (2008),

> While approach [to teaching] often reflects the teacher's conception of the practice, the constraints of a given context may make that difficult. A teacher may have a sophisticated conception, for example, but the constraints inherent in the context – high student numbers, departmental culture, time demands etc. – may dictate a less sophisticated approach. On the other hand, it is unlikely that a teacher will take a sophisticated approach to teaching without having a sophisticated conception (p. 28).

Educators in this study who are implementing PBL were challenged to maintain their goals for better and deeper student learning in a system that continued to emphasize only the acquisition of technical knowledge (Sheppard et al., 2009). Sheppard et al. (2009) described the historical engineering education model that is still largely implemented as

> …treating learning as a deductive sequence, in linear fashion, suggesting a form of mechanical causation in which each components propels the next in line. Proficiency in 'engineering science' counts most, and the proper progression is always from scientific theory to engineering practice. The implied theory of knowledge is that engineering is in the main deductive (p. 16).

Additionally, Sheppard et al. (2009) called for a transformation of the system to include increased understanding of teaching and learning in order to produce engineering graduates who are schooled in all competencies to meet the needs of professional practice. The engineering educators in this study have committed to the use of PBL in an educational system that still requires transformation and, subsequently, presents tensions that need to be managed and can serve as a launching point for innovative reform. Litzinger et al. (2011) acknowledged that "engineering curricula and teaching methods are often not aligned with goals of constructing deep knowledge, application of technical and professional skills, and engagement in authentic projects and problems" (p. 123), citing several studies that found that academic engineering culture may actually hinder the development and implementation of methods that promote deep learning approaches. Felder, Brent, and Prince (2011) concurred that it is not just a case of educating the educators in methods like PBL that promote the desired learning experiences to develop engineering graduates to meet 21st century needs, but that the need exists for a systemic effort to support engineering education reform.

Management of student discomfort

With regard to management strategies, the strategies discussed most were related to the tensions around student discomfort, the instructor-facilitator role, and the tension of depth versus breadth of curriculum.

For the management of students' initial discomfort with the transition to PBL, two assertions emerged from the data. The transition of students to PBL is supported by (1) by setting and explaining expectations to help students understand the new learning environment, and (2) tailoring the learning activities to the level of the student. See Figure 7.

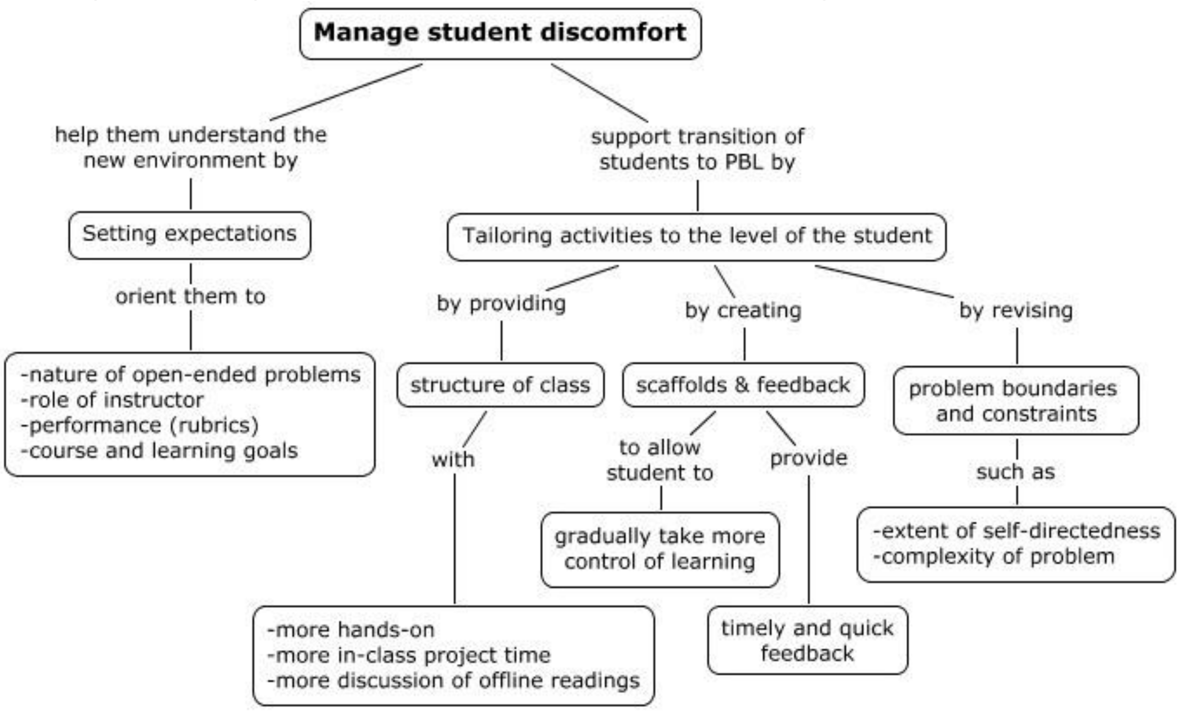

Figure 7: Thematic map of engineering educators' management of student discomfort with transition to PBL.

Orient students and set expectations: These educators were determined to ensure that students were informed and understood the PBL learning and teaching environment. The educators' adoption of the role of cheerleader evidenced their understanding that the transition to PBL – perhaps a major educational change for most students – required not only pedagogical support but also emotional support (King, 2006). Additionally, the overall approach to setting and explaining expectations aligned with Pepper (2010) and with Qualters (2003). Pepper (2010) stated that in the "early stages of PBL implementations…it is vital that students receive guidance about how and why they are expected to work in new ways" (p. 704) and this was reflected in the engineering educators efforts to not only ensure that the students were cognitively prepared for the change in process and expectations, but also emotionally supported through the educators' enthusiasm and faith in the students' ability to engage in PBL. The perspectives expressed and approaches taken by these engineering educators also aligned with the recommendations put forth by Qualters (2003) with regard to managing classroom expectations. She acknowledged that one needed to manage both the cognitive and the affective reactions of students when their expectations of a traditional learning environment are not met in an innovative and active learning environment such as PBL.

Support transition: Educators helped students transition to PBL by providing a structure to class time, providing scaffolding and feedback, and revising the boundaries and constraints of assigned problem/project scenarios, all in an effort to ensure that the learning experience was tailored to the entering capabilities of the students. Educators placed more constraints and boundaries around the problems that they gave the students in the early years of the engineering program, as opposed to the fully open-ended problems that students would receive in capstone courses. These constraints included a limit on the extent of self-directed learning required of the students and a level of problem complexity that was appropriate to their knowledge and skill level (Leppävirta, Kettunen, & Sihvola, 2011). In their use of PBL, the interview participants seemed to understand that it was not whether problems were open-ended or not, but the extent of open-endedness and the need to adapt that to their students' capabilities.

Management of instructor/facilitator role

For the management of role as instructor versus facilitator, two assertions emerged from the data. Engineering educators manage their role of instructor versus facilitator by (1) shifting the relationship between the content, the students, and the teacher, and (2) optimizing their activities and time in the formal class session.

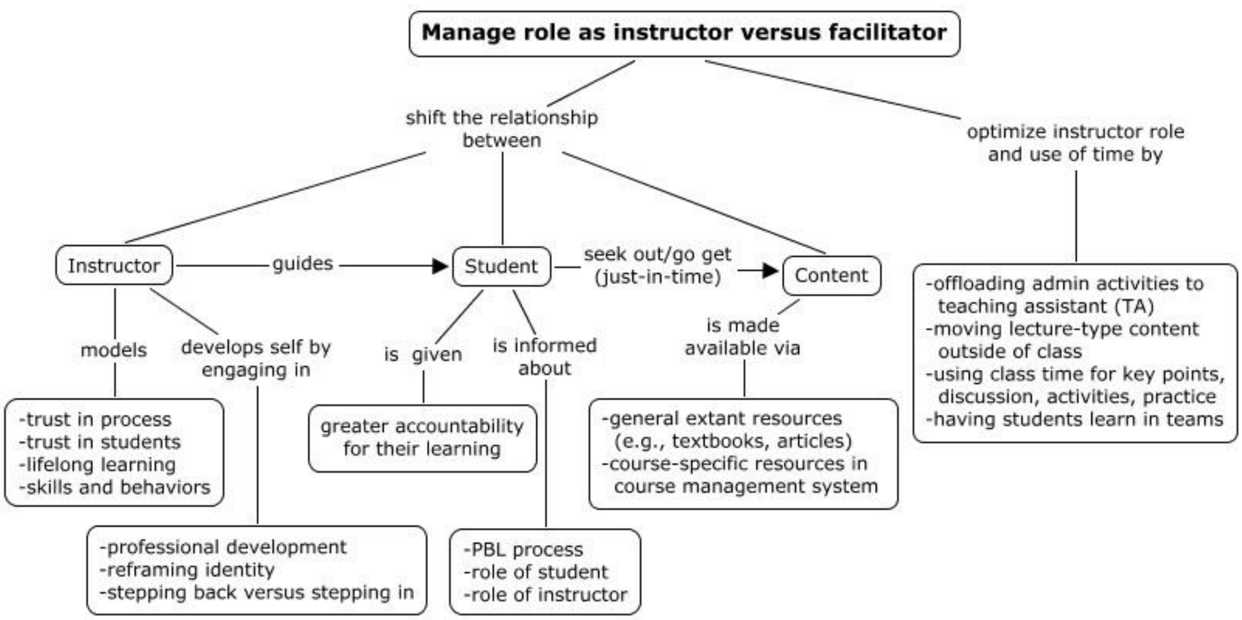

Figure 8: Thematic map of engineering educators' management of their role as teacher versus facilitator.

Shift relationships: The relationship between the instructor and the student was modified so that the instructor took on more of the role of a guide or facilitator rather than retaining the primary position as sage and purveyor of information. The instructors needed to develop themselves with regard to pedagogical content knowledge and skills to implement and support PBL in their teaching practice. Attitudinally, these educators reframed their identities as sages and endeavored to model for the students important competencies, both behaviorally and cognitively, such as self-directed and lifelong learning, as well as reflective thinking practices. The engineering educators' efforts to guide their students were in line with the premises of guided discovery which included cognitive activity and instructional guidance (Mayer, 2004). Guided discovery was described as a process "in which the teacher provides systematic guidance focused on the learning objective" (Mayer, 2004, p. 15). The relationship between the instructor and the content was also modified to the extent that the instructor was no longer the exclusive deliverer of content that could be easily consumed by students outside of class. Finally, the relationship between the student and the content was modified in that the student was now responsible to seek out or to go and get the content that he/she determined was required to address the problem. The students were given greater responsibility for their own learning, and were informed and oriented to the role of the instructor and of themselves in this new learning environment. But it was not left as a haphazard relationship. Educators designed problems so that students would be required to engage with content in a way that supported the learning goals.

Optimize activities and time: While the design and implementation of PBL generally takes longer than traditional lecture-based approaches (Litzinger, Lattuca, Hadgraft, & Newstetter, 2011), instructors optimized the use of class time by offloading administrative activities like grading to teaching assistants, then moving lecture-type content outside of the classroom so that students came to class prepared to engage in discussions and debrief the content and focus on key points. Class time was also used for hands-on activities and practice and students often worked in groups in order to benefit from collaborative learning (Ahlfeldt, Mehta, & Sellnow, 2005). With this approach, the engineering educators relegated the basic, lecture-type content outside of the classroom and reserved the class time for their facilitation of process learning, active engagement, and higher level thinking.

Management of curriculum depth/breadth

Finally, for the management of depth versus breadth of curriculum, three assertions emerged. Engineering educators manage depth versus breadth by (1) making adjustments to the learning environment, (2) making adjustments to the use of class and instructor time, and (3) making adjustments to the content. See Figure 9.

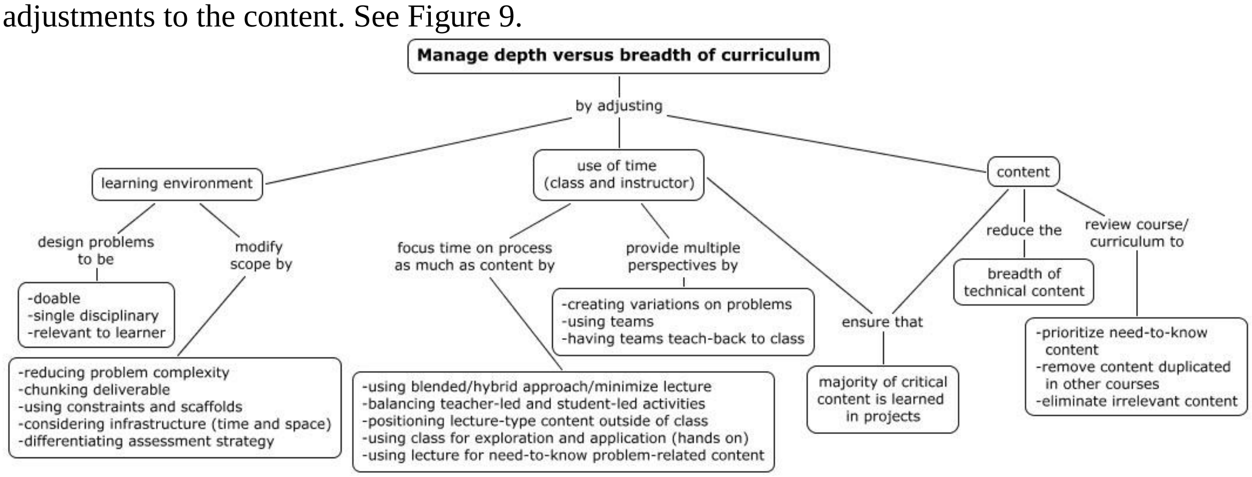

Figure 9: Thematic map of engineering educators' management of depth versus breadth of curriculum.

Adjust the learning environment: One aspect of adjusting the environment was to design problems that were doable within the parameters of the class (i.e., class duration, course duration), were meaningful to the learner and appropriate to their skill level. By initially focusing on a single discipline, educators could support the students in their in depth exploration of the problem. These insights align with Hung's (2006) 3C3R Model for designing problems for PBL. He advised that while the complexity of a problem should remain a key feature, the scope of the problem should be designed to the level of the learning goals appropriate for the learner.

Adjust the use of time: These engineering educators adjust the way that the class time was used and how the instructor's time was used within the class. In order to engage in activities that supported deep learning and kept the students within close range for scaffolding and support, the educators tended to position lecture-type content outside of the class and use class time for clarification and reinforcement of concepts or need-to-know problem-related content. The educators tried to develop multiple aspects of a problem so that the students' efforts led back to a holistic view of the problem once all parts were brought together. The use of multiple perspectives, group work, peer teaching and learning activities aligns with the deep learning strategies of Hake's (1998) interactive engagement, described as "designed to promote conceptual understanding through interactive engagement of students in heads-on (always) and hands-on (usually) activities which yield immediate feedback through discussion with peers and/or instructors" (p. 65).

Adjust the content: One of the strategies that these engineering educators used to manage depth versus breadth was to reduce the breadth of technical content. This approach was echoed by Evans, Beakley, Crouch, Yamaguchi et al. (1993) who spoke to faculty, students, industry, and alumni representatives in an effort to understand how to better prepare engineering graduates for professional practice. One of the final recommendations was to "systematically reduce the number of topics covered in many courses (e.g., mathematics, science, and engineering science) in favor of increasing the depth of understanding – cover less, uncover more" (Evans et al., 1993, p. 208). Another strategy that educators used to manage the tension was to remove content that was duplicated in other courses, and to remove content that was legacy and irrelevant to the course. The apparent goal of all the efforts of these educators was to create a learning environment where the students were supported in deep learning of need-to-know course content. The acknowledgement of the challenge of managing the tension of depth versus breadth was noted by Litzinger et al. (2011), who reinforced the approaches and intentions of the educators in this study, by stating:

> A potentially major barrier is the tension between the large amounts of content that can be covered with engineering courses and the amount of time that use of deep learning approaches requires. Many faculty members feel pressure to cover large amounts of content. Adopting teaching practices and assignments that require deep approaches to learning will potentially reduce the amount of material that can be covered while actually increasing the amount of material that is learned and retained by the students (p. 143).

Conclusion

The demands on engineering educators are high and they are being challenged to create learning environments that not only teach technical skills better, but also incorporate process skills and foster other graduate attributes (ABET, 2009; Sheppard et al., 2009). Felder and Brent (2003) stated that the "…instructional method known as problem-based learning (PBL) can easily be adapted to address all eleven outcomes of Criterion 3 [ABET]" (p. 15).

The role of educators in the implementation and adoption of new pedagogy cannot be overstated. This research provides insights on the variation of experience of instructors implementing PBL in early years of the undergraduate engineering education. The study focused on tensions encountered and the management of these tensions. The results are significant in that they show that the implementation of PBL requires adjustment at multiple levels and requires a considerable amount of shift for faculty. These shifts by faculty are necessary due to the fact that instructors support the often difficult transition of students into the new learning environment. Insights of this study contain clear recommendations for practice as well as numerous departure points for further research.

Significance of study

This study contributes to the body of knowledge of engineering education research, scholarship of teaching and learning, and problem-based learning.

For engineering educators considering the implementation of PBL into their teaching practice, this study offered not only insights into potential tensions, but also the management strategies used to mitigate the tension. Additionally, this study revealed the complexities of the interaction between student, educator, and pedagogy and the need to anticipate and support transformation of the learner and the educator when engaged in a student-centered, active learning environment.

For the administrators, this study provided insights into the tensions and strategies used by innovative engineering educators who are meeting the call to prepare engineering students for the 21st century workplace. Administrators may consider, preferably in a collaborative way, the establishment of instructor support mechanisms that facilitate and encourage the implementation of innovative pedagogies, as well as the redesign of recognition and reward policies. With a view to both of these implications, administrators may also consider creating a greater alignment between pedagogical innovation, course and educator evaluation processes, and the outcomes-based emphasis on student capabilities in order to support engineering education reform and the development of engineering graduates who are prepared for the demands of a global and rapidly changing workplace.

For faculty development specialists, implications for the design of professional development programs that focus on innovative pedagogies like PBL occur at two levels, the classroom and the larger system level. At the classroom level, faculty development programs could include not only an authentic approach to learning about innovative pedagogies, but the incorporation of management strategies that address the tensions encountered new implementations.

Finally, for curriculum design and development, this study offered a view into how educators managed the perpetual challenge of depth versus breadth of content. Curriculum designers may consider an analysis of need-to-know versus legacy content, the latter of which may carry less relevance in today's professional engineering practices; redistribution of content to allow optimal use of instructor time to support deep learning in students and; an integrative rather than an additive approach to the inclusion of new content or to meet accreditation requirements.

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