Implementing Problem-based Learning in Introductory Engineering Courses: A Qualitative Investigation of Facilitation Strategies

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ABSTRACT

Increasing pressure to transform teaching and learning of engineering is supported by mounting research evidence for the value of learner-centered pedagogies. Despite this evidence, engineering faculty are often unsuccessful in applying such teaching approaches often because they lack the necessary knowledge to customize these pedagogies for their unique contexts. My dissertation study investigated the challenges with facilitation practices in introductory PBL engineering courses and developed a pragmatic research-based model that provides insights aimed at improving PBL facilitation practices using the Innovation Cycle of Educational Practice and Research (ICEPR) as a lens. The ICEPR is useful for investigating connections between educational practice and research for scholarly and systematic educational innovations. I conducted a three-phase sequential study to address critical gaps in the ICEPR regarding both research on and practice of PBL facilitation in engineering. I focused on identifying challenges in practice, developing a model, and disseminating the model through a typology using multiple qualitative data collection and analysis methods. In Phase 1, I studied a new PBL implementation and identified a challenge with facilitator training specifically with regard to a lack of a pragmatic model of facilitation strategies in engineering. In Phase 2, I investigated the facilitation practices of five facilitators in an established PBL engineering course. This resulted in the Model of PBL Facilitation Strategies for Introductory Engineering Courses (PBL-FIEC), where I specifically operationalized the instructional methods constructs from Collins' Cognitive Apprenticeship Framework to describe the variety of ways instructors facilitate student learning in PBL introductory engineering courses. The PBL-FIEC includes six methods and 27 strategies ways for instructors to facilitate students' learning through providing and prompting demonstrations of cognitive and metacognitive processes that emphasize content and process knowledge and different ways of knowing (knowledge, understanding, and reasoning). In Phase 3, I developed a Typology of Facilitation Strategies using PBL-FIEC and observations of instructors to demonstrate how they use and combine facilitation methods. Ultimately, my dissertation research shows how the ICEPR can be used to understand that innovation in educational practice relies on the interaction between researchers and practitioners, while generating a model directly useful for both stakeholders.

DEDICATION

In loving memory of Dad.

In memory of the 32 Hokies we lost
and
In honor of the Survivors
Virginia Tech, April 16th 2007

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To my Lord and Savior, Jesus Christ: None of this would have been possible without You. You have answered my prayers, guided me along the way, given me strength when I had none left, and made what was not enough, enough. You rescued me and have been my constant throughout this journey and life.

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Chapter 1. Introduction of the Research

A significant goal of the engineering education community is to improve the teaching and learning experiences in the engineering classroom with the implementation of learner-centered (L-C) pedagogies (Dancy & Henderson, 2008). L-C pedagogies is an umbrella term that represents a range of pedagogies including inquiry learning, cooperative learning, problem-based learning, think-pair-share, project-based learning, case-based teaching, just-in-time teaching and paired think-aloud. Some of these pedagogies are instructional techniques that can be used alongside of more traditional instructive lecturing methods (i.e. paired think-aloud or case-based learning) and others are all inclusive pedagogies (i.e. problem-based learning or cooperative learning). What these pedagogies have in common is that they engage students in inductive learning and require students to be active and engaged such that they are cooperatively constructing knowledge. Achieving this goal requires cooperation between faculty who are in the classroom and faculty who conduct research on classroom experiences. However, evidence suggests that there is a divide between these groups of faculty and gaps in what should be a cycle of continuous feedback (Jamieson & Lohmann, 2009; Matusovich, Paretti, McNair, & Hixson, 2014). To influence the transformation of teaching and learning in engineering, we must try new practices in our classrooms, report on the challenges and shortcomings, seek to understand the challenges, and develop research-based models or recommendations that are directly relatable to the classroom.

One L-C pedagogy in engineering that would benefit from cycles of informed practice and research is problem-based learning (PBL) (Beddoes, Jesiek, & Borrego, 2010; Smith, Sheppard, Johnson, & Johnson, 2005). A specific area of focus with regard to PBL is facilitation; knowing how to facilitate and having models of facilitation is one primary reason faculty do not adopt PBL. While there is extensive research on the theoretical foundation of PBL, there is a need for greater connections between research and practice particularly with regard to facilitation.

1.1 Need for the Research

In the last decade there has been a push to transform teaching and learning in higher education, particularly in the science, technology, engineering, and math (STEM) fields (Dancy & Henderson, 2008; Felder, Sheppard, & Smith, 2005; McKenna, Froyd, & Litzinger, 2014). Research shows mounting evidence for the value of pedagogies that encourage active learning and build communities of learners, and it also suggests that efforts toward transformation be directed at such pedagogies (Rawlings, 2011; Shelton & Rawlings, 2015; Smith, 2011). In spite of these calls and research findings, 66% of STEM faculty cite using "extensive lecturing" in "all or most" of their undergraduate STEM courses; "extensive lecturing" is cited at higher rates in STEM courses than in non-STEM courses (37%) (Hurtado, Eagan, Pryor, Whang, & Tran, 2012). There are signs of hope, though, as the trend in reported use of L-C instructional strategies by faculty in undergraduate courses increased over a ten-year span for both STEM and non-STEM faculty (Hurtado et al., 2012; Lindholm, Astin, Sax, & Korn, 2002). This trend brings promise for additional change as each implementation of an L-C pedagogy provides examples for others to follow.

Research on L-C pedagogies has revealed many compelling reasons for integrating such practices into higher education and specifically engineering. L-C pedagogies require students to be active agents in their own learning, while the teacher acts as a facilitator who scaffolds the learning experience. The agency that L-C pedagogy affords students can lead to increased motivation toward learning, retention of knowledge, and depth of understanding when compared to traditional lecture-based approaches (Galand, Raucent, & Frenay, 2010; Prince & Felder, 2006). Learning outcomes for students engaged in L-C courses include advanced problem-solving skills, deeper understanding of course material, increased ability to work cooperatively in groups, increased communication skills and engagement in self-directed learning (Hmelo-Silver, 2004; Hmelo-Silver, Duncan, & Chinn, 2007; Prince, 2004; Prince & Felder, 2006; Strobel & van Barneveld, 2009; Walker & Leary, 2009; Woods, 2012; Woods et al., 1997). Students with these skills will be better prepared to enter the workforce, where they will encounter rapid advancements in technology and knowledge and will be well prepared to adapt to these changes and advance their careers.

One L-C pedagogy that has been the focus of research for some time is problem-based learning (PBL). PBL originated in the medical school at McMaster University in Canada in the 1960's. From McMaster, PBL pedagogy began to spread to other medical schools in Europe, Australia and North America. By the 1980's, numerous medical schools were implementing PBL in their curricula (Barrows, 1996). PBL then spread to other health-related disciplines, and then eventually it began to be implemented in more diverse disciplines including architecture, business and management, teacher education, psychology, sciences, and engineering (Prince & Felder, 2006). Though PBL began as an instructional and curriculum design method for medical education, it is now a research-based instructional strategy that has gained much attention in the last 10-15 years (Beddoes et al., 2010). In PBL the emphasis is not on the end product of the student work, but on the process the students go through to arrive at a solution and the instructor's role as a facilitator of the learning process. Research on PBL has shown many educational benefits, including those mentioned above for L-C pedagogies in general, as well as increases in students' critical thinking and self-directed learning skills (Woods, 2012). In a review of PBL, Kolmos and de Graaff (2014) argue for benefits such as increased motivation, transferable skills, and longer term retention of knowledge.

In a review of the literature on L-C pedagogies (or pedagogies of engagement), including PBL, it was noted that there is extensive research on the theoretical foundations of these pedagogies, in addition to student learning outcomes as a result of these pedagogies (Smith et al., 2005). However, there is a lack of research on implementation models for such pedagogies (Johri & Olds, 2011; Leary, Walker, Shelton, & Fitt, 2013; Savin-Baden, 2007; Smith et al., 2005). They hypothesize that the lack of research informing the practice of PBL and other L-C pedagogies in STEM fields has hindered expanded use in the classroom. Despite the lack of implementation models, studies show that *some* faculty try to implement PBL into their courses. However, most implementations have not been "informed by a scholarly understanding of learning" (Jamieson & Lohmann, 2009, p. 6) and thus a high percent (32-54%) do not sustain the practices because of the various challenges faced in implementation (Henderson, Dancy, & Niewiadomska-Bugaj, 2012). The scarce models that are available often lack depth of detail to properly inform new implementations of PBL. The models that do exist rarely acknowledge the role that context plays, which is vital in transferring pedagogy from one setting to another (Dancy & Henderson, 2010; Henderson et al., 2012). To lower the barriers to entry and influence broader change, we need to increase access to models of implementation and practical "know-how" aligned with STEM disciplines. One possible means is through greater connections between educational practice and research (Matusovich et al., 2014). Because engineering faculty find learner-centered pedagogies such as PBL particularly challenging because of the shift in the role of the instructor (De Graaff & Kolmos, 2007; Duch, Groh, & Allen, 2001; Murray & Savin-Baden, 2000) from lecturer to facilitator, my work focuses on creating a connection between research and practice, particularly with regard to facilitation.

1.2 Framework

I used the Innovation Cycle of Educational Practice and Research (ICEPR) to organize my study; shown in Figure 1.1 below (Jamieson & Lohmann, 2009). This framework is useful for investigating connections between educational practice and research for scholarly and systematic educational innovations. By using this cycle as a framework, I was able to rely on the intersections between educational research and practice to guide my study such that there might be a greater impact on innovation in PBL practices for engineering.

Jamieson and Lohmann (2009) posit that we need to create an environment where educational innovation can flourish and thus have an impact on transforming education; ICEPR is a meaningful way to evaluate the culture of educational research and practice, and to identify gaps impeding transformation of teaching and learning. The cycle has two main components represented by the large green circles – the activities of practice and research. It should be noted that neither of these components is more dominant than the other, but that they should be balanced in their interactions. The two small blue circles are the outcomes and inputs to the two activities. Starting at the top of the figure, practitioners design and implement educational practice, drawing on literature and previous research for answers and insights to improve practice.

Practitioners then identify and report questions and ideas from their implementations that serve as a basis for future research. Researchers draw on the questions and ideas reported from educational practice to develop educational research studies. Then researchers report out answers and insights from their research, which help to better inform practitioners and improve educational practice. The ICEPR necessitates that innovation requires collaboration between educational practitioners and researchers in order to transform education.

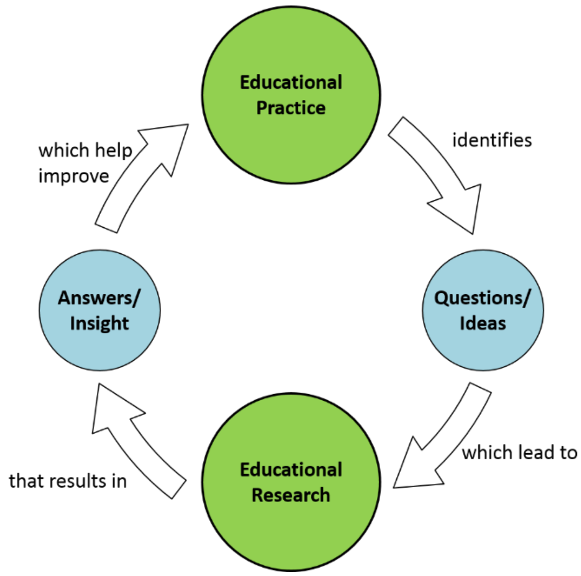


Figure 1.1 - Innovation Cycle of Educational Practice and Research (modified from Jamieson & Lohmann (2009)).

Despite a well-articulated model of collaboration, the current state of collaboration between educational practice and research leaves much to be desired. For PBL in particular, there is some work on both the research and practice sides; however, there are still significant gaps in the cycle. Gaps in ICEPR are indicated by red x's in Figure 1.2 below. Starting at the top of the cycle with practice, there has been an increase in the use of PBL pedagogy in engineering (Beddoes et al., 2010); however, there is little reported in the literature about these efforts (Crismond & Adams, 2012; Matusovich et al., 2014). With limited reports of these implementation efforts, the first gap identified in the cycle is a lack of practice-identified questions and ideas for further investigation. Additionally, without practiced-informed research questions, the research on PBL has not focused on the implementation concerns of practitioners, but instead primarily on students learning outcomes, student attitudes, and theoretical foundations (Smith et al., 2005). This is the second gap in the cycle: lack of practice-informed research. Moving from research back toward practice, there is not a shortage of PBL research in general, but a lack of PBL research that is pragmatic and informs the implementation and practice of PBL particularly in engineering – this is the third identified gap in the cycle.

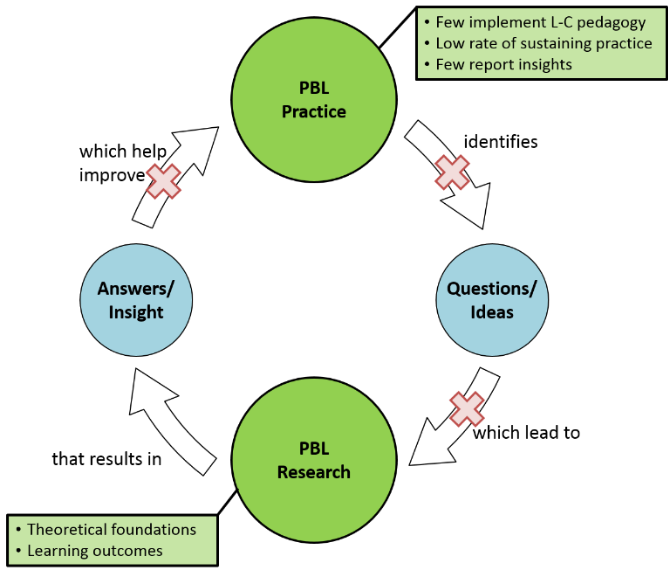


Figure 1.2 - Innovation Cycle of Educational Practice and Research (modified from Jamieson & Lohmann (2009)) with identified gaps for PBL.

Further support that the lack of collaboration between research and practice has limited innovation and growth of PBL in engineering comes from the work of Matusovich et al. (2014). In their work they found that a noticeably missing piece of the conversation is practice-informed research, meaning "research that examines the real, lived concerns and challenges experienced by practitioners and consequently increases the likelihood of subsequent implementation" (p. 325). This is an oversight of both researchers and practitioners; where practitioners often do not report their experiences and researchers are not collaborating with practitioners to identify specific concerns to be addressed by research. The lack of collaboration between the two parties, limits the ability of researchers to develop "pragmatic, easily accessible, and actionable findings" based on research for practitioners (Matusovich et al., 2014, p. 305).

While there is significant work on PBL theory, many components of ICEPR need attention. It is important to close the gaps in the cycle, such that practitioners have the information they need to design and carry out implementations of research-informed PBL practices and researchers know the questions that should investigate to better inform implementations of PBL practice in engineering.

1.3 Purpose of the Study

Given these gaps the purpose of my research is to serve as a bridge between research and practice on PBL, demonstrating how practice can be used to inform research and how research can be used to directly inform practice. Towards this purpose, my research was guided by the following overarching question.

How can the Innovation Cycle of Educational Practice and Research be realized for problem-based learning (PBL) in engineering?

To answer this question I used a three-phased exploratory sequential study, where each phase had its own research question, and I used the results that emerged from each research question to inform the design of the following phase and corresponding research question. The research questions for each individual phase are as follows:

1. What challenges arise in the practice (training and implementation) of PBL facilitation in an engineering course with a high student to faculty ratio?
2. How can the Instructional Methods component of Cognitive Apprenticeship framework be operationalized to describe a theory of PBL facilitation in introductory engineering courses?
3. How does the Model of PBL Facilitation Strategies for Introductory Engineering Courses describe practices of PBL facilitators in an introductory engineering course?

In answering these research questions I completed a manuscript-style dissertation, where each phase of the study represents a manuscript. More specifically, I identified challenges with facilitator training when implementing research-based PBL practices in an introductory engineering course (Manuscript 1). I then used the practice-based evidence to inform a research study that developed a framework for facilitation practices (Manuscript 2). Lastly, I used the newly developed framework to develop implementable outcomes to inform facilitator training and practice (Manuscript 3). Completing this study in this manner allowed me pay adequate attention to each step in ICEPR, particularly the practice side of the cycle which is often overlooked in research studies. Together results of the three phases inform the larger research-to-practice and practice-to-research gaps and allowed me to address the purpose of my study.

1.4 Study Context: NSF-funded Research Project

My study was part of a larger NSF-funded project (# HRD-0936704) that focused on how different components of PBL pedagogy impact women's interest and persistence in engineering (Jones, Osborne, Paretti, & Matusovich, 2014; Paretti, Jones, Matusovich, & Moore, 2010). The project was a mixed-methods, two-site, longitudinal investigation that employed quantitative surveys informed by motivation theories and qualitative analysis of student observations and student interviews. The two sites were both introductory engineering courses at large public universities located in the southeastern United States. The course at State University 1 (SU1) was an introduction to biomedical engineering that used PBL pedagogy and had an enrollment of approximately 200 students. At State University 2 (SU2), the course was an introduction to engineering design that was taught using traditional experiential design (TED) pedagogy and had an enrollment of approximately 1,100 general engineering students. The general engineering students were intending to major in one of 11 engineering disciplines.

Year 1 of the project (2010) included students enrolled in the courses at SU1 and SU2. Students at both sites responded to surveys and participated in observations of their group meetings and in semi-structured interviews. In year 2 of the project (2011), the research team used observations from the SU1 course and published literature to inform an implementation of PBL at SU2 in the introductory engineering course. The implementation was developed using an experimental design that included three treatments to investigate the influence of different aspects of PBL facilitation (i.e., interaction with trained facilitators, PBL learning cycle scaffolds or both) on student motivation. Like the year 1 study, the students who participated in the year 2 implementations were surveyed, observed, and interviewed. In addition to the student data, the facilitator training sessions were also recorded. The year 1 students also responded to follow-up surveys and participated in follow-up interviews. In year 3 of the project (2012), students from year 1 and year 2 were again surveyed and interviewed. All data collected during the three-year project is shown below in Table 1.1, where the checks (√) represent data from the larger study that were used in my dissertation and the Xs represent data that was not used in my dissertation.

Table 1.1 - Data Collected for the larger NSF-funded project.

			Data Collection Year		
Context		**Data Type**	**Year 1**	**Year 2**	**Year 3**
SU1	PBL Course	Classroom Observations	√	-	-
		Student Interviews & Surveys	X	X	X
SU2	Year 1 TED Course	Classroom Observations	X	-	-
		Student Interviews & Surveys	X	X	X
	Year 2 PBL Experiment	Classroom Observations	-	√	-
		Facilitator Training Observation	-	√	-
		Student Interviews & Surveys	-	√	√

Key: √ used in dissertation; X not used in dissertation; - not collected

To answer the research question for Manuscript 1 regarding challenges with training and implementation of PBL facilitation, I used all of the qualitative data from the PBL experimental implementation. The qualitative data included student interviews and observations of both the classroom and the facilitator training. The student surveys were not used, because the focus of the surveys was on student motivation. For manuscripts 2 and 3, the research questions were focused on understanding the ways experienced facilitators enact various facilitation roles and describing their facilitation practices in the classroom observations of the established PBL course. To answer these questions I used the classroom observations of the established PBL course.

1.5 Significance of the Research

In this manuscript-style dissertation, there are three research manuscripts. The first manuscript identifies the challenges faced during a research-informed implementation of PBL in engineering. As noted above, the challenges identified during the implementation led to research questions related to the facilitator roles in PBL. In the second manuscript, I studied an established PBL course in engineering and built a framework for understanding the roles and strategies of PBL facilitators. In the last manuscript, I utilized the framework developed in Manuscript 2 to develop a typology of facilitation practices that is directly implementable for training facilitators for PBL practice. The following are the individual outcomes of this study related to each of the manuscripts:

1. Challenges in training facilitators; identified from an implementation of PBL in engineering (Manuscript 1).
2. A practice informed research question, based on these challenges to explore the roles and strategies of PBL facilitation in engineering (Manuscript 1).
3. An operationalized framework for understanding PBL facilitation roles and strategies in engineering (Manuscript 2).
4. A facilitator typology that can be used to inform training of PBL facilitators to improve PBL practice in engineering (Manuscript 3).
5. An example of how to close the gaps in ICEPR, thereby impacting innovation of PBL in engineering using a research method that privileges neither research nor practice.

These outcomes together contribute to an overall outcome regarding how to leverage educational research and practice to influence change in education. Educational researchers and practitioners both have roles to play in this cycle. My work is one example of how these two groups need to build partnerships in their work to have a wider impact on changing education for the better. In Manuscript 1, I found that training on facilitation practices can influence changes in facilitator behaviors; however, in the implementation these changes were limited and several challenges in training facilitators were identified. These challenges include 1) limited knowledge of strategies for enacting facilitator roles, 2) limited understanding of when to use certain facilitation roles or strategies, 3) tendencies to fall back on familiar teaching practices, 4) need for more feedback on their practices, and 5) overcoming initial student resistance to self-directed learning. Though I further investigated only two of these challenges, there are several other avenues for further research that have been identified. Additionally, having identified these challenges, other practitioners can be better informed about challenges that should be considered when developing a PBL implementation.

In Manuscript 2, my work focused on two challenges identified in Manuscript 1, specifically knowledge of strategies and understanding of when to use particular facilitation roles and strategies. The research question developed as a result of Manuscript 1 sought to operationalize the cognitive apprenticeship model to describe a theory of PBL facilitation in engineering courses. The cognitive apprenticeship model has five instructor roles that can be attributed to facilitators. I refined the definitions for each of these roles and for each role I identified and defined corresponding strategies. For each role there are between two and six strategies, with a total of 27 strategies. The operationalized framework developed in Manuscript 2 is useful for both training facilitators and further studying facilitation practices. In Manuscript 3, I used the operationalized framework that was the outcome of Manuscript 2 to develop a facilitator typology that classifies how different instructors might use a variety of different facilitation strategies. The typology can be used by practitioners preparing to implement PBL in engineering or by faculty developers who are designing instruction to train faculty for PBL facilitation. Overall this work took a holistic approach to facilitating change in engineering education that accounted for both educational research and practice without privileging one over the other, but saw both as integral parts that must work in partnership to influence educational transformation.

1.6 Study Limitations

There are two limitations in my overall study. The first limitation is that the study is based on analysis of secondary data. Secondary data analysis is "analysis of an existing qualitative database, or databases, for the purpose of reviewing the literature, answering original research questions(s) using different methods or answering new questions with 'old' data" (Turner, 1997, p. 4). A significant challenge that can arise when using secondary data is that the purpose of the new study can be quite different than the original project, which can raise questions of alignment of the data with the research questions and data analysis (Smith, 2008). The data for my study was collected as part of a larger project that focused on student experiences, particularly influences on student motivation resulting from varying levels of PBL facilitation. For my study, the focus was on the facilitator roles, particularly the strategies facilitators use to enact those roles; thus asking new questions of the data. Though there was a shift in the focus between the two studies, the current study relied on the same observation data from the NSF-funded project and the new research questions remain consistent with the original study design. The observations were recorded (both audio and video) and when used for analysis observations were transcribed verbatim; thus the collected data was not biased by a particular theoretical framework and does not cause a problem concerning the difference in focus. The benefit to having videos of the observations was that they can be analyzed for any number of research inquiries as long as there was care taken to ensure consistency with the context of the larger project. While the conditions under which the data were collected were inescapable, the data collection methods and instruments had little impact on biasing the video data. Although there were video observations of the facilitators, the data set did not include facilitator interviews, which would have been valuable in understanding the facilitators' behaviors. This would have been useful in developing a model of facilitator strategies. However, the data set for the observations was large and included many examples of similar interactions and thus inferences regarding the facilitators' behavior could be drawn from the observations alone.

The second limitation of my study is that the operationalized framework and the facilitator typology were developed using data from a single context (university, course, and problem statement). To minimize this impact, I used observations of five facilitated PBL teams that had five different faculty facilitators with diverse backgrounds. Additionally, the observation data was longitudinal – collected over a seven-week period – to account for changes in facilitation strategies as the students developed knowledge and as the solution to the problem evolved.

1.7 Definitions

The following definitions are intended to remove ambiguity in regards to terms that were used in this research, as the terms have been used inconsistently throughout literature. These definitions scoped the way I interpreted and applied PBL as a pedagogy:

Problem-based learning (PBL) is a learner-centered instructional approach that empowers students to conduct research, integrate theory and practice, and apply knowledge and skills to develop solutions to problems. The defining elements of PBL philosophy are: (1) problem statements are the stimulus for learning and will determine the content, (2) the problems are complex, ill-structured, authentic to practice and can have multiple solutions, (3) learning occurs in small collaborative groups, (4) the groups are self-directed, meaning that the students have responsibility to determine what knowledge and skills they need to learn and then apply to the problem, (5) the instructors act as facilitators (sometimes called tutors) in the groups and guide the students primarily with open-ended questioning when necessary (Barrows, 1996; Boud & Feletti, 1998; De Graaff & Kolmos, 2003; Duch et al., 2001; Hmelo-Silver, 2004; Prince & Felder, 2006; Savery, 2006; Savin-Baden, 2007).

Facilitator is an instructor that supports student learning through knowledge building discourse by asking open-ended metacognitive questions designed to get students to make their thinking visible and fostering group process(Hmelo-Silver, 2004; Hmelo-Silver & Barrows, 2008).

1.8 Summary

The following chapters are divided into three distinct manuscripts, with one manuscript per chapter, and a final chapter discussing the overarching impact of the three manuscripts. In Chapter 2, the first manuscript is an investigation of the challenges in implementing PBL in an engineering course, with a focus on both the training of facilitators and facilitator practices in the classroom. The third chapter is the second manuscript, which address challenges identified in the first manuscript by developing a framework of the roles and strategies of PBL facilitators in an engineering context. The next chapter is the third manuscript that utilizes the framework developed in Manuscript 2 to develop a typology of facilitation in engineering. This typology is directly implementable to influence the training and practice of PBL facilitation in engineering. The fifth and final chapter will be a discussion of how these three manuscripts build on each other to create a complete cycle of innovation in educational research and practice. I will reflect on the research-practice method used and how it can influence future paths around the cycle and partnerships between researchers and practitioners.

Chapter 2. The Inherent Challenges with PBL Facilitation Practices in Engineering: Training and Implementation (Manuscript 1)

2.1 Introduction

During the last decade there has been an increase in pressure to transform teaching and learning in higher education—particularly in engineering (Dancy & Henderson, 2008; Felder et al., 2005; McKenna et al., 2014). This desire for change in engineering is supported by mounting research evidence for the value of learner-centered (L-C) pedagogies (Dancy & Henderson, 2008; Rawlings, 2011; Shelton & Rawlings, 2015; Smith, 2011). L-C pedagogies is an umbrella term that represents a range of pedagogies that engage students in inductive learning and requires students to be active and engaged such that they are cooperatively constructing knowledge. Despite this evidence, engineering faculty are often unsuccessful in putting such approaches to teaching into practice due to the challenges associated with implementing L-C pedagogies. More specifically, several studies have found that faculty (broadly) often do not have the necessary knowledge to customize the pedagogies for their situations while preserving the philosophy of practice (Henderson & Dancy, 2007), and low fidelity of implementation is often a result (Borrego, Cutler, Prince, Henderson, & Froyd, 2013). If we want to see faculty implemented L-C pedagogies more successfully in engineering, low fidelity is undesirable and we need more knowledge on how to successfully implement L-C pedagogies in this context.

While there are numerous L-C pedagogies, problem-based learning (PBL) has gained attention in the last 15 years within engineering (Beddoes et al., 2010; Kolmos & De Graaff, 2014). As with other L-C pedagogies, implementing PBL comes with a set of challenges, including a lack of faculty training or support, limited pedagogical content knowledge (PCK), and faculty concerns about how to fit the pedagogy within the context and constraints of their courses (Beddoes et al., 2010; Finelli, Richardson, & Daly, 2013; Henderson & Dancy, 2007; Hmelo-Silver, 2004, 2012; Murray & Savin-Baden, 2000; van Barneveld & Strobel, 2011). These challenges can either prevent faculty from implementing PBL or result in unsuccessful implementations. As a result, we need more research on PBL implementation in engineering.

Reviewing the current literature, we know that facilitation is an important and critical piece to the successful implementation of PBL (e.g., (Hmelo-Silver, 2004; Matusovich, Jones, Paretti, Moore, & Hunter, 2011). We have also identified the various roles that an instructor may enact when facilitating PBL (e.g., (Hmelo-Silver & Barrows, 2006). However, our knowledge is limited with regard to the strategies associated with *how* to enact these facilitator roles. While the literature on PBL facilitation is not void of studies on facilitation strategies in other disciplines, similar studies in engineering specifically are limited. Studies specifically examining engineering are important because there are unique considerations that need to be accounted for during PBL implementing within a discipline, including expectations of content coverage, hierarchical knowledge structures, common misconceptions of concepts, assessment and accreditation practices, disciplinary norms, student resistance, and class size (Dancy & Henderson, 2008; Savin-Baden, 2007; van Barneveld & Strobel, 2009). To address this research gap, the purpose of this manuscript is to understand the challenges associated with facilitating PBL in an undergraduate engineering course. We begin addressing this purpose by describing and analyzing a PBL implementation developed for a 5-week module within a course that was historically taught using lecture/workshop practices. The analysis was guided by the following research question:

RQ: What challenges arise in the practice (training and implementation) of PBL facilitation in an engineering course with a high student to faculty ratio?

Answering this research question provides insight into the unique considerations that we need to account for in developing strategies for PBL facilitation in engineering. In this manuscript, the following sections include an overview of literature relevant to PBL facilitation, a detailed account of the PBL implementation including specifics based on the context, a description of the data and analysis methods, a summary and discussion of the results, and concluded with recommendations for research and practice.

2.2 Literature Review

At the time of the PBL implementation studied in this manuscript (i.e., spring 2010) available research had revealed many facets of PBL facilitation roles. Although studies had begun investigating facilitation strategies connected with the various roles, the strategies were largely developed from studies on experienced PBL learners in medical education and with low student-to-faculty ratios. Consequently, it was insufficiently known how to translate these strategies for engineering education and in courses with higher student enrollments. Included in this section is a review the literature regarding the importance of facilitation in PBL; the roles associated with facilitation; and the strategies to enact these roles within medical disciplines and secondary-teacher education. It should be noted that the literature reviewed in this section was used to develop the PBL implementation and facilitator training that we examined in this analysis. As a result, studies conducted after spring 2010 are not included.

2.2.1 Importance of Facilitation

Facilitation is an important component of PBL pedagogy. In a study focused on student perceptions that explain faculty roles in a PBL course, it was found that "it was not just the PBL structure of having a facilitator, but rather the way that facilitators enact their role that is important" (Matusovich et al., 2011). The ways that facilitators enacted their roles had a strong impact on students' motivation, particularly their sense of empowerment and beliefs about success, as well as their awareness of self-directed learning processes and their ability to connect course work to professional practice. Additionally, it was found that PBL facilitation was able to shift students from being grade-focused to learning-focused, with this shift students engaged in more self-directed learning activities, which could lead to a greater sense of motivation.

As further support for the vital role of facilitation in PBL, in response to a claim that PBL is a minimally-guided pedagogy that "does not work," Hmelo-Silver, Duncan and Chinn (2007) argue that it is the scaffolding and guidance of the facilitator that separates PBL from minimally-guided learning approaches. Furthermore it is because of this active role of the facilitator that there is evidence that PBL does manifest positive learning outcomes in students. The question that still needs to be answered is, "What kinds of support or scaffolding are needed for different populations and learning goals?"

2.2.2 The Roles and Strategies of PBL Facilitators

Facilitators serve multiple roles in guiding students to achieve learning outcomes in PBL courses. To achieve the learning goals commonly associated with PBL, the facilitator needs to create opportunities for constructive discourse that supports student learning and collective knowledge building. An effective facilitator should have a variety of strategies that are flexible and can be adapted to different situations to achieve these different learning outcomes. Hmelo-Silver and Barrows (2006), showed that different conversational moves, particularly questions and statements, can be used to foster different learning goals. Particularly they identified the following strategies for instructors to facilitate PBL courses, 1) asking open-ended and metacognitive questions, 2) pushing for explanation, 3) revoicing, 4) summarizing, and other strategies that help to manage group process (i.e. check consensus that white board reflects discussion, creating learning issues, encourage visual representation). They found that these strategies can help to achieve a variety of goals including, 1) help students recognize limits of knowledge, 2) clarify knowledge, 3) subtly influence direction of discussion, and 4) help students synthesize information.

Hmelo-Silver and Barrows (2008) built on their prior work (2006) to further develop a more detailed list of categories of question and statement types that an expert facilitator uses. They identified 19 types of questions and 6 types of statements. This was an important work as it was one of the first to give a detailed analysis regarding the strategies of PBL facilitation. It does have its limitations though, as it was situated in only one discipline (medical education), with students that were experienced PBL learners and for a short duration. Though these strategies are a useful starting point, the limitation is in how they could be transferred for use with novice PBL students in different disciplines.

Different facilitation strategies will be needed with a change in context. In their study Zhang et al (2010) sought to understand how experienced facilitators used questioning to guide PBL group discussions in a teacher education course. Compared to the Hmelo-Silver and Barrows studies (2008; 2006) these students were novice PBL learners, as this was their first experience with a PBL approach, yet experienced learners as they were K-12 teachers in a continuing education course. In this study on facilitation of K-12 teachers, a new framework for PBL facilitation questioning strategies was developed. There were eight different question types identified; the most frequently used included soliciting ideas, reframing ideas, clarifying ideas, pushing for elaboration, and checking for interpretation. These question types are different but similar to the question types identified in the work by Hmelo-Silver and Barrows (2006). A significant finding in this study compared to the Hmelo-Silver & Barrows (2008) study was that a larger percent of the facilitator questions was used to help students become more self-directed in their learning; perhaps because the students in this study were new to PBL, they required more guidance in the type of learning expected of students in PBL. A limitation of this study was the short duration of the problem-solving sessions; each session lasted from two to three hours and involved solving one problem from beginning to end. However there was variety in that were three different problems and two PBL groups per problem. There is a need for additional studies to understand general strategies that are useful across a variety of settings (i.e. medical, professional teacher development, sciences, and engineering).

These prior studies suggest that facilitation is important, and supporting novice PBL-students as they learn to be self-directed in their learning is crucial in developing the learning outcomes expected of PBL. In each study mentioned above, the instructors were expert PBL facilitators, thus it would be prudent to provide adequate training to instructors that are new to PBL pedagogy. Though there is little in the literature regarding how to train PBL facilitators, the strategies mentioned above provide a place to start. However, it is important to note that there are limitations in using these strategies to train new PBL facilitators in engineering disciplines; specifically, these strategies were developed within specific disciplines and in both settings there were either one or two facilitators per group of 5 – 10 students. These strategies may be useful in engineering disciplines, but it will be important to consider how to adapt these strategies for different contexts, goals, and developmental level of the learners. Further hindering the ability to facilitate well is that typical engineering courses have more students than one instructor can facilitate well (Steinkuehler, Derry, Hmelo-Silver, & Delmarcelle, 2002). Further work is needed to investigate how to distribute facilitation and facilitate novice PBL learners in classrooms with one facilitator and multiple PBL groups.

In this manuscript we document our investigation of the literature on PBL facilitation, particularly what is known about problem-based facilitation in engineering, training novice facilitators for an implementation of PBL in an engineering course with a 30:1 student to instructor ratio and the challenges in training and implementation.

2.3 Methods

The current study emerged from a larger project that investigated the impact of PBL pedagogy on engineering student motivation, with a particular interest in women engineering students. We designed an implementation with three experimental conditions to enable us to examine the impacts of having a facilitated PBL experience compared with a traditional workshop experience. In the traditional workshop experience, which served as a control, students engaged in hands-on exercises, but workshop leaders operated more as monitors than facilitators. The three experimental conditions were designed to look at varying levels of problem-based facilitation and scaffolds in the classroom; they included a full PBL implementation and two modified implementations that focused on either the use of learning scaffolds or instructor facilitation. Results showed that there was a wide variation in facilitation practices among trained facilitators and student motivation was only partially linked to whether they were in an experimental group with trained facilitators. These initial findings led us to explore facilitator practices and the impacts of facilitator training on the instructors.

This current analysis is a single-case study of the full PBL experimental condition, which provided the highest level of facilitation and scaffolding (i.e. the training provided to facilitators and the supporting materials provided to guide students through the 5-week project, all developed using PBL literature). The case is defined as the three course sections where this full PBL experimental module was implemented, and it draws on three sources of data: observations in the classroom, facilitator reflections, and student interviews. The full PBL implementation will be described in the following sections.

2.3.1 Course Context

The setting of the PBL experiment was an introductory engineering design course that was part of a common first-year program for engineering students at a large public university in the United States, State University 2 (SU2). The total course enrollment across 37 sections was approximately 1,100 first-year and transfer engineering students. The students were general engineering majors, but were on track to declare a specific engineering major in one of 11 engineering disciplines in the college at the end of the semester. Learning objectives for this course focused on three topics: graphics, computer programming, and engineering design methods. Content for the course was divided into three 5-week modules; each module corresponded with one of the topics.

The students attended two weekly meetings: a large (100-300 student) 50-minute lecture at the beginning of the week and then a 110-minute workshop (~30 students/each) in the second half of each week. Lectures were led by one instructor and were designed to give the students an introduction to the content, with some instructor-student and student-student interaction. Workshops were led by another instructor, often a graduate student, and were designed to give the students hands-on learning experiences with the content introduced during the lectures. The workshop portion of the course was the setting for the PBL implementation, which occurred during the design module.

During a typical workshop meeting the instructor gave a mini-lecture, reviewing material that was provided in the large lecture, and introduced an activity that presented the students with an opportunity to work collaboratively. The activities were open-ended but limited-scope problems, designed for in-class learning to reinforce understanding of the concepts (Jonassen & Hung, 2008). The students worked in groups and applied the content presented by the instructor to the problems. During the activity, the instructor circulated among the teams to answer questions and provide assistance. Students then applied their content knowledge to their design projects outside of workshop.

In addition to the in-class group assignments, the course also included traditional out of class homework assignments, and midterm and final exams. For the design module, students were also given a significant open-ended design problem typical in first year engineering courses, such as 'design a device to assist seniors with arthritis in opening a window.' Though the design module included a design project, it also included traditional elements including homework assignments and exams.

The workshops met in classrooms that were designed to facilitate group work. The rooms were set-up with tables forming clusters, such that the 30 students were divided into 6 to 8 working groups, but the rooms could be quickly reconfigured, as the tables and chairs were on wheels. A summary of the course features are listed in Table 2.1 below.

Table 2.1 - Summary of Course Features.

Course Features
1. Introduction to engineering design
2. Enrollment: 1,100 first-year and transfer engineering students
3. Students intending to pursue one of eleven different engineering majors
4. Learning objectives: graphics, programming, design methods
5. One 1-hr lecture per week with one instructor and 100-300 students
6. One 2-hr workshop per week with one instructor and 30 students
7. Workshop instructors were generally GTAs
8. Workshop classrooms designed for group work

2.3.2 *Implementation of PBL within the Course Context*

To create our PBL implementation design, we considered findings from both literature and an observation of a PBL practice in an introductory engineering course at another university (Barrows, 1992, 2002; De Graaff & Kolmos, 2003, 2007; Du, de Graaff, & Kolmos, 2009; Hmelo-Silver & Barrows, 2008; LaPlaca, Newstetter, & Yoganathan, 2001; Matusovich et al., 2011; Newstetter, 2005; van Barneveld & Strobel, 2009; Wilkerson & Gijselaers, 1996). In the design we focused on understanding PBL theory from the literature and implementation methods for engineering from observing PBL practice, in such a way to maintain consistency with PBL philosophy, while making adjustments to fit within our context. Our implementation was focused on the design module and situated in the workshop portion of the course. The course was taught in the traditional way for the first 10 weeks, and in the last 5 weeks we implemented PBL. The most critical change from the traditional model was to move the design project from an out-of-class assignment to the focus of all in-workshop activities such that students were able to gain design method knowledge and understanding (i.e. course content) through working on the project under the facilitation of the workshop leaders. This context resulted in three implementation considerations for the PBL module that directly impacted facilitator roles and training.

First, students were faced with a new type of problem. Consistent with PBL philosophy, the statement for the design problem was open-ended, authentic to practice, and complex with multiple possible solutions (Jonassen & Hung, 2008; Jonassen, Strobel, & Lee, 2006). This problem was in contrast to prior semesters and the control sections during the intervention semester where the problem statements were open-ended with multiple possible solutions, yet smaller in scope with fewer design considerations and often less complex and diverse solutions. Additionally, the complexity of the problem made the projects large enough that it required participation of all the team members (Hung, 2006; Jonassen et al., 2006). The new problem statement posed to the PBL students focused on safety of emergency rescue squads, particularly during patient transport in ambulances (Appendix A). Specifically the problem asked the students to "design a device, system and/or process that improves the safety and effectiveness of the EMS personnel and/or the safety and comfort of the patient during transport to the hospital." The students were tasked with scoping the large open-ended problem to a specific issue, which was unlike prior semesters and the control sections during the intervention semester. This breadth also meant that the instructors had to help students not simply solve a problem, but learn to define it in a different way, and had to manage a broader range of potential projects. Similar to prior semesters, the students then worked toward a solution and culminated their efforts with a design report and presentation. To facilitate the learning process, the students were given the opportunity to meet with local Emergency Rescue Squads for a demonstration, display, and Q&A session.

The interactions with the Rescue Squad personnel and the ambulance provided the students an authentic to practice experience of meeting with a client and discussing the problem to be addressed.

Second, the workshop sessions were restructured and required that the workshop instructors switch instructional modes and enact PBL facilitation for the final 5 weeks of a 15-week course. Lecturing was removed from the workshops and replaced with new learning scaffolds, and instead of completing the traditional in-class "practice" activities, students worked toward a solution for their design problem. The students' project work was facilitated by their workshop instructor. In this new structure, during workshop each group was working on something slightly different, rather than a common canned exercise. For the facilitators, this diversity was an added challenge as they could not as easily predict what kinds of problems and questions students might have. In addition to facilitation, the students work was also scaffolded by a PBL learning cycle. The learning cycle was developed based on a combination of our own analysis of an established PBL course and findings from literature (e.g. (De Graaff & Kolmos, 2003; Duch et al., 2001; Hmelo-Silver, 2004) and included the following steps: 1) discuss observations about the problem, 2) determine constraints and requirements of the problem, 3) probe knowledge and reasoning, 4) generate a list of concepts that need to be explored, 5) assign concepts for research, 6) research to fill knowledge gaps and report back to group, 7) reflect on group process, 8) further cycles of observations and research, and 9) present solution. Structuring the learning cycle in this way brings student learning closer to PBL philosophy by making the problem statement the impetus of learning, requiring students to self-determine what knowledge is needed to solve the problem and self-directing the investigation and integration of new knowledge. The learning cycle and the instructor facilitation acted to scaffold the teams' activity during the workshop. Additionally, traditional homework assignments were removed, though for consistency across the full course, the students still had a traditional final exam where they were tested on design methods.

Additionally, the role of the facilitator was further challenged by the large course enrollment. In a typical PBL course, the student to facilitator ratio would be 8:1 (or less) (Barrows, 1996; De Graaff & Kolmos, 2003); however, we were constrained by the 30:1 student to instructor ratio in the workshop setting. Students in each workshop section were divided into six teams of approximately five students each, such that there was a 6:1 team to facilitator ratio. However, having multiple teams per workshop instructor meant that we expected the instructors to act as *floating facilitators* where they would circulate from team to team during the 110-minute session. As a floating facilitator, they worked with teams in shorter segments of time, but were still expected to use metacognitive questioning strategies while monitoring the teams' problem solving process, which is common in PBL (Hmelo-Silver, 2004; Hmelo & Ferrari, 1997). Additionally, to provide more one-on-one guided time the instructors provided two out of class meeting times during the duration of the project, where each team could meet for 30 minutes with their instructor.

Finally, because the floating facilitator method did not allow for constant facilitator presence with each team, the teams were provided with handouts for more constant guidance. The handouts were a type of distributed facilitator that is used when the learning process is asynchronous or the instructor is not continuously with the team (Barrows, 2002; Steinkuehler et al., 2002). In this course, the handouts guided the steps in the learning cycle and acted as a scaffold in the absence of the facilitator and asked the types of questions a facilitator would ask. The facilitators provided handouts to the teams in phases to guide the steps in the PBL learning cycle; each handout focused on a specific step of the learning cycle most likely to be applicable at that point in the project (e.g. during the second week, the handout included questions and activities to help students determine the constraints and requirements). At the beginning of each workshop students received the first handout, and prior to receiving the next handout the group needed to demonstrate that they had adequately completed the prior phase; each week the students would work through up to 4 phases. A sample of the handouts is included in Appendix B. Note that the students did not work through each step of the learning cycle during each workshop meeting, because some steps required more time than others. Outside of workshop meetings, students continued their work toward a solution and built on the work that occurred during workshop.

2.3.2.1 Training of Floating Facilitators

The "floating" facilitator role is significantly more challenging for instructors, because they have to jump into group discussions and quickly ascertain how the group is doing – what the group has already done and what their projected path forward is likely to be – and decide how to effectively facilitate the group at that moment. And in any given workshop session, they have to be prepared to do that for six different teams. We prepared the instructors with training on how to prepare students for self-directed learning, general philosophy and methods of PBL pedagogy, facilitator roles and strategies for PBL, a primer on the problem statement the students solved, and specific facilitation strategies relevant to the problem statement. Additionally, we provided tips for how to be a "floating facilitator," facilitating multiple teams simultaneously. All training was grounded in the available literature at the time. Facilitator training occurred in two phases. The first phase started at the beginning of the semester, prior to the implementation of the PBL module, and the second phase occurred during the implementation of the PBL module.

All three instructors trained to be facilitators were PhD students in engineering with an M.S. in a traditional engineering discipline and varied work and teaching experiences. For their doctoral work, two facilitators were studying engineering education and one was studying in a traditional engineering discipline. As for work experience, one of the facilitators had several years of experience in the engineering field, while the other two had experience in engineering research labs in academia. All of the facilitators had prior teaching experience at either the high school or college level. Two were new to this particular course, while one had four semesters of experience in this course. All three facilitators were new to PBL facilitation.

Phase 1 Training

The first phase of training occurred in biweekly sessions with author Paretti for a total of five meetings over ten weeks. The training included: 1) discussions on how to influence classroom atmosphere in a way that prepares students for self-directed learning, 2) reading and discussing research articles about PBL pedagogy in general and more specifically about PBL facilitation roles and strategies, and 3) an introduction to the problem statement that the students would be given and working through part of it with the trainer as facilitator and the instructor as students.

With regard to influencing classroom atmosphere two topics were discussed: facilitator-student interaction and setting the classroom environment as a learning space and not a lecture/grading space. In a prior study, we found that students in traditional first-year engineering courses saw the role of their instructor as a person of authority who evaluated their work. In contrast, students in a first-year PBL engineering course saw their facilitator's role as providing models of engineering problem solving processes. The trainer discussed with the instructors how to position themselves not as an authority or grading figure but as a guide and role model there to facilitate student learning. The atmosphere that the instructors were encouraged to create was one of mutual shared knowledge, where they were not the provider of knowledge, but that knowledge could be co-created in a cooperative space. Additionally, the trainer reminded the instructors that the students are used to instructors who give them the answer and will want the same from them, thus the instructors will have to draw them into discussions.

Regarding PBL facilitator roles and strategies, the instructors were first asked to read articles about PBL pedagogy and watch videos of PBL in practice with a focus on the structure of the instruction. These articles and videos were meant to give them a broad overview of how the student-facilitator interactions foster a self-directed learning environment and the learning outcomes expected of the students. The instructors also discussed the general learning cycle for PBL of students to determine what they know, what they need to know, and how to learn what they do not know; then assign learning tasks; and finally report the results of the learning tasks back to the group, where the instructor acts as a guide of the learning process. The instructors then discussed the following roles:

- monitoring group process – such that all group members participate, everyone's' ideas are heard through collective sharing and the ideas are captured,
- encouraging and mentoring the students,
- guiding the learning cycle, and

- pushing student to expand thoughts and ideas by asking questions and not providing explanations.
- providing models/examples from engineering practice to aide students' development of conceptual understanding

More specifically the instructors discussed different discourse moves that can be used as strategies to enact the facilitator roles: these discourse moves were questions or statements based on Hmelo-Silver and Barrows' (2008) exploration of facilitator behaviors. Questions are designed to open up, constrain or guide discussion and problem solving process. One way questioning can be used is to prompt students to think about what they need to know, where they will go and what they will need to look up to find the knowledge. It is important to listen to what they are saying and ask them questions that guide their problem solving path or that reminds them of a key piece they have forgotten. Hmelo-Silver and Barrows (2008) mention three types of questions: short answer or long answer or regulatory/meta questions. Short answer questions prompt students to respond with short answers such as verification, specification or quantification. Long answer questions prompt students to respond with more elaborate types of responses such as definitions, examples, or interpretations. And regulatory/meta questions prompt students to discuss or negotiate group dynamics, monitoring progress, or define self-directed learning goals. Statements are designed to initiate episodes of knowledge construction. Statements include an assertion, elaboration of an idea, or reformulation. An example of an elaboration of an idea might be to get them to articulate a concept and then giving them the specific word for what they have described. An example of a reformulation is "What I hear you saying is …" and can be used to connect the ideas of multiple students.

For the last training meeting in the first phase, the instructors talked through the ambulance transport problem statement together with the trainer, focusing on both how to approach solving the problem statement and how to facilitate students' engagement with the problem statement. The trainer gave the instructors the problem statement, asked them to read it and then to start discussing how to solve the problem. As part of the discussion that trainer highlighted the various design steps the students would be expected to go through in solving the problem – research, scope the problem, identify constraints and requirements, generate solutions, explore, evaluate, feasibility. While the instructors were discussing their approach to a solution, the trainer facilitated the problem-solving process. In this way the instructors were able to both experience facilitation and observe how to facilitate learners through problem-solving. When the instructors faced cross-roads in their problem-solving, the trainer prompted them to discuss how to they would facilitate their students through similar situations. Additionally, the trainer brought up potential challenges in facilitating novice PBL students and prompted them to articulate how they might handle those challenges. However, while the trainers were able to experience *being* facilitated, they were not given an opportunity to role play as the facilitator while others worked on solving the problem.

Phase 2 Training

The second phase of training began one week prior to the start of the PBL module and continued through the duration of the module. The facilitators met with authors Williams, Hunter, and Paretti weekly for five weeks, with each session lasting one-hour. During this phase the focus of the weekly meetings was on 1) instructor self-reflection on their role as facilitator, 2) the learning cycle, and 3) specific facilitation strategies related to the problem statement. This training was more of a just-in-time training to help the instructors reflect and process the prior week and to prepare them for the coming week.

At the start of these training sessions, the facilitators were asked how the prior week went for both them and their students. During this time the facilitators were able to discuss their classroom experiences (e.g. what went well and what were the challenges) and to strategize ways to handle the challenges in the coming week. These discussions also gave the trainers an opportunity to provide additional training focused on the specific challenges.

The second part of the phase 2 meetings focused on the distributed facilitator handouts that acted as a guide through learning cycle for the students. The facilitators were given the handouts that they would distribute to the students and the trainers walked through them with the facilitators. The trainers gave an overview of the learning objectives and the student deliverables associated with each handout.

In the last part of these meetings, the facilitators were given a resource that was designed to aid them in guiding the students' use of the distributed facilitator handouts, and the trainers would walk them through the resource and field questions. The facilitator resource had three components: a guide for the learning cycle the students would progress through, additional information about the design method content the students used, and additional suggestions about facilitator techniques at particular phases in the learning cycle. The facilitator resource corresponded to the phases in the distributed facilitator. It provided the facilitator with information about the work students would complete in each phase and suggestions on ways to provide feedback or help to the students if they were stuck or headed in a wrong direction; it also helped the facilitator with ways to know if the students were ready to move to the next phase of the learning sequence. Also included in the facilitator resource were helpful reminders of big picture facilitation strategies and possible types of questions to ask during different phases of the learning sequence. Big picture strategies included the following: listen to the students, be slow to speak, use questions to guide students, and don't just give answers to their questions. The guide also included questions to ask in certain situations, and general types of questions to ask. In particular phases where we presumed students might get stuck or take wrong paths we suggested ways the facilitators could model the process for the students or types of questions that might help to coach the teams toward a solution. Example questions were: What is the root of the problem? What is the context? Who are the users? Who else do the design decisions effect? A sample of the facilitator resource is included in Appendix C. Each week the facilitators received a new resource based on the current step of the learning cycle for the students. In the first two weeks there were much more detailed techniques and sample questions. The reason was that all the students started with the same design problem statement and would walk through the same steps toward a design, but as the weeks progressed the students' designs would begin to diverge and different teams would need different type of help.

2.3.3 Data

As part of a larger NSF-funded study, multiple sources of data were collected. To understand the training and practices of the trained facilitators in the current analysis we used three of these sources: facilitator training sessions, observer reports, and student interviews.

The facilitator training sessions were a source of data that provided the perspective of the trained facilitators. The instructors met for a combined total of ten facilitator training sessions with authors Paretti, Williams and Hunter. In Phase 1 training, two of the five one-hour sessions were audio recorded and later transcribed. During Phase 2 training, all five of the one-hour sessions were audio recorded and later transcribed. Though the training sessions mainly focused on instruction and practice on problem-based facilitation roles the facilitators were regularly prompted to reflect on this their experiences in the workshop as well as their perception of their students' experiences.

Observer reports included both observer field notes, which addressed facilitator behaviors and student interactions during the workshop observations and an observer report-out meeting at the end of the implementation (Patton, 2002). Observations of the workshop meetings were conducted each week during the five-week implementation of the PBL module; the weekly workshop meetings lasted for 110-minutes. In the workshop meetings all six teams were present with the facilitator. Two teams per workshop section were enlisted to participate in the observation portion of the study, for a total of six teams. Observations focused on the interactions of the facilitator with the students, interactions of the students and facilitator with the handouts, and student-to-student interaction. The observations were recorded (audio and video) and field notes were written by the observers. However, because there were many teams meeting in a confined space, excessive background noise made it impossible to transcribe the audio and video recordings. Consequently, this analysis relies more heavily on the field notes, which included comments regarding instructor roles, student use of learning strategies, and students' beliefs and values related to engineering. In addition to the field notes, the four observers met with a member of the research team after the implementation concluded to discuss trends in their observations. This was a one-hour meeting that was audio recorded and later transcribed, and that transcription is also included in this analysis.

The final piece of data came from semi-structured student interviews (Patton, 2002). Six students who were part of the observed teams also participated in end-of-semester interviews, and three of these students participated in follow-up interviews one year after the course. The focus of the interviews was on motivation and intent to remain in engineering, but students were also asked about their classroom learning experiences and interactions with their facilitator and design team. Interview prompts regarding learning and interactions with facilitators included: “Describe your interactions with your course instructor.” and “How would you describe your learning process in this course?” Each interview was approximately 45 minutes long and was audio recorded and transcribed verbatim.

2.3.4 Analysis Methods

The analysis generally followed guidelines suggested by Miles and Huberman (1994) including data reduction and displays and drawing conclusions. The first step of data analysis was to segment the transcripts of all three data sources (i.e. facilitator training sessions, observer reports, and student interviews). These transcripts were segmented into three categories: 1) reflection on facilitator behaviors, 2) reflection on student responses to facilitation, and 3) context-dependent challenges. Reflection on facilitator behavior included statements from the facilitators, observers, or students regarding instructor teaching/facilitating practices and absence of facilitation, including interactions or lack of interactions with the students. Similarly, reflection on student responses included statements from the facilitators, observers, or students regarding student behavior in response to the facilitator behaviors. Lastly, the challenges category included statements regarding factors that made teaching or learning in this setting challenging for the facilitators or students (e.g. students thought they did not receive adequate time with their facilitator). After segmenting the data, first author, Hunter, open coded each group of segmented data to identify themes related to the categories. Next, Hunter triangulated the data looking for similarities and differences in themes across the three perspectives (e.g. observer, facilitator, and students). Triangulation of the three data sources (Patton, 2002) contributed to the trustworthiness of the analysis by showing that multiple perspectives converged. Additionally, Hunter regularly met with authors Paretti and Matusovich for researcher triangulation (Patton, 2002) regarding the emerging themes. A representation of the analysis method is depicted in Figure 2.1 below.

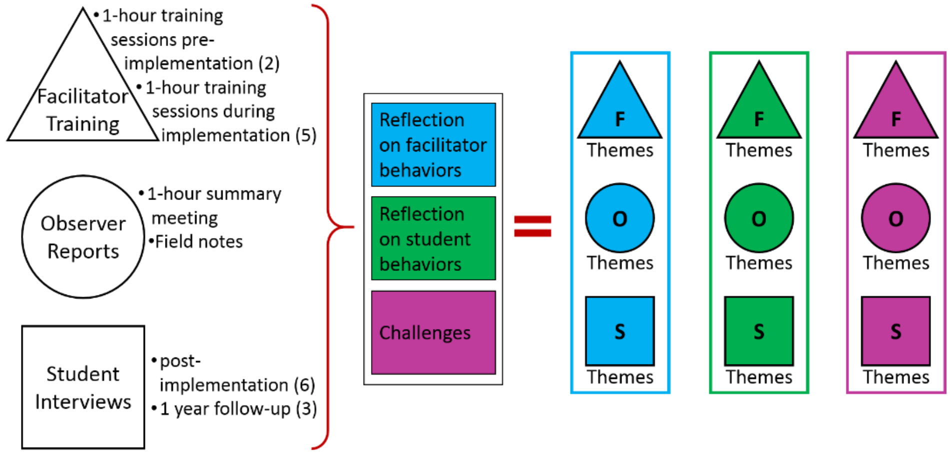


Figure 2.1 - Data analysis methods

2.4 Results

Using the methods mentioned above Hunter used three perspectives on the implementation and identified: 1) instructional behaviors enacted by the three trained PBL facilitators, 2) student responses (or lack of response) to the facilitation strategies, and 3) challenges with the training and implementation that were dependent on context. Instructional behaviors of the facilitators included facilitation behaviors that aligned with the topics discussed in training and behaviors that were counter to the training. For the students, Hunter identified a shift in some of their behaviors; however, some negative behaviors or attitudes persisted. Lastly, there were three specific context-dependent challenges that emerged. Results for each of these topics are summarized in the following sub-sections. In this section, direct quotes from the participants are used, each is identified with a pseudonym to protect their identity while assisting the reader in identifying when the voice of a participant belonged to someone different.

2.4.1 Reflection on Facilitator Behaviors

The instructors participated in ten facilitator training sessions over fifteen weeks. The reflections on the facilitator behaviors indicate that there was some success in the training, as some of the facilitator behaviors aligned with the topics discussed in training; however, there were also two behaviors identified that were counter to PBL philosophy. The facilitation behaviors enacted by the instructors that aligned with the training included 1) using questioning strategies to engage students in meaning making, 2) coaching to guide student learning and facilitate the team process, 3) using examples from engineering practice to help further student understanding, and 4) providing feedback on student progress. Although a variety of PBL facilitator behaviors were identified, in their interviews, students generally spoke of limited interaction with their facilitators; only after several prodding questions were we able to get students to speak more specifically of their interactions with their facilitator.

Overall, the most widely used facilitation strategy was **questioning**. When asked about her interaction with her instructor, a student responded,

> *"She would ask us leading questions…She would inquire about our projects, so we would have to think about things that we might not have been thinking of, rather than just saying, 'Did you think about doing this?' She let us come up with it on our own. But she asked questions." – June*

Here June portrays her facilitator as a questioner, asking leading questions to get the students to think more deeply about their design decisions, rather than telling them what decisions to make. Additionally, a facilitator described how they used questioning strategies during an interaction with students to push their understanding. This facilitator asked their students, *"'What's a way you can measure that, how can you quantify that?' … I had to pull it out of them" (Facilitator).* This facilitator's aim was to draw out knowledge and understanding held by her students and avoided simply giving students information. This behavior was confirmed in the observer report-out meeting as well, where there was consensus among the observers that questioning was the primary strategy used by all three instructors.

The instructors also acted like **coaches** to guide and direct student learning, approach to solving the problem, and team interactions. One student's perspective on her team's interaction with their facilitator was, *"He would be like trying to pry questions out almost like he was pulling us with a rope trying to pull us along" (Teagan)*. Additionally, another student described the role of her instructor as, *"Sort of facilitate our discussion a little bit, and get us moving" (June)*. Here these students describe their facilitator's behaviors as one who was guiding their teams through the learning process; the facilitators were not necessarily telling the students *what* step to take next, but offered encouragement to take steps and make further progress. In addition to this coaching of the problem solving and learning process, a facilitator described their role as a coach or mentor of the team dynamic in this way: *"Two teams were really quiet and I have to go over there and get them to talk."* Another facilitator had this to say in regards to managing team dynamics: *"I've gotten some of the really overt people to kind of step back and go 'Okay, wait a minute. I need you to talk too'" (Facilitator).* Here the facilitators talk about their roles in coaching the teams on peer interactions and cooperative learning. With some teams they encouraged students to speak up and participate in the co-construction of knowledge and solving the problem. With other teams the facilitators had to nurture an environment where all team members had space and were held accountable to participating in the team process. The observers did not directly describe the instructors enacting coaching roles; however, it is possible the observers simply did not mention these roles.

The facilitation strategy of using **examples** from engineering practice to help further students' understanding was observed primarily in two of the instructors. In the observer report-out meeting, two facilitators were cited as using *"a lot of life experiences. Even if it wasn't from [their] direct experiences, [they] would use [their] friend's experiences or practical applications and parallels" (Observer).* As an example of drawing on examples one instructor shared the following interaction during reflections,

> *"Some of them were like, 'Okay, so do we have to do those charts?' and I was like, 'Well what are the charts doing?' I had to go through and try to pull it out of them, 'Why do you need these charts?' And they just couldn't understand, so I had to be like, 'Well if you're taking this to a client how do you tell them this is the best?' And they were like, 'Well it's obviously the best because it meets all our criteria the most'. I was like, 'But how do you know that? How can you quantify that? Can you say it's so much better than another one?'" – Facilitator*

Here the facilitator developed an example situated within a professional engineering context to help the students better understand what they needed to do and why. In the student interviews there was no direct mention of this facilitation strategy.

Lastly, it was mentioned in both the student interviews and the instructor self-reflections that the instructors provided the students with **feedback** on their problem solving processes in order to help the students develop deeper understanding of their design decisions. Teagan described the way her facilitator provided feedback on her team's design by making suggestions for how to expand on or shift the direction of their design process saying, *"He gave us lots of feedback… 'Have you thought about this? Have you looked into this, it already exists?'" (Teagan)*. A facilitator described one way they gave feedback to their students was through written comments on their team Google document.

> *"I think one thing I found reviewing the doc and things like that was not all teams did a really good job of categorizing their questions and then dividing those up so I made comments on their document." – Facilitator*

It was necessary to give feedback to the teams on both during workshop and in their written records, since the amount of time a facilitator could spend with each team was limited.

However, there were two instructor behaviors that are counter to PBL theory and the facilitator training that emerged from the data; one an active behavior and one an absence of a behavior. The first was an active behavior where the facilitators were described as giving students answers when they were unable to answer questions prompted by the facilitator. As an example, in the observer reports it was mentioned that one facilitator *"just kind of went in there and said, 'all right, we're doing these weightings, these weightings, these ... this, this, and this'" (Observer)*. Here an observer notes that instead of guiding students through the logic of making decisions the facilitator resorted to giving the students answers. Additionally, at times in the instructor self-reflections, instructors described their interactions with the teams as them *telling* or *explaining* to the students, which is in contrast with PBL theory that emphasizes self-directed learning. A facilitator described this type of interaction saying, *"I had to just go to each group and sit down with them and explain" (Facilitator).* This was also brought up in the student interviews where Edward said, *"We'd ask [our instructor] questions about our stuff … during the group meetings, [they] would explain it in more detail."* Here instead of guiding students toward self-directed learning behaviors and helping the students discover the answer to their questions, the student described his facilitator as one who conveyed knowledge and understanding.

A second disconnect between instructor behaviors and PBL facilitation was an absence of facilitator behavior, where the facilitators did not prepare the students well for a PBL style of teaching and learning. This theme emerged from both the observer reports as well as the instructor self-reflections. The observers reported the absence of facilitators preparing their students for the change from traditional workshop pedagogy to PBL pedagogy at the start of the design methods PBL module. PBL pedagogy requires different behaviors and skills for both the facilitator and the students. At the start of the PBL module the facilitators did not explain to the students the switch in pedagogy, specifically what they were doing, why they were doing it, and the expectations of the students in regards to the PBL structure. Upon reflection a facilitator echoed this sentiment stating, *"I probably didn't do a good job of prefacing it at the beginning saying, 'Now it's all up to you guys to start learning on your own'" (Facilitator).* In hindsight this facilitator realized that there was more they could have done to prepare the students for the PBL self-directed learning style.

2.4.2 Reflection on Student Behaviors

In response to the facilitator behaviors, shifts in student behaviors toward self-directed learning and a deeper interest and engagement in the learning process were expected when compared to students in a traditional lecture-workshop format course. For the students in this experiment change was slow, which is not surprising considering these are first-year college students and that the PBL learning module was only five-weeks long which is a relatively short time period to see changes in behavior. However, changes in students were identified, both positive and negative. Students were initially 1) resistant to self-directed learning and 2) disengaged from learning, but 3) shifted to becoming more self-directed and engaged. There was however a negative effect of becoming self-engaged such that students became 4) overly independent of their facilitators. One behavior we hoped to see change was a shift from being 5) grade-focused to learning-focused, but this did not occur as students remained very grad-focused. This was a consistent behavior throughout the semester and during the PBL module was manifested in the way the students used the handouts as checklists for earning grades with a 6) 'just-get-done' mindset.

At the beginning of the PBL module the students were described as both resistant to self-directed learning and disengaged. A facilitator described their students' **resistance to self-directed learning** saying,

> *"They said, 'We get these worksheets and you just kind of expect us to go through the worksheets. There's all these words that don't matter.' And I was like, '[I'm not] able to be there for you all the time.' And they said '[We] just didn't like the set up.' And I asked them 'Would you prefer this, or this, and they said they preferred the standard thing kind of set up." – Facilitator*

In showing preference to didactic teaching and learning another student even stated that he thought it *"would have been better if the [facilitator] had told us this is what you need to" (Edward)*. Not only did the students have a preference toward traditional modes they also grew frustrated with the expectation to be self-directed in their learning:

> *"Like we needed to already know it to be able to use it as a team, but they wanted us to learn it through the experience of the team project, I guess. So, I definitely get what they were trying to do, but at the time it was kind of just frustrating, and kind of just like, let us just figure it out, you know?" – Audrey*

These quotes show that students had a strong preference toward the didactic type of instruction they are accustomed to and they felt frustrated with having greater expectations of their participation in constructing knowledge.

In addition some students were also **disengaged** from learning in the classroom; this disengagement was seen mostly by the facilitators. A facilitator described one team saying,

> *"I'd come over and it'd seem like they weren't really doing anything until I came over and then they were like, 'Oh yeah, we need to do work.'" – Facilitator*

Another facilitator saw something similar about their teams saying,

> *"They'll do their research and stuff and bring it back, but they don't seem like they spend a lot more time on it. I definitely have one team that sticks out where they just don't want to do anything." – Facilitator*

The prior two quotes indicate that the students choose not to engage with learning during or outside workshop. Instead of saying 'we want our facilitator to tell us what to do' the students responded by doing nothing at all, thus disengaging from the learning process. This disengagement was also seen by an observer who noted students consistently coming in to class late or being absent, saying:

> *"I think I saw one team where everyone was involved, but the other ones were showing up late. One week a team with six people had two people absent. Another team, two of them kept showing up consistently late." – Observer*

This quote indicates that some students had a lack of commitment to the team and in general disengaged from the team learning process by not being present and participating.

However, as the project progressed there was some **shift in the student behavior**, where students slowly became less resistant to self-directed learning and more engaged with the learning process. An example is student response to the facilitators pushing for them to back their arguments with engineering logic. One facilitator described this shift in student behavior saying,

> *"I had to push my teams … 'Is there a way you can build off not just your own intuition, but can you pull research to justify your numbers.' They were like, 'Aren't we just making this up?' I said, 'You're not making it up.' I was like, 'What can you use?' And they were like, 'Well I guess we can look up some things.' [And I said], 'Yeah, use real sources and some engineering judgment may come into play there.'"*

Here the students responded in a way that indicates they knew the facilitator would not simply give them an answer, but that the responsibility was on them to find an answer. Additionally, students became more engaged in the learning process, even self-initiating research tasks to find answers to their questions, as noted by another facilitator saying:

> *"They're more apt to do research now as we work through the process. They're going to go back and 'Oh, I need to look that up.' I asked them 'What about this?' And before they would just stand there and look at me like 'What, I don't know what the value of that is.' But now they're like, 'Oh, I'll look that up now.'" – Facilitator*

In this quote, the students seem more engaged in the learning process and not sitting back waiting for something to just happen.

However there were also negative changes in the students' behavior, such that they were described as becoming **overly independent of the facilitators**, which led to students' understanding and decisions often going unchallenged. One observer described this student over-independence saying: *"They were going along; they were doing their own thing" (Facilitator).* This facilitator thought the students' behavior indicated that the students thought they did not need the guidance or expert opinion on their design decision. This idea was even echoed in the student interviews. Several students talked about not needing the help or interaction with their facilitator, saying:

> *"Coming up with our own design on our own and we didn't really have to get much approved by our [instructor], that was actually pretty nice because we were on our own by the end of the semester just doing whatever we wanted." – Joni*

Additionally, Naomi was asked if she used her facilitator as a resource in the learning process and she replied,

> *"There was never anything that major that I couldn't either figure out on myself or have somebody that was working on the same thing kind of point out my mistake." – Naomi*

These two quotes show a lack of student interactions with their facilitators regarding course content and engineering design processes and decisions. Joni and Naomi's perception was that their facilitators were not there to provide input or guidance on their project, but that their teams were fully capable of making decisions unchallenged by their facilitator.

Although the students thought they were capable of such independent work and preferred to work in this way, they still sought facilitator input, but only as a means to ensure they would end up with a good grade. In this independent phase, a student described the types of questions they had for their facilitator saying,

> *"We'd have questions about interpreting the directions of our assignments. …Were we doing it the way that we were supposed to be doing it to get a good grade on it." – Naomi*

The independence seen in the students can be more attributed to their desire to do exactly what was necessary on the assignments and nothing more to get good grades, than to an over-confidence confidence in their ability to work independently. This sentiment is reveal by Audrey saying,

> *"We just wanted to do a good job and get a good grade… I wanted to get it done quickly and not have any big problems." – Audrey*

Here it is seen that the students' efforts were more focused on receiving a good than on the learning outcomes. The students' independence and lack of interaction with the facilitator seems to be connected to not want push back from their facilitator that would cause them to do extra work or to think deeper. Additionally, the prior two quotes reveal that a majority of students were very **grade focused as opposed to learning focused**. Both the facilitators and observers described this student focus on grades. An observer noted that students confronted their instructor during workshop concerning their grades saying,

> *"Even on the day of the presentation, they started criticizing him for the way he graded their paper, and would not let it go." – Observer*

A facilitator also noted their students' focus on grades saying,

> *"They're so tripped about grades. It's been pretty continuous from the first week [of the semester]. Started off, if you get a 90 then it's an A." – Facilitator*

These two quotes show that even from the start of the semester students were more concerned about their grade than their learning outcome, and that even through the end they were fighting for points as opposed to conveying their learning gains.

In line with being grade focused, another behavior that was consistent for a majority of the students throughout the experiment was using the handouts as check-sheets with a **mindset to 'just get done.'** When a facilitator pushed their teams to go deeper with the tasks in the handouts, some groups responded saying, "they wanted to be done" and move on to the next handout without demonstrating that they had completed the learning task on the prior handout. One student said regarding her use of the handouts,

> *"They were helpful…but the sheets just made you have to hit all the objectives before you left, because chances are you weren't going to be meeting out of class." – June*

Here June indicates that her use of the handouts was more focused on 'covering topics' than reaching for deeper knowledge or understanding. Additionally, there is a lack of interest in carrying the learning forward outside of workshop. The students seemed to believe that simply completing the items on the handouts would equate to a good grade and that learning was not a priority. This is seen in a quote by Naomi describing her use of the handouts and her limited interaction with her facilitator.

> *"I think, really the only questions that we had that we couldn't look up were those questions about wording [in the handouts] and were we doing it the way that we were supposed to be doing it to get a good grade on it." – Naomi*

Here Naomi speaks of wanting to do the tasks on the handouts well and only getting input from the facilitator when they were unsure about wording in the handouts; in this way the tasks became a checklist for them to complete to achieve the grade they desired as opposed to tasks that would guide their learning and the potential for additional tasks to deepen their understanding. However this sentiment is not true for all students, a student experienced the class as changing her mindset saying,

> *"That class was kind of instrumental to changing my mindset that an engineering degree isn't about a checklist of textbooks, and a checklist of technical information, it's about gathering a toolset, and gathering up a knowledge, a game plan, a strategy for attacking problems." – Teagan*

Here Teagan sought to have a learning experience that reached beyond grades or a check list of textbook information; she desired knowledge and understanding that would be meaningful and useful to her future career.

2.4.3 Context-Dependent Challenges

In the data analysis three themes emerged in the context-dependent challenges category, 1) the student to facilitator ratio greatly limited the amount of time the facilitators had to spend with each team, 2) the facilitators lacked feedback on their facilitation practices, and 3) students' poor perception of the course in general.

The **facilitators had limited time with each team**, as there was a larger student to faculty ratio than is typical with PBL and thus multiple teams with one facilitator. The facilitators struggled to manage and spread their time effectively across all groups and the students struggled to gain the attention of their facilitator when needed during workshop. This theme was mentioned in all three data sets. A facilitator described the workshop saying, "They were not happy 'cause they said, 'You can't get around to all of us at once and we all have questions'" (Facilitator). A similar sentiment was heard in the student interviews where a student stated,

> *"They'd go around and they'd like help you if you had questions, but everybody had questions, and it would take forever to get help. I just didn't feel like, I don't know it was really frustrating." – Edward*

The students felt frustrated by the lack of time and attention they received from their facilitator, likewise the facilitators felt the pressure in sharing their time equitably among the six teams. From the perspective of the observers they thought "three teams may be doable, but six is too many."

The second challenge emerged from the instructors' self-reflections and also the observers' reports, that the facilitators felt a **lack of feedback on their PBL facilitation practices**. One observer stated that a facilitator "asked me how they were teaching" and another observer seconded saying, another facilitator "was curious on how things were going." This was also brought up during the training meetings when an instructor directly asked for help in managing a problem with one of their teams, they asked,

> *"What are some other strategies for getting a really quiet person to speak up? 'Cause in my meetings I've had some people who just sit back and even when I ask them, 'what are you thinking, can you give me some idea', they just sit there and. I mean I even tried to switch up the order in the meetings, where I have that person try to say something first, and they're like 'I don't know what I'm thinking' they just didn't seem to want to engage." – Facilitator*

Here during the training the facilitator openly asked for feedback. Because the trainers were not observing the facilitators in the workshop, the facilitator had to describe the situation and what actions they had tried in this particular situation. This is poignant, because in this implementation the observers were not positioned to provide feedback to the facilitators and those that were positioned to give the facilitators feedback (e.g. trainers) were not observing the workshops.

The third challenge was in general **students have an overall negative perception of the course**. Joni voiced an often mention concern stating,

> *"I generally like the engineering program, in general, but both semesters was just definitely like a weed-out class. That was all it was geared towards; it wasn't really geared towards*

> *helping people. I felt it was just geared towards kicking out the people who weren't really good in math." – Joni*

Here Joni voices a general student opinion that this course is intended to be a 'weed-out' class; she did not see this course as useful or that the faculty cared about student learning outcomes.

2.5 Discussion

Through this study author Hunter investigated the implementation of PBL facilitation—training and practices—in an introductory engineering course; this resulted in the identification of both successes and challenges. The successes indicate that PBL can be effective in introductory engineering courses with novice learners and novice facilitators. The challenges emphasize the importance of training facilitators, and particularly the need for understanding of facilitation strategies in an engineering context.

2.5.1 Facilitators Can be Trained

The trained facilitators in this study responded well to the training, as aspects from the training sessions were observed in their facilitation practices. In both phases of the training, emphasis was placed on questioning as a primary strategy to engage students in the learning process. Thus, it was not surprising that this was also the primary strategy utilized by the facilitators. Additionally, facilitators acted as coaches by guiding and directing the PBL teams. This strategy was also discussed during the training sessions and it is a common and comfortable role for instructors working with student design/project teams (Felder, Brent, & Prince, 2011; Murray & Savin-Baden, 2000). Using examples of professional practice or modeling cognitive process is another important role for PBL facilitation. This role was discussed in the training sessions, however to a lesser degree than questioning and coaching. Therefore it was not surprising that this facilitation behavior was seen in only two of the facilitators and less frequently. Even so the students did not mention their facilitators as providing examples or models of expert practices.

While Hunter observed positive facilitation behaviors that reflected the types of behaviors discussed in the training, we also observed both the absence of desired behaviors and behaviors that were counter to PBL philosophy. Though we saw evidence of the instructors enacting the several types of facilitation behaviors that were discussed in the training, in general facilitators heavily relied on basic and limited facilitation strategies, and all of them at times fell back on old traditional teaching habits (i.e. direct instruction, giving answers to the students). These facilitator behaviors may be because of time constraints on the course; the facilitators had 1) relatively limited time (e.g. five weeks) to practice and adapt to new instructional behaviors, and 2) limited time with each team during one class session maybe necessitated progressing the discourse with teams quicker so the facilitator could move on to the next team. Additionally, if opportunities were built in for observation and feedback from the trainers on the facilitators' practices then the trainers could have challenged and assisted the facilitators to attempt new facilitation strategies or given feedback on avoidance on the counter behaviors (Felder et al., 2011).

Overall the facilitators had less interaction with each team than is desirable in a PBL format; it requires extended interaction with a facilitator to see the types of learning outcomes in students that PBL is known for (Barrows, 1996). There were some context-dependent challenges that contributed to the limited interaction, such as only one meeting per week and the presence of six teams with one facilitator. A five-week time span is a relatively short amount of time to see the kind of change we hoped for especially compounded with the limit interaction between each team and their facilitator during this time span. Additionally, the facilitators received limited training on practical ways to manage the multiple teams.

Lastly, the facilitators did not prepare their students well for the transition from the traditional workshop methods of teaching and learning to PBL methods. In some of the workshop sections there was no mention of this transition or what it meant for the students—what the facilitators would expect of the students and what the students should expect of the facilitators. The facilitators were told that the students would likely find this transition difficult and the students might resist the change (Kolmos, Du, Dahms, & Qvist, 2008; van Barneveld & Strobel, 2009). During training the trainer discussed with the facilitators that they would need to help the students' transition; however, there was little discussion about practical ways to do this.

2.5.2 Novice PBL-Learners Can Adapt

The students responded to the use of PBL in their classroom as was evidenced by an observed shift in their learning behaviors from disengaged and resistant to self-directed learning to more engaged and independent in learning. At the start of the PBL module the students were quite resistant to self-directed learning and were in favor of a more didactic approach. This is not surprising as it has been mentioned in the literature before (De Graaff & Kolmos, 2007; van Barneveld & Strobel, 2009); however, the students in this study were not prepared well for this shift in learning style. Some students disengaged from the learning all together; this is possibly from a feeling of frustration due to a lack of understanding why things were different and what was now expected of them. As the project progressed student behavior changed and we saw more self-directed learning behaviors and engagement with their teams and the problem.

While we observed positive shifts in student behavior, Hunter also observed both negative shifts and lack of desired changes in behavior. As the students shifted toward self-directed learning modes, they also became overly independent. This over-independence was evident by the limited interaction with the facilitators and the interactions that did occur were often more focused on asking the facilitator questions to find out 'what exactly do we need to do to get a good grade.' It is possible that the students developed this independence out of necessity, because they needed to make progress on their problem even in the absence of the facilitator. However, when the facilitators interacted with the teams and attempted to push on their knowledge and understanding to deepen the student learning experience, a common response from the teams was, 'we already finished those steps on the handout.' Additionally, in response to being asked where they went for help on content related to the design problem, the students generally stated that they relied on their peers. Asking peers before professors is not uncommon in engineering problem-solving courses (McCord, 2014). However, by doing so, students were not appropriately utilizing the resources of the facilitator or the handouts in engage in deep meaningful learning; instead, the facilitator and the handouts became a means to 'crack the code' to getting a good grade. Indicators of self-directed learning include planning one's own learning, developing and applying strategies, *and* appropriately using learning resources (Hmelo-Silver, 2004); the students' lack of appropriate use of their resources is an indicator they had not yet developed into self-directed learners.

Lastly, though PBL pedagogy has been shown to increase student motivation toward and focus on learning (Galand et al., 2010; Walker & Leary, 2009), the students in this study generally remained very grade-focused. This may be attributed to the pervasive student perception that this course is a "weed-out class." When students see a course as a weed-out class, they believe that the course material is unimportant and feel the need to fight to keep their grade above the average (Suresh, 2006). Thus their behavior in the course is more aligned with getting a grade and less concerned with learning outcomes. As with the facilitators, five-weeks is a relatively short duration for significant change to occur in learning behaviors, yet we are encouraged to see some change and it seems promising that a longer timeframe could create more change. Though some of these negative changes or lack of desired changes can possibly be attributed to context-dependent challenges, there are some recommendations based on this study that apply more broadly to PBL facilitator training and practices in introductory engineering courses with novice PBL-learners.

2.5.3 Limitations

There are two primary limitations in this study in addition to the context-dependent challenges previously cited (i.e. the relatively short duration of the PBL, lack of feedback to the facilitators on their facilitation practices, and poor student perception of the course). First, all three of the instructors trained to be facilitators were graduate students, which suggests that they are more novice instructors as they generally have fewer teaching and professional experiences. However, the graduate students in this study had a variety of teaching and professional experiences and two of the three graduate students were pursing doctoral degrees in engineering education and were highly invested in improving engineering education. Second, the data set did not include transcribed observations of the facilitators' practices in the classroom, which limited the study to the analysis of the perceptions of observed behaviors. However, we did include three perceptions and used triangulation to verify trends. Therefore, when the same themes were identified in more than one data set we had increased confidence that the themes were valid.

2.5.4 Recommendations for Practice

A robust training program is recommended for instructors new to PBL facilitation. The training can have a greater impact if it starts prior to the instructors beginning a PBL module, such that they have time to try out the practices they are learning without the immediate pressure of having to be on point. As the facilitators roll out a PBL module they will continue to need training, support from other new facilitators, and a place to reflect on their practices. We suggest that a robust facilitator training program include:

1. A pragmatic model of facilitation strategies for engineering courses
2. Practical ways for the instructor to manage multiple teams and spend adequate time with each
3. Practical ways the instructor can prepare students for transition to self-directed learning
4. Practical ways the instructor can engage resistant students
5. Frequent observation and feedback on instructors' facilitation practices.

Additionally, it is not uncommon that an instructor would want to include one or two PBL problems in their course alongside other instructional methods (Henderson & Dancy, 2007). This method can be successful, but we suggest instructors proceed with caution. The challenge comes less with the shift of instructional methods and more with the shift in instructional philosophy (i.e. didactic instruction to learner-centered instruction). We recommended for those shifting instructional philosophy mid-course to be incredibly transparent and clear with the students about the instructor's expectations of the students, what the students can expect of the instructor, and the reason for the shift (i.e. the types of learning outcomes that can be expected from the new pedagogy). To help the students learn new behaviors, it is highly beneficial to explicitly model for the students the types of behaviors you hope to see in them.

2.5.5 Recommendations for Research

There are two recommendations for research that support the development of robust facilitator training for the engineering disciplines. First, the findings revealed that engineering instructors trained based on facilitation strategies for medical education contexts enacted a limited variety of strategies that had limited impact in producing the student behaviors expected of PBL. This indicates the importance of pedagogical content knowledge and instruction on pedagogies to be situated in relevant disciplines; this point is further highlighted in a review by Felder et al. (2011), where they state that, "in the absence of discipline-specific examples it is easy for engineers to dismiss [pedagogical content knowledge] as irrelevant to their courses, subjects, students, and problems." Therefore, future research should develop a pragmatic model of facilitation strategies for facilitation in engineering courses that includes,

1. Clarification of facilitator roles and a variety of associated strategies for each
2. The intent of utilizing different strategies (i.e. the learning goal achieved with each)
3. Examples of strategies being used in engineering settings

Second, because of the challenge of the facilitators having limited time with each team and the continuing challenge of high enrollment in university course, the need for distributing facilitation will remain. Thus, future research should develop low-technology ways to distribute facilitation. Low-technology, because instructors generally do not have the time or skills to create software that distributes facilitation. Additionally, because PBL facilitation is dependent on the discipline and other aspects of course context a single software program might not provide the flexibility needed to customize the program for a specific course.

Chapter 3. A Framework for PBL Facilitation in Engineering (Manuscript 2)

3.1 Introduction

Despite its many benefits to learners, problem-based learning (PBL) is in limited use in engineering education. A primary reason for the under-utilization of PBL is the lack of understanding of how to implement the pedagogy—particularly the facilitator roles. Engineering faculty find learner-centered pedagogies such as PBL challenging because of the shift in the role of the instructor (De Graaff & Kolmos, 2007; Duch et al., 2001; Murray & Savin-Baden, 2000). Traditionally engineering faculty rely heavily on lecture-based methods for teaching (Hurtado et al., 2012), whereas in PBL the instructor's role in teaching is being a facilitator of knowledge-building discourse(Hmelo-Silver & Barrows, 2008). With lecture-based methods the instructor has more control over the progression of learning and the material covered, in comparison to PBL where the instructor relinquishes some control as the students gain agency in their learning and in deciding what material is necessary to solve the problems presented to them (Hmelo-Silver et al., 2007). Furthermore, the challenge of enacting facilitator roles for PBL is compounded by the limited understanding of facilitator strategies for these roles in an engineering context.

The advancement of PBL pedagogy within engineering education is currently impeded by a lack of connection between practice and research (McKenna et al., 2014). The Jamieson and Lohmann (2009) framework for creating a culture for scholarly and systematic innovation in engineering education suggests that innovative educational practices can be advanced by research that provides insight and understanding for educational practice as well as practice that informs educational researchers of what questions or ideas to investigate. This framework, adapted for PBL, is shown in Figure 3.1 below. In this cycle neither practice nor research is more important than the other, and both receive from and give to each other. On the practice side, there has been a low rate of sustaining practice when PBL has been implemented in engineering because of the challenge in modifying the pedagogy for the engineering disciplinary context (Henderson et al., 2012). Additionally, insights from implementations of PBL—whether the practice is sustained or not—regarding what worked or did not work have seldom been reported. On the research side, the PBL literature has focused on theoretical understandings of PBL or the student outcomes as a result of PBL courses (i.e., (Hmelo-Silver, 2012; Jones, Epler, Mokri, Bryant, & Paretti, 2013; Woods, 2012; Xian & Madhavan, 2013), and there is little research on facilitation (Beddoes et al., 2010; Hung, 2011). The current shortcomings in a research-practice cycle for PBL specifically are 1) a lack of practice informed questions for research and 2) a lack of research-based insights that inform the practice of PBL in engineering. Questions or ideas for research identified by practice have an important role in informing research that can in turn transform educational practice. In an effort to better inform the practice of PBL in engineering, the goal of this study was to seek insight into the roles and strategies of PBL facilitators for engineering courses.

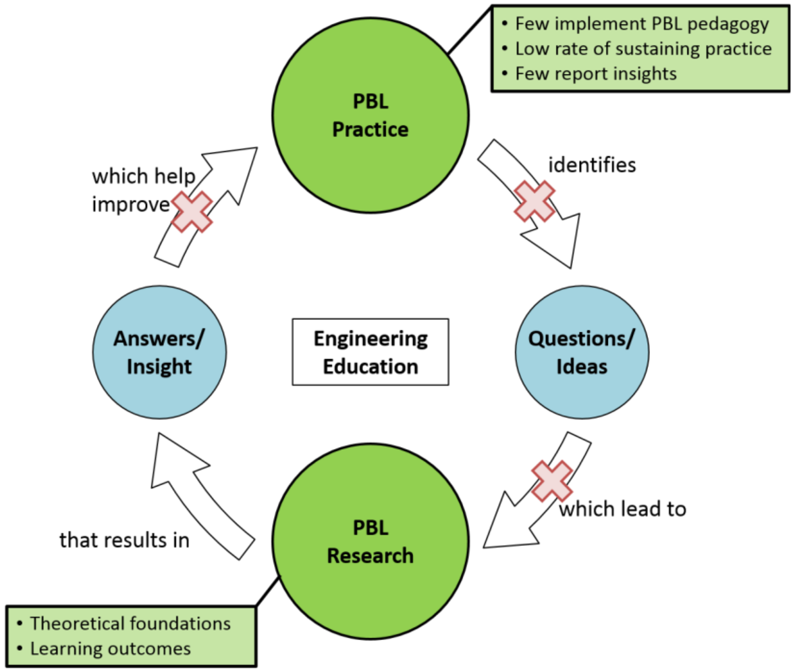


Figure 3.1 - Jamieson and Lohmann (2009) framework with current state of PBL research superimposed.

For this analysis, a PBL facilitator was defined as an instructor that guides student learning by supporting critical thinking, conceptual learning, and the acquisition of knowledge necessary to solve a complex, ill-structured problem. A facilitator is responsible for guiding the process of learning at the metacognitive level in a way that develops students into independent, self-directed learners (Dolmans et al., 2002). This is accomplished through knowledge-building discourse of asking open-ended metacognitive questions designed to elicit students to make their thinking visible and fostering group process (Hmelo-Silver, 2004). Additionally, the facilitators' actions are often faded as students gain skills and begin to take responsibility for guiding their own learning process (Hmelo-Silver & Barrows, 2008).

To develop insight into specific facilitation roles and pragmatic strategies, I used a Framework Analysis (Ritchie, Lewis, Nicholls, & Ormston, 2013; Srivastava & Thomson, 2009) to identify a framework appropriate for analyzing PBL facilitators' behaviors. Cognitive Apprenticeship, an instructional design framework, emerged as the most appropriate framework for this context. Following the steps in Framework Analysis I then qualitatively examined observations of a PBL introductory engineering course with a focus on facilitator practices. Specifically I used the Methods component of Cognitive Apprenticeship, which considers the instructional *methods* used by instructors to give students opportunities to observe, engage in, and invent or discover expert strategies in context. Ultimately, I answered the following research question that was identified through the practice of PBL in an engineering course (Hunter, Manuscript 1):

RQ: How can the Instructional Methods component of Cognitive Apprenticeship framework be operationalized to describe a model of PBL facilitation in introductory engineering courses?

Answering this question allowed me to describe and interpret facilitator behaviors in an engineering course towards the effort of developing a model of PBL facilitation in introductory engineering courses.

3.2 Cognitive Apprenticeship Framework

In the first step of a Framework Analysis (Ritchie et al., 2013; Srivastava & Thomson, 2009) the researcher becomes familiar with the data (in this case observations) and then selects a framework that is consistent with the themes within the data. Cognitive Apprenticeship instructional design framework (CA) was selected as the most appropriate framework based on the initial analysis of the observation transcripts because the emergent analysis themes best matched the constructs in this framework. The CA framework, developed by Collins (1988), was created as a model for designing situated learning environments. The philosophy of CA (which is similar to that of apprenticeships in the trades) is that students can be apprenticed in the cognitive domain by making thinking processes visible (Dennen, 2004). For this reason, the CA framework is valuable in all of academia; it is particularly useful in engineering education as students learn to become practicing engineers through the learning and application of complex knowledge and skills (Jonassen, 2011). In a cognitive apprenticeship, the expert guides a novice learner by clearly modeling the behavior of an expert and pushing the learner to think deeply and develop meta-cognitive practices. The role of the expert in CA is similar to that of the PBL facilitator as defined above in Section 3.1.

The CA framework (Collins, Brown, & Holum, 1991) has four main components—Content, Method, Sequencing and Sociology. For the purpose of developing a pragmatic model of facilitation I focused on the Method component, which encompasses the instructional methods (or strategies) used by teachers (experts) during the learning process. The Method component contains six constructs (or methods) that the teacher can employ to help students acquire skills and knowledge through observing, engaging, and discovering. Collins divide the six constructs into three groups, based in intent of the constructs. The first grouping contains *Modeling*, *Coaching*, and *Scaffolding*, which are the most commonly cited constructs for facilitation in situated learning pedagogies (Collins et al., 1991; Jonassen, 1999; Pembridge, 2011). This group of constructs is delineated as strategies a teacher uses to assist students in acquiring new knowledge and skills and integrating them into practice and are the core of CA instructional methods as they are methods by which the facilitators make cognitive processes visible for students. *Modeling*, as defined by (Collins et al., 1991), is when the teacher “performs a task so that the students can observe and build a conceptual model of the processes that are required to accomplish it” (Collins et al., 1991, p. 13). The teacher *models* by making known to the students the heuristic and control strategies he or she uses while applying domain knowledge to a task, as opposed to keeping the strategies internal. *Coaching* is defined as, “observing students while they carry out a task and offering hints, scaffolding, feedback, modeling, or reminders” (Collins et al., 1991, p. 14). *Coaching* occurs when an event or issue arises and the teacher can direct the students’ attention to information they have missed or reminding them of information that has been overlooked. Third, *Scaffolding* is defined as, “supports the [teacher] provides to help the student carry out the task” and “involves the [teacher] executing parts of the task that the student cannot yet manage” (Collins et al., 1991, p. 14). A *scaffold* can have many forms, including offering a suggestion, physically doing part of the task, or providing a tool that limits the cognitive burden of the task. It is important that the teacher diagnose students’ current skill levels and be aware of when the students face difficulty beyond these levels. Also, once a teacher provides a *scaffold*, they should fade the support as the students gain knowledge, skill, or confidence to complete the task (Collins et al., 1991; Dennen, 2004). In Table 3.1 below each constructs is listed along with a definition and general associated teacher practices.

Table 3.1 - Definitions and associated practices of the six constructs in the Method component of Cognitive Apprenticeship framework (Collins et al., 1991)

	Construct	Definition	Associated Practices
Method	Modeling	Teacher performs a task so students can observe and build a conceptual model of the processes that are required to accomplish it	▪ Think – aloud ▪ Verbalize heuristic and control strategies while completing a task ▪ Sharing of experiences that relate to the students’ current situation
	Coaching	Teacher observes and facilitates while students perform a task and offering hints, scaffolding, feedback, modeling, or reminders	▪ Offer feedback or advice ▪ Offer encouragement ▪ Using questions to guide students
	Scaffolding	Teacher provides supports to help the students perform a task	▪ Perform tasks for the students that is beyond their ability ▪ Supply tools that can organize students understanding
	Articulation	Teacher encourages students to verbalize their knowledge, reasoning, or problem solving processes.	▪ Prompt students with questions ▪ Prompt students to verbalize or draw their understanding
	Reflection	Teacher enables students to compare their performance with that of an expert other student, or an internal cognitive model.	▪ Provide space for reflection ▪ Provide examples of which to compare
	Exploration	Teacher invites students to pose and solve their own problems	▪ Prompt students to scope problems or frame questions to solve

The second group of constructs within the Method component contains *Articulation* and *Reflection*. These two constructs are delineated as ways the teacher helps students to develop control or metacognition of their own problem-solving strategies. The first, *Articulation*, is the teacher prompting the students "to *articulate* their knowledge, reasoning, or problem-solving process" (Collins et al., 1991, p. 14). This can involve any number of means, but most often comes in the form of questioning or prompting a student to formulate his or her thought process aloud. The second, *Reflection,* is when the teacher prompts and provides space for students to compare their own problem solving processes with that of an expert, or eventually to their own "cognitive model of expertise."

The last construct, *Exploration*, of the Method component is in a group by itself, and this group is delineated as encouraging students to have autonomy in their learning. The teacher role within *Exploration* is to prompt students to *explore* new domains in which their knowledge can be applied; this can be accomplished by the instructor setting general goals (or broadly scoping problems) and encouraging students to set sub-goals (or to narrow the scope of a problem). Eventually it is desirable that the students identify their own goals or problems.

Collins, Brown, and Newman (1989) developed the CA framework by observing teachers who were practicing pedagogies rooted in situated-learning. These observations were from three disciplines, namely reading, writing, and mathematics at the primary and secondary school levels. The Method constructs came from a generalization of the teacher behaviors they observed in the different settings (Collins et al., 1989). Dennen (2004) conducted a review of research using the CA framework. She found that studies using CA spanned both theoretical and practical perspectives and covered many pedagogies, disciplines, and educational levels. However, she also noted a lack of pragmatic models for implementation of CA and recommended that future research, "generate empirical based prescriptions for putting [Cognitive Apprenticeship] into practice" (Dennen, 2004); this suggests that although the framework includes the generalized behaviors, there is a need to further articulate how these behaviors are enacted in different contexts. Since Dennen's review a few researchers have published studies using CA to design instructional environments (e.g., Adenowo & Patel, 2014; Al-Dmour, 2010; Chandra & Watters, 2012; Newstetter, 2005). The most notable of these studies is Adenowo and Patel's use of CA to create a model for developing intelligent tutoring system software; their model was built based on theory and is a unique paring of CA and Conversation Theory. However, the model has not yet been tested. My research addresses these gaps by creating a model based on theory and built from practice of actionable behaviors for each of the six Methods constructs for facilitators in first year engineering courses.

3.3 Methods

To answer my research question, I followed a Framework Analysis approach (Ritchie et al., 2013; Srivastava & Thomson, 2009) to describe and interpret the facilitation strategies used by the facilitators during observed PBL meeting sessions. Framework Analysis is a procedure to interpret qualitative data—typically participant observations, focus groups, or interviews—and is similar to Grounded Theory (e.g., Strauss and Corbin, 1998). Framework Analysis sets out to answer specific questions regarding a particular setting and builds on existing frameworks. The primary goal of Framework Analysis is to describe and interpret what is happening in a particular situation, which may lead to generating a theoretical framework. This method involves five steps, 1) familiarization, 2) identifying a thematic framework, 3) indexing and sorting, 4) charting, and 5) data display and interpretation; each of these steps will be described in detail in the following sections. Analysis of PBL facilitation in engineering in this way provided a theoretical understanding of PBL in this context through developing operationalized definitions of the CA constructs and identifying strategies for PBL facilitation. The observations that I analyzed in this study were from a larger NSF-funded project (# HRD-0936704) that investigated how PBL influences motivation in engineering students.

3.3.1 Study Participants and Context

To develop a model that describes PBL facilitator strategies in engineering courses, I studied a well-established PBL program in an introductory engineering course for first-year students. This course was situated in a biomedical engineering program at a large public institution in the United States, State University One (SU1). There were three broad content topics for this course: 1) build research skills, 2) design and conduct an experiment and analyze the data, and 3) mathematically model a phenomenon. The course enrollment was approximately 200 students, who were divided into groups of approximately 8 students each with one facilitator per group. Facilitators were either faculty or postdocs in engineering, though their experience with PBL pedagogy ranged from first experience to several semesters of experience. Five groups were selected for this study, where each group included the students and the accompanying facilitator. Each group met in designated PBL rooms twice each week for 90-minute sessions. The PBL rooms were small enclosed spaces designed to facilitate group work. Each room had a single table surrounded by chairs and ample whiteboard space for collaboration. The students were given three problem statements throughout the semester; each corresponded to one of the three content topics. This study was conducted during the second problem (i.e., experimental design) where the students were presented with a problem statement and were given six weeks to complete their work on the problem. The exact problem statement corresponding to the experimental design changes each year, but in general prompts the students to “develop a hypothesis concerning a factor, other than device malfunction or misuse, which may contribute to error" in a store bought medical device (i.e., pedometer, body-fat analyzer, oximeter) and to "develop an experimental design to produce statistically significant results to test the hypothesis."[1] The six weeks were marked with a few milestones: during Week 1, the students were presented with the experimental design problem statement; during Week 3, the students presented their proposed experimental design to an audience of peers and other faculty; during Week 5, the students conducted their experiments; and during the sixth and final week, the students presented their experimental analysis and results. There were two presentation days during this module; presentation days were different than a typical PBL session, as multiple PBL groups met together to present to their peers and several faculty members.

Additionally, all students attended a weekly 50-minute seminar that included topics ranging from how to read a technical paper, team dynamics and applying for IRB approval to more technical topics such as experimental design, statistics, and data analysis. However, these lectures came after students were already confronted with these issues in the context of their problem statements.

3.3.2 Data Collection

Data collection was conducted during a single spring semester academic term, and included observations of biweekly 90-minute PBL sessions of the participating groups (Patton, 2002). Each group was observed approximately six times over a six-week period, with data collection occurring during Week 1, Week 3, and Week 6. This longitudinal perspective enabled analysis of the facilitators and students behaviors as they worked through a complete problem, from problem statement to presenting their final solutions. The observations were recorded (both audio and video) and field notes were handwritten. The recordings of the observations were later transcribed verbatim. Next, the field notes and transcribed observations were organized into five cases (identified by a pseudonym for the facilitator), where each case corresponds to an individual PBL group and consisted of six observations for all but one group. The one exception was the Petersen PBL group that only had five observations, because during one of the scheduled observation periods they met in a different location without notifying the observer.

Table 3.2 provides an overview of the observation data available, where check marks indicate that video and field notes were available; check marks with a P indicate dates when the PBL groups gave presentations and did not have a typical PBL meeting; F indicates that only field notes were available due to the sensitive nature of the discussion during the session; and X indicates that an observation did not occur and field notes were not taken. Of the available data, the only data used for this analysis were the observations of the typical

[1] Adapted from the course assignment

PBL meetings where video recordings were available and is indicated by the grey shading. Observations of the presentation days are not included, because on these days there was limited interaction between the group and their facilitator and other students and facilitators from the course were present. The observations that only included field notes were also not used in this analysis because the lack of recorded student-facilitator interaction prohibited direct analysis of the facilitator behaviors.

Table 3.2 - Available observation data of the PBL group meetings where the shaded boxes represent data that was used for this analysis.

	Week 1		Week 3		Week 6	
PBL Group	**Tuesday**	**Thursday**	**Tuesday**	**Thursday**	**Tuesday**	**Thursday**
Tostig	√	√	√	√p	√	√p
Harper	F	√	√	√p	√	√p
Kahn	√	√	√	√p	√	√p
Sennett	F	√	√	√p	√	√p
Petersen	F	√	**X**	√p	√	√p

Key: p – presentation day, X – no observation, F – field notes only, √ – field notes and recordings

3.3.3 Framework Selection

Familiarization and identifying an existing framework are the first steps in Framework Analysis. I started by immersing myself in the data, which included reading through a subset of the observation transcripts (several times) while recording notes. These notes were used to describe the behaviors of facilitators and to identify themes in facilitator roles and strategies. Upon the completion of this process, I selected the Methods component of the Cognitive Apprenticeship (CA) because it was consistent with the identified themes (Collins, 2005; Collins et al., 1991). More specifically, the Methods component was selected because it considers the *methods* instructors use to promote the development of expertise in students as opposed to other constructs that more broadly examined the development of the course content.

3.3.4 Data Analysis Methods

For this study I divided the five steps of the Framework Analysis approach into three phases. Phase 1 included familiarization with the data and identification of a thematic framework; this phase was described above. The second phase included two steps, indexing and sorting and charting. The third and final phase included the final step of data display and interpretation.

Phase 2 included a series of steps to develop operational framework with constructs, sub-categories and definitions informed by the data. The first step of Phase 2 was indexing, which started with developing labels or codes based on the Methods constructs from the CA framework and them applying these codes and annotations to segments of the data. Two cases (e.g., Sennett and Tostig) were strategically chosen for maximum variation in demographics. Sennett had prior experience with PBL facilitation, a non-traditional background for an engineering faculty member, and was female. Where Tostig had no prior PBL facilitation experience, his background was in biomedical engineering, and he was male. In this step, I started with a priori codes for the six constructs corresponding to the literature definitions of the six Methods in the CA framework. Using MAXQDA software, I applied all six a priori codes to all the observation transcripts of Sennett. After coding the Sennett transcripts, the second step of this phase was to sort the coded segments by grouping similar segments. I sorted all of the coded segments from the Sennett transcripts and developed operational definitions for each grouping. The operational definitions were informed by the data for each code using researcher triangulation. With the new definitions I then indexed the Tostig transcripts by applying the a priori codes with the new operational definitions. Then I similarly sorted all of the coded segments from both Tostig and Sennett into categories by code. Transcript segments which had more than one code applied were grouped with both code categories. The next step was to chart the coded segments. Charting is organizing the data segments to make coherent groupings of the data. Within each category, I sorted the coded segments into subcategories based on similarities and differences of the strategies used by the facilitator. Through an additional iteration of researcher triangulation, I created names and definitions for each of the subcategories and added these as sub-codes to MAXQDA. The codes, sub-codes and updated definitions together formed an operational framework.

The final phase, Phase 3, included data display and interpretation, which was used to check for completeness and refinement of the codes, sub-codes, and definitions. Using the operationalized framework developed in Phase 2, the codes and sub-codes were applied to three additional cases (e.g., Harper, Kahn, and Petersen) while allowing for any additional themes that were not already included in the operational framework to emerge. During this Phase subtle changes to definitions were made to enhance clarity and account for slight differences between facilitators. Additionally, during this phase tables and graphics were created to represent the relationships between the codes and sub-codes. A representation of this process is shown in Figure 3.2. In the results section I share the findings of the analysis.

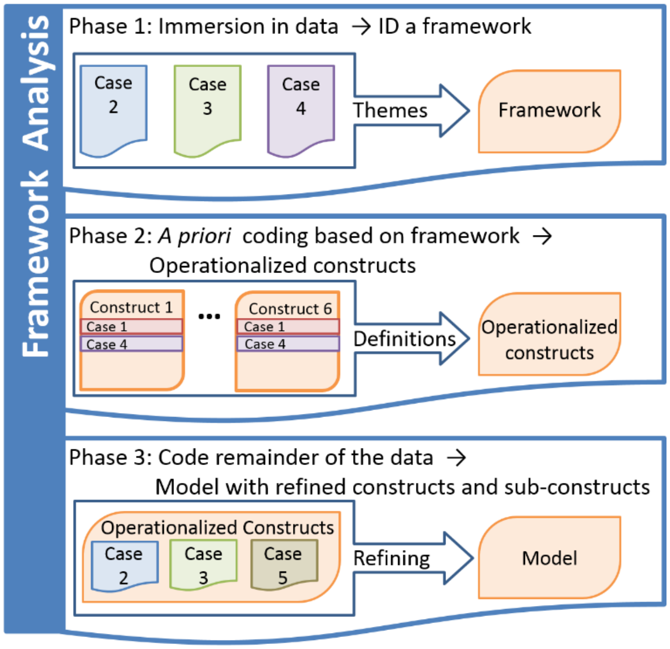


Figure 3.2 - Framework Analysis Method

3.3.5 *Quality of the Research*

Throughout the data analysis several steps were taken to ensure the trustworthiness and validity of the analysis and results (Creswell, 2008; Ritchie et al., 2013). Overall the Framework Analysis method is designed to use multiple passes through the data and multiple cases, which helps to ensure an accurate representation of the phenomena studied. In Phase 2, while developing the refined definitions of the constructs and then again when developing the visual display (or charting), I used researcher triangulation to ensure an accurate and valid representation of the data. To maintain trustworthiness in coding the observation transcripts, two researchers coded the transcripts separately, then discussed and resolved any differences. The researchers were both familiar with qualitative research methods within engineering education though one was much more novice than the other. Additionally, in Phase 3 I validated the definitions and sub-categories defined in Phase 2, by coding three additional cases with the newly developed framework making only minor adjustments were necessary.

3.4 Results

The Framework Analysis process was used to create a Model for PBL Facilitation Strategies in Introductory Engineering Courses (PBL-FIEC) by operationalizing the Instructional Methods component of the CA framework. Recall that the six Methods constructs in CA are *Modeling*, *Coaching*, *Scaffolding*, *Articulation*, *Reflection*, and *Exploration*. The process of operationalizing the constructs included refining each definition as well as identifying corresponding facilitation strategies, which included defining each strategy and providing example practices situated in an engineering context. Through this process I identified 27 distinct facilitation strategies (i.e., subcategories), with 3-6 facilitation strategies for each of the six constructs.

3.4.1 Operationalized Definitions for the Six Constructs

In using Framework Analysis and CA to analyze facilitators' behaviors in an introductory engineering course the goal was to develop a theoretical understanding of facilitation roles and strategies. The first result of this process was a set of operationalized definitions for the six CA Methods constructs (e.g., Coaching, Modeling, Scaffolding, Articulation, Reflection, and Exploration). The original definitions for these constructs, given by Collins (1991), were broad and though each had associated practices, there was an overall lack of concrete actionable ways to enact these instructional methods, especially when course context is considered. The goal of the new operational definitions was to develop concrete and actionable (yet not prescriptive) facilitation strategies for enacting the facilitation roles corresponding to each Method construct, situated in the introductory engineering context. In developing the new operationalized Methods definitions the first thing to emerge from the indexing and sorting steps of the analysis procedure was the facilitator actions. For Coaching this action was, "instructor observes while students perform a task and guides them by providing models or scaffolds or prompting them to articulate, monitor, or explore." This definition is similar to the one given by Collins (1991), such that the meaning is not changed; however, the new definition provides specific verbs to give direction to the facilitators actions (e.g., observers, guides, provides, and prompts). Similarly a definition of the facilitator action emerged for each construct and is listed in Figure 3.3. The new verbs (e.g., provides and prompts) associated with the facilitator actions for each construct give clarity as to whether the facilitator is performing an action or prompting the students to take action.

The second part of the definitions that emerged from the data was the intent (or aim) of each Method. The original definitions for the constructs, given by Collins (1991), included intent, however, the intents were broad covering multiple constructs and provided limited direction for facilitators on how and when to use a particular Method. From the indexing and sorting process, clear and pragmatic intents for each Method emerged. Now a limitation of this data set is that it did not include facilitator interviews that might have asked facilitators about their behavior; however, intent of facilitator actions can be inferred based on the student response to the facilitator's actions. In building a model the actual outcome of a Method is more important than if the facilitators had intended a different outcome, as the model should include the expected outcomes of using a give Method. As an example, here is an interaction between Dr. Tostig and three of his students. To set the stage, just prior to this exchange several students mentioned jogging their mind to recall prior knowledge of statistics.

> Dr. Tostig: What is the different between the independent sample t-test and a paired t-test?
>
> Haley: I don’t know.
>
> Trent: It's like the paired t-test is like each, like a matchup of each specific…
>
> Dr. Tostig: Yeah, but you're doing an experiment, how would you do it? What is the difference between paired and independent sample t-test?
>
> Haley: Isn't each person their own control. Is that it?
>
> Dr. Tostig: Let's work on that. What else? How, what, what is the meaning of a paired t-test?
>
> Haley: To eliminate bias and error.
>
> Dr. Tostig: Not exactly. Yes and no. What does the word paired mean?
>
> Jasper: Together.
>
> Dr. Tostig: Exactly. Ok so let's work from that. Ok I will let you guys Google that and find out exactly what is the difference between a paired sample t-test and an independent sample t-test.

Dr. Tostig’s intention cannot be confirmed, however based on the responses of both the students and facilitator, it can be inferred that this line of Articulate prompts uncovers gaps in student knowledge. Thus for Articulate the intent is defined as “assisting students to identify the limits of their knowledge and refine understanding. Using this same process to analyze the outcomes, I inferred the intention of the other Methods used by facilitators. The intent of each Method is also included in Figure 3.3.

As a result of this operationalizing process, it became evident that a new name was needed for the Reflection construct given the new operationalized definition. The new definition adds more depth to this construct as it prompts the students at a level deeper than comparing their performance to that of an expert or other student (which was included in the original definition) and additionally prompts them to adjust their performance based on the comparison. This shift in the definition called for a new name. ‘Monitor’ was chosen because as it is described in theories on metacognition, more closely reflects the definition and intent of the construct as defined in my refined framework (Flavell, 1979; Whitebread, Bingham, Grau, Pastemak, & Sangster, 2007). To create a consistent naming structure across all of the constructs, I simplified the other constructs to simple verb tense (e.g., Coaching was changed to Coach and Articulation was changed to Articulate).

Method	Facilitator Action	Intent
Coach	Instructor **observes** while students perform a task & **guides** them by **providing** models or scaffolds or **prompting** them to articulate, monitor, or explore	...with the aim of bringing student performance closer to that of experts.
Model	Instructor **provides** an example of expert knowledge, understanding, reasoning, or performance of a physical or cognitive task (while verbalizing thought process)	...to aide students in building conceptual models.
Scaffold	Instructor **provides** a support that assists students to perform a task (e.g.: rubric, framework, format, table/chart, breaking problem into steps)	...with the aim bridging gaps in students knowledge or understanding of content or process.
Articulate	Instructor **prompts** students to make known their knowledge, understanding, or reasoning of content or problem solving processes	...with the aim of assisting students to identify the limits of their knowledge and refine understanding.
Monitor	Instructor **prompts** students to monitor (compare with experts, other students, or their self) knowledge, understanding, or performance	...with the aim of students evaluating performance and adjusting learning goals or tasks.
Explore	Instructor **prompts** students to scope problems, sub-problems, questions for research tasks, or learning goals	...with the aim of fostering self-directed learning.

Figure 3.3 - Operationalized definitions for the six methods constructs

3.4.2 Revising Construct Grouping

In Collins' framework (1991) the emphasis of grouping the constructs was placed on the intent; however in developing the new operationalized definitions each Method now included its own specific intent. The newly defined intents removed the reason for the grouping of the Methods and opened an opportunity to develop a new grouping. Considering that the new operationalized definitions contained verbs to specify the facilitator action and that the purpose of this model is to assist instructors in how to facilitate PBL groups. The new grouping places emphasis on the facilitator action and is also represented in Figure 3.3, which highlighting of the verbs that represent the facilitator actions. The first group places Coach by itself because this Method was more encompassing than the any of the other Methods, specifically Coach is seen as an overarching Method that encompasses both facilitator actions of providing and prompting. The second group places Model and Scaffold together because both methods involve the facilitator providing the students with something physical or a demonstration of an action or cognitive process. The third group places, Articulate, Monitor, and Explore together because these constructs involve the facilitator prompting the students to take action.

3.4.3 Subcategories for the Six Constructs

After revising the definitions, names and grouping of the six constructs, the next outcome of the data analysis process (e.g., charting) was the identification of subcategories within each construct. I identified 27 distinct subcategories, with 3-6 subcategories per construct. Additionally, the subcategories each fall into one of two domains: *content* or *process*. The *content* domain includes subcategories that initiated an exchange of conceptual knowledge between students and with the facilitator. An example of *content* in this context is knowledge of 2-Sample t test. The *process* domain includes subcategories that initiated an exchange of or action on procedural knowledge. An example of *process* in this context is knowledge of the sequence in how to apply the 2-Sample t test.

In this section, I will walk through *Articulate* as an example. *Articulate* is the modified construct name for Articulation and the operational definition for this construct is,

> *Facilitator prompts students to make known their knowledge, understanding, or reasoning of content or problem solving processes with the aim of assisting students to identify the limits of their knowledge and refine understanding.*

Dissecting this definition, the first thing to note is 'facilitator prompts students', which means that the facilitator used questions or statements as a means to move students to respond. The students responded to the prompt by either verbally *articulating* their knowledge, understanding, or reasoning or by writing on the white boards or other visual representation. The original definition only included verbal responses; the new definition expands to include other forms of communication. The next part of the definition is 'to make known their knowledge, understanding, or reasoning.' Depending on the question or statement offered by the facilitator, the students shared different levels of cognitive thought from Knowledge, to Understanding, to Reasoning. The next part of the definition is 'of content or problem solving processes,' which describes the two domains in which the facilitators' prompts may align. Combining the three levels of cognitive thought (knowledge, understanding, and reasoning) with the two domains (*content* and *process*) yielded six subcategories.

In Table 3.4, I listed the three subcategories of *Articulate* that are related to the *content* domain and in Table 3.5 I listed the three subcategories of *Articulate* that are related to the *process* domain. Each table includes the name of the subcategory, corresponding definition, and an example practice. The subcategories (listed in the first column) are differentiated based on the depth of cognitive thought requested by the facilitator's prompt. For example, in the subcategory *Articulate - Knowledge of Content* shown in Table 3.4, the example practice demonstrates a facilitator using a line of questioning with the intent of getting students to articulate a *definition of a term* they were using. In contrast, in the subcategory *Articulate - Understanding of Content*, the facilitator prompted the student to give a *description of a concept*. Lastly, in the subcategory *Articulate - Reasoning of Content*, the facilitator prompted the student to explain their reasoning (e.g. why) and state a hypothesis. The difference between these three examples is each engages students in different types of cognitive tasks (e.g., repeating a definition vs. describing the meaning of a concept in your own words vs. drawing conclusions using the concept.) To assist the reader with identifying these difference, key features of the definition for each subcategory are bolded in the definition.

Table 3.3 - Example practices for each of the *content* domain strategies in the *Articulate* construct.

Subcategory (or Strategy)	**Definition** The facilitator uses statements or questions that prompt students to make known their…	**Example Practice**
Knowledge of Content	…knowledge of content related to the problem. It is common to use **'What'** questions. (e.g. What is…?, Tell me about…) The prompt intends for students **to share facts, terms, basic concepts, etc.**	**Dr. Tostig:** How much amps? **Haley:** 50 kilohertz of current. **Dr. Tostig:** Kilohertz? What is a kilohertz? **Ira:** A thousand hertz. **Dr. Tostig:** Come on. Let's go back to basics. What's a hertz? **Shreya:** 500 micro-amps **Dr. Tostig:** It's a measurement of what? **Jasper:** Frequency **Dr. Tostig:** Frequency. So it's not a measure of… electricity
Understanding of Content	… understanding of content related to the problem. It is common to use **'How'** questions. (e.g. How does…?, Explain more about…) The prompt **intends for students to share meaning, descriptions, comparisons, etc.**	**Dr. Sennett:** Can you, could you explain this better on the whiteboard? **Jared:** Probably not really. **Dr. Sennett:** Not really. Not really? **Jared:** I mean, so, my understanding is limited, because I still haven't taken statistics. [while writing on the whiteboard] But, we have our two distributions, right? So, okay well these suck, but you're looking at, a left-sided T-test is only gonna look over here, okay? A right-sided is only gonna look over here….
Reasoning of Content	… content reasoning related to the problem. It is common to use **'Why'** questions. (e.g. Why is…?) The prompt **intends for students to analyze, give evidence to support, make inferences, etc.**	**Dr. Tostig:** Why body temperature would change? **Zavier:** Because the blood, if it's cold outside then all of your blood will go to your major organs to protect it so the skin blood flow will go down. So, the veins go down as well. **Haley:** But if it's hot outside then your body wants to maintain its normal temperature so it's gonna send the blood out. **Zavier:** It's gonna send it away from your major organs. **Dr. Tostig:** So, what's your hypothesis when you guys put them in the steam room? **Haley:** That their BIA reading will decrease because their resistance will decrease.

Table 3.4 - Example practices for each of the process domain strategies in the Articulate construct.

Subcategory (or Strategy)	**Definition** The facilitator uses statements or questions that prompt students to make known their…	**Example Practice**
Knowledge of Process	…knowledge of method/process related to the problem. It is common to use **'What'** questions. (e.g. What are the steps to…?, Tell me about the process of…) The prompt **intends for students to share knowledge of ways, methods, processes, heuristic strategies, etc.**	**Ira:** So they take your weight underwater and then you're lighter under water which means your fat floats. So there is a difference and then do math. **Jasper:** [Laughs] Do math. **Marcell:** Ah, math. **Dr. Tostig:** What is your baseline then? What is your standard? What is this math, then? I don't know the answer. That's why I'm just asking you.
Understanding of Process	…understanding of method/process related to the problem. It is common to use **'How'** questions. (e.g. How will you…?, Explain your process for…) The prompt **intends for students to share descriptions or explanations of ways, methods, processes, etc.**	**Dr. Tostig:** OK. So now, that is a good point. You just said you're trying to see measurements of change in a related term **Ira:** Yeah. **Dr. Tostig:** So how would you do that in gender? **Ira:** We'd need similar weight? So like… A guy, we need a guy and a girl same like weight and take their measurements?
Reasoning of Process	…process reasoning related to the problem. It is common to use **'Why'** questions. (e.g. Why did/will you…?, Explain your chain of logic…) The prompt **intends for students to provide evidence or logic that supports process decisions.**	**Dr. Tostig:** So did you guys decide already what you guys want? **Ira:** Yeah, that one. [motion to board]) **Haley:** No… **Dr. Tostig:** That one? Are you sure? **Jasper:** We didn't even talk about the other ones. **Dr. Tostig:** Yeah. Are you guys even going to discuss the other ones? Why not use the other ones?

A similar structure of the subcategories emerged in four of the other five constructs: *Model*, *Scaffold*, *Monitor*, and *Explore*. What these five constructs have in common is that the subcategories within each were grouped into the two domain areas, *content* or *process*. This is depicted in Figure 3.4 below, where the tan color represents subcategories within the *content* domain and grey represents subcategories in the *process* domain.

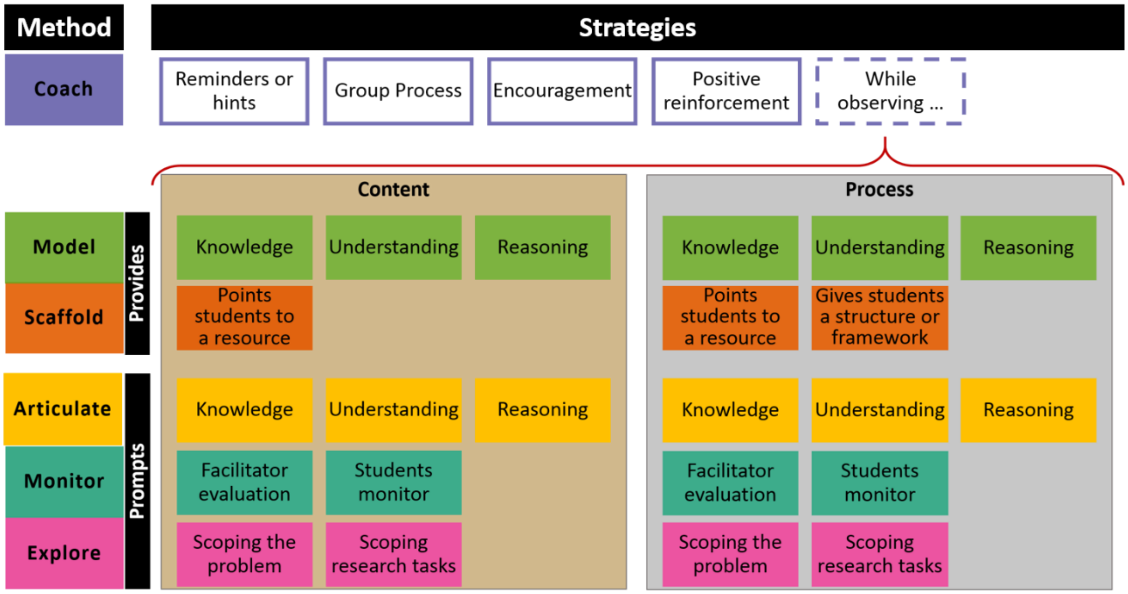


Figure 3.4 - Facilitation Strategies by Construct

Additionally, for the subcategories of the *Model* construct a similar structure parallel to the *Articulate* subcategories emerged. The difference between these subcategories of *Model* and *Articulate* is whether the facilitator is sharing cognitive thoughts (i.e., *Model*) or has asked the students to share theirs (i.e., *Articulate*). *Model* is a way for the facilitator to *articulate* to the students, knowledge, understanding, or reasoning of *content* or problem solving *processes*, though this is usually not done directly but through using a *model* or an example that helps the students build a conceptual model that can be transferred to their problem. These two constructs were also the most commonly used facilitation methods by the facilitators in this data set.

Lastly, as mentioned earlier the *Coach* construct was unique compared to the other constructs and thus grouped by itself. The emphasis of *Coach* is that 1) the facilitator's actions are preceded by an observation of the students and 2) the facilitator subsequently takes action to guide them in the form of prompting or providing. In this way, any of the subcategories in *Model*, *Scaffold*, *Articulate*, *Monitor*, or *Explore* can be an act of *coaching* if the impetus to act was in response to an observation of the students. In addition to the subcategories associated with the other five constructs, *Coach* has four additional strategies (i.e., subcategories), which includes *Reminders and Hints*, *Group Process*, *Encouragement*, and *Positive Reinforcement*. The definitions for all subcategories shown in Figures 3.5, 3.6, 3.7, 3.8, 3.9, and 3.10.

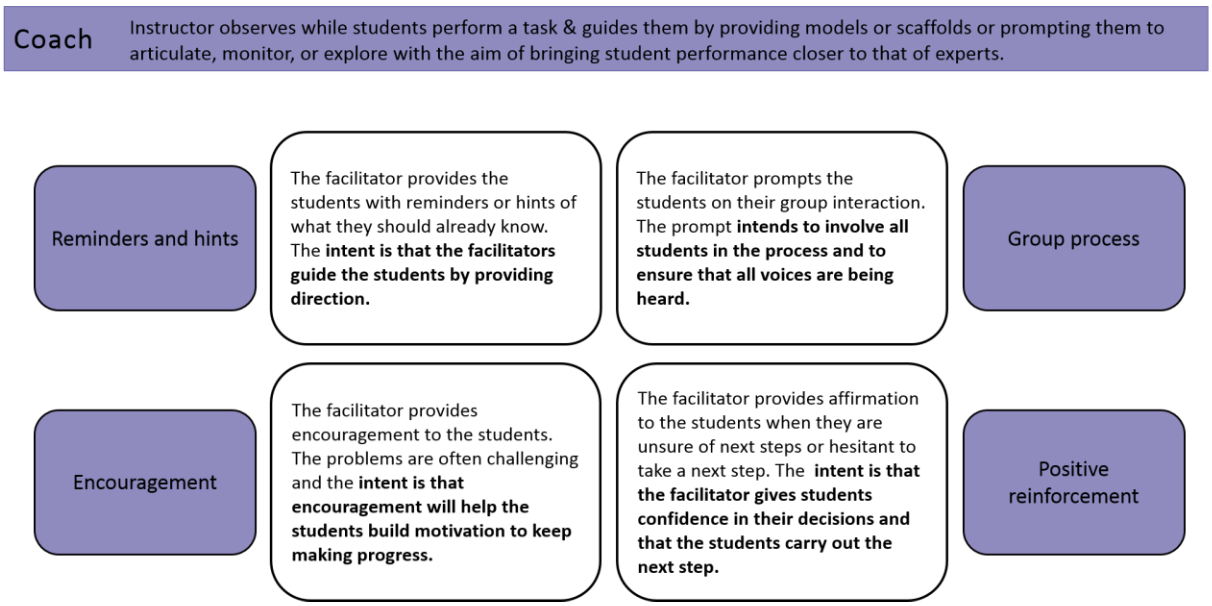


Figure 3.5 - Definitions of the Coach Subcategories.

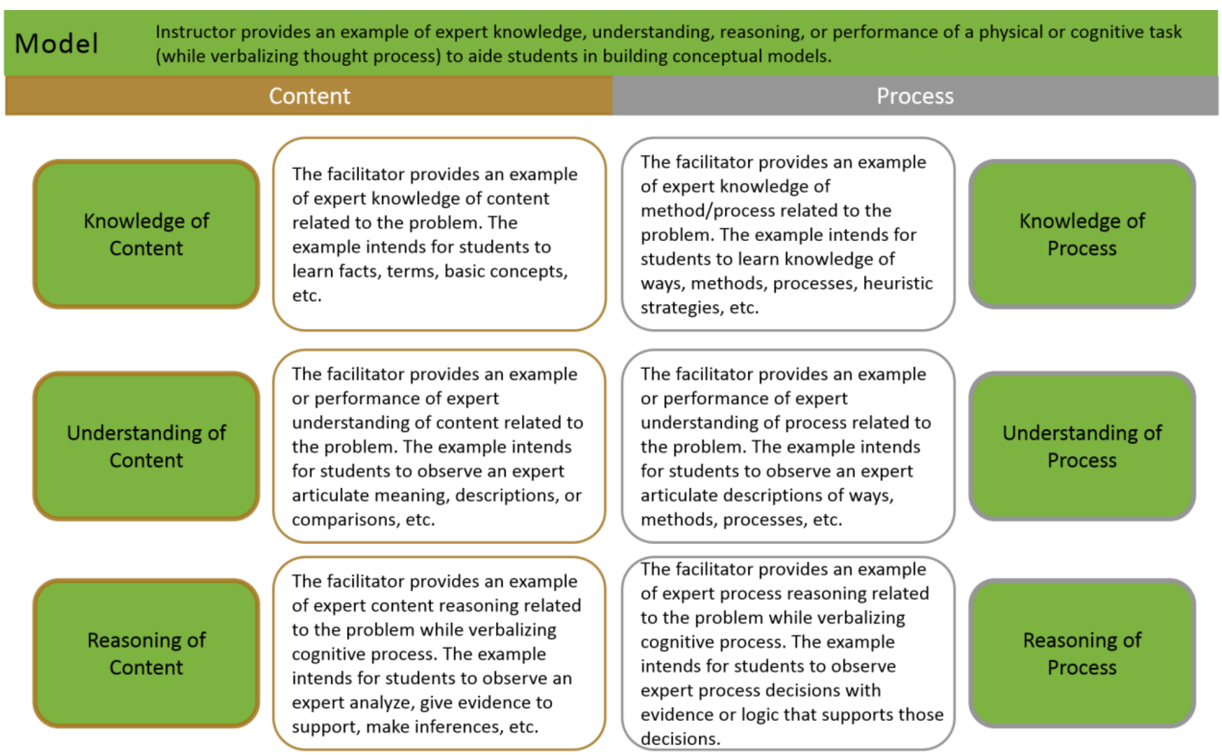


Figure 3.6 - Definitions of the Model Subcategories

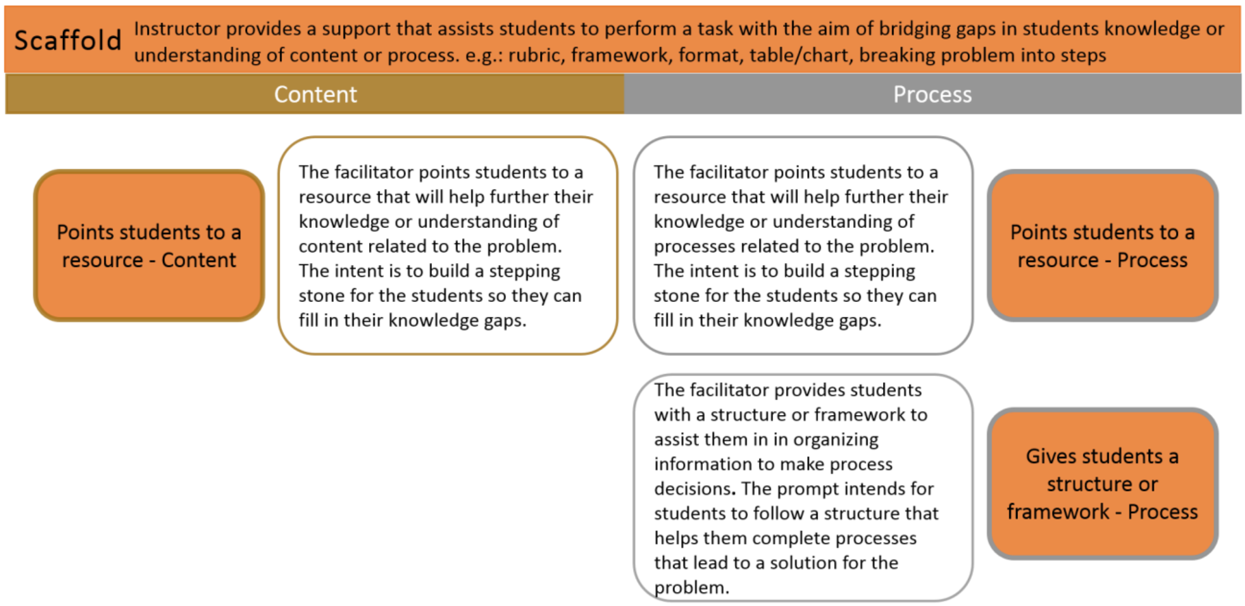


Figure 3.7 - Definitions of the Scaffold Subcategories

Figure 3.8 - Definitions of the Articulate Subcategories

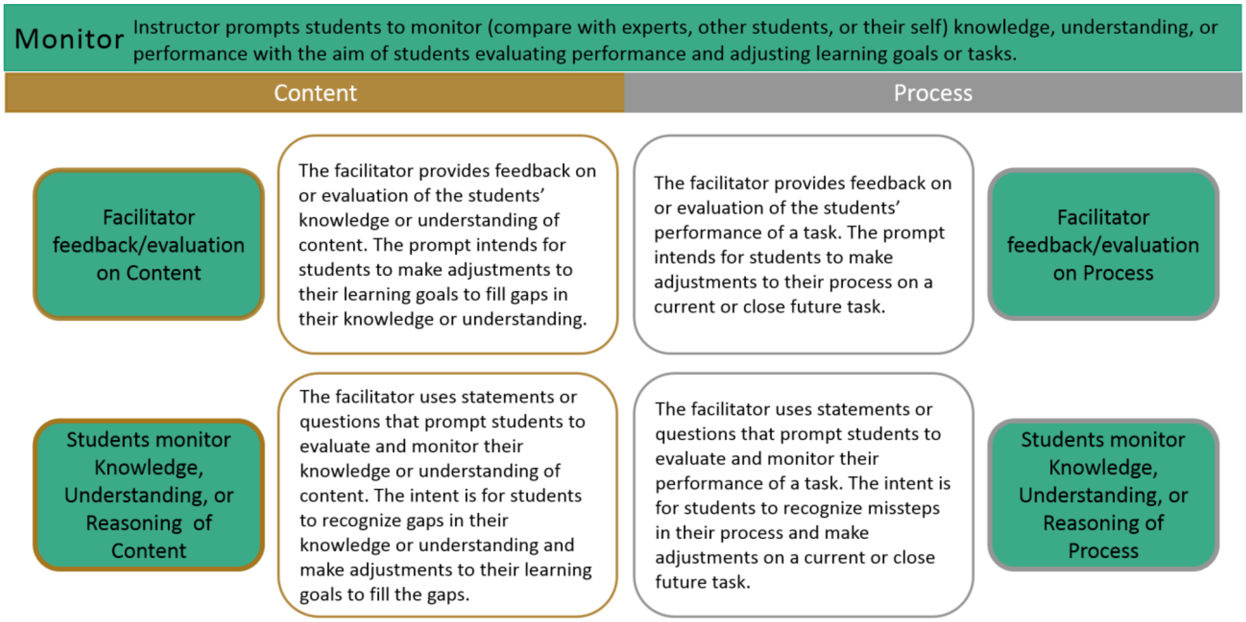


Figure 3.9 - Definitions of the Monitor Subcategories

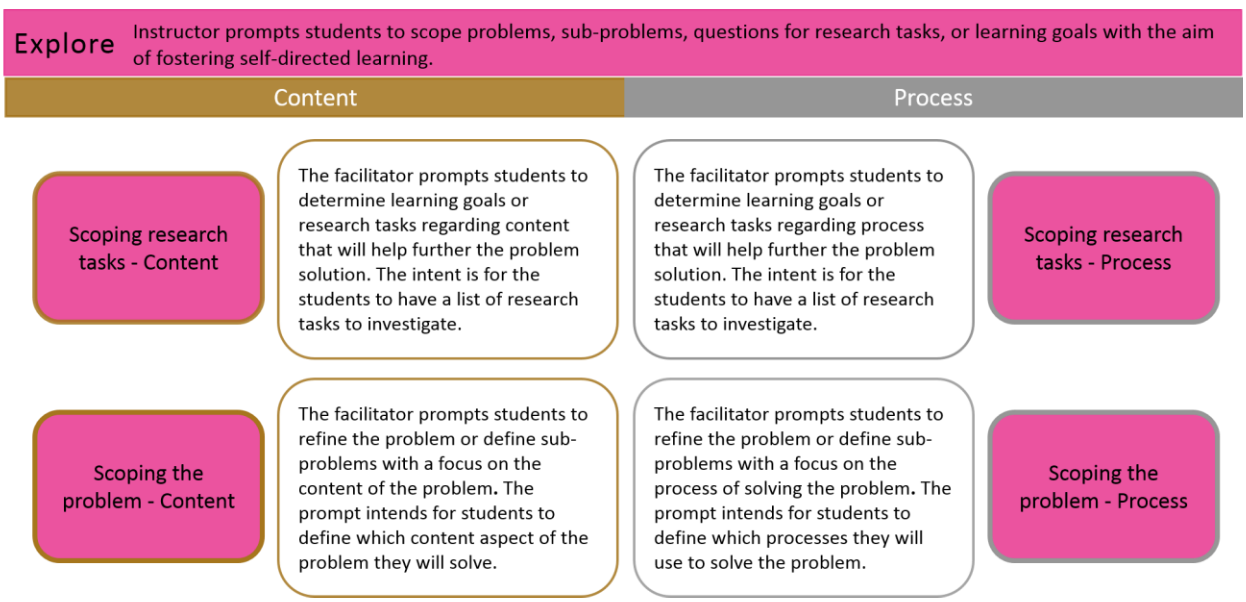


Figure 3.10 - Definitions of the Explore Subcategories

3.5 Discussion

Through this study I have expanded and operationalized the *Instructional Methods* component of the Cognitive Apprenticeship framework; this resulted in the development of the Model for PBL Facilitation Strategies in Introductory Engineering Courses (PBL-FIEC). This model for facilitation builds on CA framework (Collins et al., 1991): it does not change the meaning or intent of the instructional methods, but adds depth and clarity by making the definitions pragmatic for engineering instructors and clarifying a specific intent for each construct. The *Instructional Methods* component of Collins' (2005) CA framework is an instructional design philosophy, which broadly describes instructional practices for learner-center pedagogies; where PBL-FIEC was developed to more specifically consider instructional practices for PBL pedagogy in engineering contexts. In developing the PBL-FIEC model from Collins and Brown's CA framework, I made three additions and two modifications to operationalize the CA instructional methods for understanding PBL facilitation strategies for introductory engineering courses. These changes are described in the following sections.

3.5.1 The Model Expands the CA Framework (additions)

The additions to the framework include, 27 subcategories for the six constructs, two domains areas for the subcategories (e.g., process and content), and three ways of knowing (e.g., Knowledge, Understanding, and Reasoning) that further distinguish the subcategories. The addition of the subcategories or facilitation strategies works to expand on the CA framework and does not contradict it; this addition brings a greater understanding to how each of the instructional *Methods* could be used in practice. The process and content subcategories are perhaps similar to the ideas of procedural and conceptual knowledge that are prevalent in literature on conceptual understanding (Rittle-Johnson, Siegler, & Alibali, 2001; Venters, 2014). Where conceptual knowledge has been defined as "explicit or implicit knowledge of the principles that govern a domain and their interrelations," and procedural knowledge defined as "the ability to execute action sequences to solve problems" (Rittle-Johnson et al., 2001). Both kinds of knowledge are important in learning, and Rittle-Johnson et al. argue that it is not one or the other, but that they are on opposite ends of a continuum and not always separable. This interconnection suggests that they are both required and meaningful for learning, therefore it was not surprising that facilitators in this study prompted students in both types of knowledge and that this is an essential piece of PBL-FIEC. The three ways of knowing were inspired by Bloom's taxonomy (Bloom, 1956; Anderson et al., 2000; Krathwohl, 2002). From Krathwohl's Revised-Bloom's taxonomy there are six cognitive levels, Remembering, Understanding, Applying, Analyzing, Evaluating and Creating. Remembering is recognizing or recalling knowledge and in the PBL-FIEC model is represented as *Knowledge*. Understanding is constructing meaning, such as interpreting, inferring, explaining or comparing; this is represented in PBL-FIEC as *Understanding*. *Reasoning* in PBL-FIEC is a combination of the other four cognitive levels, which includes implementing, making judgements or critiques, or reorganizing elements into a new structure. The names are not that important, but it is important to challenge students to engage at different levels in the cognitive domain and work with different types of knowledge (e.g., content and process). Moving from knowledge to understanding to reasoning represents a progression in depth of cognitive knowledge. As students move through developing a solution to an open-ended problem it is perhaps not surprising that all three ways of knowing would be important.

3.5.2 New Names of the Methods (modification)

The development of the PBL-FIEC model the first modification included the renaming of the *Reflection* instructional method construct included in Collins and Brown's CA framework. They used the word *Reflection* to describe an instructor "enabling students to compare their own problem solving processes with those of an expert, another student, and ultimately and internal cognitive model of expertise" with the intent to "help students focus their observations of expert problem solving and to gain conscious access to (and control of) their own problem solving strategies." In this definition, the notion of 'comparing' in order to 'gain access and control' is quite similar to the concept of monitoring in theories of metacognition (Flavell, 1979; (Whitebread et al., 2007). In metacognition, monitoring is included in the 'regulation of cognition' aspect of metacognition, which describes one's ability to regulate (or control) based on one's knowledge of cognition. Monitoring is defined as "the ongoing review of one's performance while working on a task" and involves tracking progress on the task, effort expended, checking for errors, self-correcting, and checking and correcting peers (Whitebread et al., 2007). This definition of monitoring conveys the intent of the CA *Reflection* construct and carries a more precise intent of the pause for reflection. Thus in the PBL-FIEC model, the construct was renamed *Monitor*, and the definition was refined and changed to, "Facilitator prompts students to *monitor* (e.g., compare with experts, other students, or their self) knowledge, understanding, or performance." This change does not minimize the importance of reflection as part of the learning process in PBL; indeed, reflection is inherent throughout the learning process (Hmelo-Silver, 2004). In fact, reflection is necessary when students are prompted to Articulate, Monitor, or Explore. Additionally, reflection is a built in step in the PBL learning cycle, where students are prompted to reflect on their team process and learning process at various points throughout.

3.5.3 New Grouping of the Constructs (modification)

The second modification from CA to PBL-FIEC is a re-grouping of the constructs. Collins et al. (1991) grouped the instructional methods (i.e. constructs) based on how each method was designed to help the students— i.e., to acquire an integrated skill set through observation and guided practice, based on observations to gain conscious access to (and control of) their own problem solving strategies, and to gain autonomy in expert problem solving processes—but noted that these were loose groupings. In the PBL-FIEC, I grouped the instructional methods based on the specific actions (i.e., prompting, providing, or observing and guiding) that a facilitator might enact. By operationalizing model, I was able to include the intent, which was previously used to group the constructs, within the definitions and made them more specific. Decoupling the intent of each construct from the organizational grouping of the constructs provided a dimension of freedom to re-group the constructs. Additionally, regrouping the constructs highlights who has the responsibility to act. In other words, the grouping visually demonstrates whether the instructional method calls the facilitator to act and the students to observe or the inverse, where the facilitator calls the students into action while the facilitator observes.

The re-grouping does not negate the overall intents as described by Collins et al.; it has changed the aspect of the grouping from the intent of the method to the person called to action by the instructional method. Grouping the constructs in this way is more pragmatic, aiding the facilitator in considering which strategies to employ to further student learning: the facilitator should first try to call the students to action using *Articulate*, *Monitor*, or *Explore* strategies; if the students need further guidance, the facilitator can use a *Model* or *Scaffold* strategy to help the students build conceptual models. However, the re-grouping does contradict the claim by Collins et al. that there is not a hierarchy within the constructs (1991). *Coach* was placed in a group of its own and acts as an overarching category, though Collins and Brown directly state, in their framework there was no hierarchical structure for the six constructs despite their definition of *Coaching* including both *scaffolding* and *modeling*. Accordingly, in the new operational definition, I placed the emphasis on the facilitator actions of observing students and subsequently guiding them using any of the other Methods: *Model*, *Scaffold*, *Articulate*, *Monitor*, and *Explore*.

3.6 Limitations

As with all education research, my study has limitations. First, the observations were limited to one course and one problem statement, which potentially limits transferability across contexts. However, the data set for this study was rich in that there were five groups observed throughout the duration of one problem from beginning to end, which gave both a varied and longitudinal perspective. Therefore the PBL-FIEC model accounts for different facilitation styles based on varied demographics and qualities of the instructor and students, as well as changes in facilitation needs as a variety of problem solutions were developed by the five PBL groups. Second, this study of PBL facilitator strategies was limited to the context of an introductory engineering course with novice university learners. Consequently, it is uncertain if the results of this study are more broadly applicable to intermediate or advanced engineering courses. However, given the context of the study and that novice university students generally require more guidance and facilitation as they are developing self-directed learning skills, the PBL-FIEC model benefits from facilitators enacting a range of strategies as the students are gaining in skills. While there was growth in the students' skills and fading and transformation of facilitation strategies, it is possible that the PBL-FIEC model did not reach saturation, particularly strategies that might be used with advanced learners. For example in senior design courses, other aspects of facilitation or mentoring have been found to be salient, such as protection, role modeling, and rapport (Pembridge, 2011). A third limitation of this study was the absence of facilitator interviews; facilitator interviews would have been useful in understanding the observed facilitator behaviors by providing the opportunity to ask about intentions and anticipated outcomes. Despite the lack of facilitator interviews, the intent of facilitator actions were inferred from the student response to the facilitator's actions. In building a model, the actual outcome of an action is more important than if the facilitators had intended a different outcome, as a model should include the expected outcomes as a result of a given action. Lastly, I selected one framework (e.g., CA) for the analysis, although other frameworks could have also been just as appropriate (i.e., mentoring models or constructivist learning environments). However, the CA framework was chosen because of the alignment of the themes and that it is pragmatic and thus lends itself well to practice. Although, using a different framework would have brought about different findings, the PBL-FIEC model is still an appropriate facilitation model for engineering contexts.

3.7 Implications

This study has important implications for practice. By providing a concrete set of actions useful in PBL facilitation, instructors have guidance on how to enact facilitation. This was a significant hurdle preventing the propagation of PBL. Previous studies of PBL facilitation roles and strategies did not account for engineering contexts. The PBL-FIEC was developed within an engineering context and for engineering contexts- particularly introductory courses. PBL-FIEC not only provides operationalized definitions for facilitation methods, it also provides 27 unique strategies for these methods and examples practices situated in an authentic engineering practice for each strategy. The example practices make the model actionable for practitioners to improve their PBL facilitation practices. This study also has important implications for future research. I have developed a model of facilitation strategies that is contextualized and operationalized for introductory engineering courses, and fills a gap as there were no prior facilitation models for this context. This model is a useful tool for future researchers when considering facilitator behaviors in engineering contexts.

3.8 Future Research

While this study advances our understanding of PBL facilitation strategies for introductory engineering courses, there are avenues for future work that will be important if we are to see wider implementation of PBL pedagogy in engineering. In particular, I suggest two future studies. First, we could investigate individual facilitators to identify unique patterns in the way they enact different facilitation strategies. The PBL-FIEC model is large and complex and would be burdensome for a new facilitator to master all of the methods and strategies. Thus, it would be beneficial for training instructors in the PBL-FIEC facilitation strategies is there were example profiles of how various facilitators enact sub-sets of strategies. Second, we could use the PBL-FIEC model to study PBL facilitator behaviors in other settings (i.e., intermediate and advanced engineering course, and courses in other engineering disciplines) to validate or expand the current PBL-FIEC model. This would address the context limitations in the current study and strengthen the model.

Chapter 4. Translating Research to Practice: A Typology for PBL Facilitation in Engineering (Manuscript 3)

4.1 Introduction

Despite research revealing the benefits of nontraditional teaching methods such as problem-based learning (PBL) (Galand et al., 2010; Prince & Felder, 2006; van Barneveld & Strobel, 2009; Walker & Leary, 2009), engineering faculty still primarily lecture (DeAngelo et al., 2009; Hurtado et al., 2012). Faculty have cited lack of pedagogical content knowledge (PCK)—the knowledge of how a pedagogy is applied in practice—as a barrier to implementing innovative teaching practices (Matusovich et al., 2014). Additionally, when innovative teaching practices are implemented, researchers have found that a lack of fidelity in implementing pedagogy prevents sustained practice (Dancy & Henderson, 2008; Henderson & Dancy, 2007; Henderson et al., 2012). Specifically with regard to implementing PBL in the engineering classroom, a significant challenge lies in the transition of the faculty role from instructor to facilitator. If we want to adequately address this issue we need to translate existing research knowledge into PCK that can readily inform the roles and strategies of PBL facilitation and support sustained practice.

One way to address this research-practice gap is to use Jamieson and Lohmann (2009) model for scholarly and systematic educational innovation, which sets a path for innovation in education that requires cycles of research and practice that inform each other. Using Jamieson and Lohmann's model (Figure 4.1) as a scaffold, we can conduct an analysis—using a research-based framework (i.e., current research knowledge) for PBL facilitation—to describe the individual practice of PBL facilitation in context (i.e., PCK). The purpose of the current analysis was to take such an approach, using the Model for PBL Facilitation Strategies in Introductory Engineering Courses (PBL-FIEC) to produce research-based PCK that is actionable for PBL instructors in engineering. PBL-FIEC is a repurposed version of the *Instructional Methods* component of the Cognitive Apprenticeship (CA) framework that was adapted specifically for describing PBL facilitation methods in introductory engineering courses (Collins, 2005); Hunter, Manuscript 2). Ultimately, the goal of this analysis is to take a first step in increasing access to and transferability of PBL to new contexts by providing profiles of facilitation in action. To achieve this goal and address the purpose, I used multiple-case study methods to answer the following research question:

RQ: How does the Model of PBL Facilitation Strategies for Introductory Engineering Courses describe practices of PBL facilitators in an introductory engineering course?

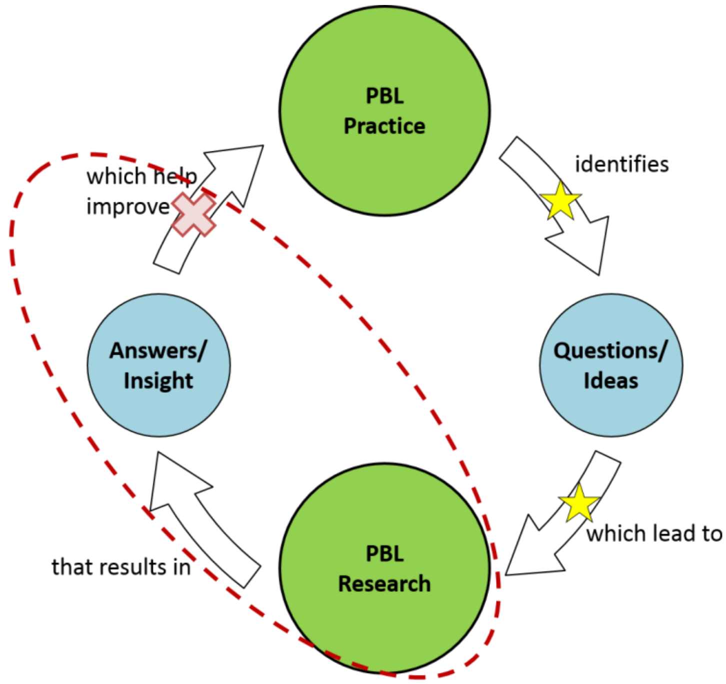


Figure 4.1 - Jamieson and Lohmann (2009) cycle of educational innovation.

To answer my research question, I used PBL-FIEC and a multiple-case study method to analyze the observations of PBL groups in an introductory engineering course, particularly the behaviors demonstrated by five facilitators while they interacted with students (Miles & Huberman, 1994; Stake, 2006; Yin, 2009). It should be noted that the observations I used for the current analysis were collected as part of a larger NSF-funded project (#HRD-0936704) investigating PBL and components of facilitation as a means for influencing motivation of engineering students in introductory engineering courses. These observations were chosen for this analysis because they come from a well-established engineering course with more than 10 years of continuous use of PBL pedagogy. By analyzing the facilitators as individual cases, I developed facilitator profiles that describe each facilitator's practices. I then grouped facilitators with similar profiles to create a typology of facilitator practices. The typology offers pragmatic examples of PBL facilitation practices in first-year engineering courses that are actionable and have high fidelity. Analysis of PBL facilitation in engineering in this way increased our understanding of PBL facilitator practices and provided research-based models describing the roles and strategies, which are directly useful for PBL practitioners.

4.2 Literature Review

This literature review is comprised of three parts. First, I describe the problem, lack of understanding and models for preparing instructors for the role of PBL facilitator, as it was identified by Hunter (Manuscript 1). Next, I review the literature to discuss what is known regarding facilitation in PBL. Then, I conclude by introducing the PBL-FIEC model that is useful for investing PBL facilitation strategies in engineering.

4.2.1 The Problem: Lack of PCK for PBL Facilitation

Through the analysis of an intentional PBL implementation, Hunter (Manuscript 1) revealed two key challenges for PBL in engineering including: 1) preparing instructors for the role of PBL facilitator – a role that significantly differs from the traditional instructor role – coupled with the lack of actionable PCK on facilitation roles in literature, and 2) the context of the implementation has significant implications on facilitator practice. Facilitation was identified as an important component of PBL (if not the most important) (Matusovich et al., 2011); however, facilitation is the aspect of PBL with which faculty are most uncomfortable. Importantly, lack of PCK and low competence in pedagogical practices among engineering faculty is not limited to PBL (Matusovich et al., 2014) and engineering faculty state that they prefer pedagogical models that are situated in an engineering context (Felder et al., 2011).

4.2.2 Current Understanding of PBL Facilitator Roles and Strategies

There has been some promising work examining PBL facilitation strategies (Hmelo-Silver, 2002; Hmelo-Silver & Barrows, 2008; Hmelo-Silver & Barrows, 2006; Hmelo-Silver et al., 2007; Zhang et al., 2010). For example, Hmelo-Silver (2002) analyzed 5 hours of observations from two sessions of a PBL group. The setting of this class was in the second year of medical school with 5 students who were experienced with PBL pedagogy. The analysis focused on identifying the questions and statements offered by the facilitator during the sessions and examining the goals and strategies of the facilitator. This work identified different types of questions that a facilitator might ask during a PBL session and categorized them into one of four question types including short answer, long answer, task oriented, and meta. Additionally, an interview with the facilitator was conducted where he described his goals and strategies of facilitation. His main goal for the students was for them to construct a "causal explanation of how." (e.g. How a disease leads to a particular pattern of signs and symptoms.) His main strategies to help the students to achieve this goal include pushing students for explanations and re-voicing, which were achieved through a variety of question types. While this question typology is useful, it was developed based on a single facilitator, with a specific goal for his students, whereas the other facilitators may have different learning goals for their students dependent on the academic discipline and level.

In a second set of two papers, Hmelo-Silver and Barrows (2006, 2008) re-examined the same data set as in the 2002 paper (described above). In the first analysis they expanded on how the facilitator's goals align with the particular strategies. The second analysis adopted a discourse analysis approach to analyze how facilitator questions allow for or do not allow for student agency. While it is useful to understand the connection between facilitation strategies and learning goals, this study was conducted in a medical education course and thus the goals are specific to medical students and further studies are needed to understand what this connection would look like in other disciplines.

Hmelo-Silver et al. (2007) wrote a review of facilitation in student-centered learning, including PBL. One important finding was that facilitators use scaffolds to "reduce [students'] cognitive load" and "to help students acquire disciplinary ways of thinking and acting" (p. 101) and that the facilitators' strategies in using these scaffolds align to the learning goals of the population. An example of this is in a medical school PBL course where the facilitator pushed students to explain their thinking *to* help build a causal explanation of disease and symptoms and identify the limits of the students' knowledge. The authors conclude that future work should investigate the types of facilitation that are needed for different populations and different learning goals, e.g., there are basic strategies for facilitation of PBL though application differs on contexts such as discipline.

Zhang et al. (2010) built on the previous work of Hmelo-Silver and colleagues to investigate the types of questions facilitators ask and how the questions impact group discussion in education courses. Their goal was to develop a questioning framework for facilitators that applies to the education disciplinary context. Zhang's study was also limited in time scale with 6 PBL groups, each participating in one session with each session lasting 2-3 hours, for a total of 15 hours of observations. The students in this study were secondary school teachers participating in a continuing education course. The authors found that the facilitators' primary tool was questioning and some of questions types were similar to that found in the work by Hmelo-Silver. However, the facilitators relied more on different types of questions than in the prior studies, which the authors attribute to the inexperience of the students with PBL. This study is important as it highlights that there are differences in facilitation strategies based on disciplinary contexts and students experience with PBL, therefore, it is particularly important for future studies to investigate facilitation strategies in disciplinary contexts that have not yet been investigated (i.e., engineering). Additionally, the studies by Hmelo-Silver et al. and the study by Zhang et al. indicate there are different facilitation strategies based on the level of PBL experience of the learners, furthermore, it is important to understand how facilitation strategies would differ for students at lower academic levels (i.e. first-year university students versus post-bachelor students).

As demonstrated by these studies, significant groundwork has been laid for the evaluation of facilitation roles and strategies, but limitations and findings from these studies show that further work is needed. The limitations of the previous studies include: 1) analysis of facilitation roles and strategies limited to one discipline (i.e. medical education), 2) most of the analysis is limited to more advanced students with experience in PBL classrooms, and 3) prior studies analyzed observations of a very limited length (i.e. 5 hours over 2 sessions). I recognize that this list of studies is limited predominantly to one set of authors and limited data. While other suggestions on facilitation exist (e.g.(Kolmos, Du, Holgaard, & Jensen, 2008), the research-based origins of such works are not evident. To address these gaps in research and further promote PBL implementation in engineering disciplines, we need to analyze facilitation roles and strategies in an engineering context at the undergraduate level, and use a longer longitudinal perspective.

4.2.3 Model for PBL Facilitation Strategies in Introductory Engineering Courses

To facilitate analysis and research of PBL facilitator roles and strategies for the benefit of PBL practice, Hunter (Manuscript 2) developed the Model for PBL Facilitation Strategies in Introductory Engineering Courses (PBL-FIEC) building on Collins' (2005) cognitive apprenticeship (CA) framework. Using framework analysis, the Methods component of CA framework was modified from an instructional design framework to an operationalized model suited for analysis in engineering education research. Additionally, based on the findings in the literature that mentioned the importance of context and population in considering PBL facilitation roles and strategies, the PBL-FIEC model was developed for the context of PBL in introductory engineering courses. Operationalizing the CA framework in this way provided a concrete way to analyze facilitator roles and strategies in the engineering context.

The PBL-FIEC model consists of six constructs to describe facilitator roles and strategies: *Coach*, *Model*, *Scaffold*, *Articulate*, *Monitor*, and *Explore*. These constructs are organized into three groups. *Coach* is set alone as it is an overarching facilitation method that a facilitator uses to guide students. The definition for Coach emphasizes that 1) the facilitator's actions are preceded by an observation of the students, and 2) the facilitator subsequently takes action to guide them in the form of prompting or providing, with the aim of guiding student performance closer to that of experts. The second group of facilitation methods includes *Model* and *Scaffold*, which are methods that involve the facilitator providing the students with something physical or a demonstration of an action or cognitive process. A facilitator uses *Model* strategies to provide students with an example of how an expert approach to a physical or cognitive task, with the aim of helping students build conceptual models. The *Scaffold* strategies include times when a facilitator provides students with a scaffold or framework that will assist the students to complete a physical or cognitive task. The third group of facilitation methods includes Articulate, Monitor, and Explore, which are methods that involve the facilitator prompting the students to take action. Facilitators use *Articulate* strategies to prompt students to make known (i.e., verbally, written, sketch, etc.) their knowledge, understanding, or reasoning of content or problem solving processes, with the aim of assisting students to identify the limits of their knowledge. Monitor strategies are used by facilitators to prompt students to monitor or evaluate their knowledge, understanding, reasoning, or performance, with the aim to adjust learning goals or tasks if necessary. Lastly, facilitators use *Explore* strategies to scope the problem or sub-problems they will solve as well as to define research tasks that will assist them in gaining new knowledge to be applied to the problem. These six facilitation methods do not necessarily occur independently from each other or in any particular sequence.

The definitions and strategies associated with each construct are listed in Table 4.1. Note there are also 27 strategies that fall under these six Methods (Manuscript 2).

Table 4.1 - Model for PBL Facilitation Strategies in Introductory Engineering Courses - construct definitions and strategies

Construct	Construct Definition	Construct Strategies
Coach	Facilitator **observes** while students perform a task & **guides** them by **providing** models or scaffolds or **prompting** them to articulate, monitor, or explore *with the aim* of bringing student performance closer to that of experts.	▪ Reminders and Hints ▪ Group Process ▪ Encouragement ▪ Positive Reinforcement
Model	Facilitator **provides** an example of expert knowledge, understanding, reasoning, or performance of a physical or cognitive task (while verbalizing thought process) *with the aim* of helping students build conceptual models.	▪ Knowledge of Content ▪ Understanding of Content ▪ Reasoning of Content ▪ Knowledge of Process ▪ Understanding of Process ▪ Reasoning of Process
Scaffold	Facilitator **provides** a support that assists students to perform a task *with the aim* of bridging gaps in students' knowledge or understanding of content or process. (e.g., rubric, framework, format, table/chart, breaking problem into steps)	▪ Points students to a resource – Content ▪ Points students to a resource – Process ▪ Gives student a structure of framework – Process
Articulate	Facilitator **prompts** students to make known their knowledge, understanding, or reasoning of content or problem solving processes *with the aim* of assisting students to identify the limits of their knowledge and refine understanding.	▪ Knowledge of Content ▪ Understanding of Content ▪ Reasoning of Content ▪ Knowledge of Process ▪ Understanding of Process ▪ Reasoning of Process
Monitor	Facilitator **prompts** students to monitor (e.g., compare with experts, other students, or their self) knowledge, understanding, or performance *with the aim* to evaluate knowledge, understanding, or performance and to adjust learning goals or tasks.	▪ Facilitator Evaluation of Content ▪ Students Monitor Content ▪ Facilitator Evaluation of Process ▪ Students Monitor Process
Explore	Facilitator **prompts** students to scope problems, sub-problems, questions for research tasks, or learning goals *with the aim* of fostering self-directed learning.	▪ Scoping the Problem – Content ▪ Scoping Research tasks - Content ▪ Scoping the Problem – Process ▪ Scoping Research tasks - Process

4.3 Methods

To answer the research question, I followed multiple-case study methods (Miles & Huberman, 1994; Stake, 2006; Yin, 2009) to describe individual facilitator practices (within-case analysis) and to define a typology of facilitation practices (cross-case analysis) to deepen our understanding of how instructors might approach facilitation in introductory engineering courses. Case study methods provided a structure for analysis within each case to pull out the nuances of each case and then cross-case analysis to provide a more generalizable description of varied approaches to facilitation. The cases that were analyzed in this study were from a larger NSF-funded project (# HRD-0936704) that investigated how PBL influences motivation in engineering students (Jones et al., 2014; Paretti et al., 2010).

4.3.1 Study Participants and Context

To investigate the different instructors' practices of PBL facilitation strategies, I studied a well-established PBL introductory engineering course for first-year students. This course was situated in a biomedical engineering program at a large public institution in the United States, which we call State University One (SU1). There were three broad content topics for this course: 1) introduction to research skills, 2) design and conduct an experiment and analyze the data, and 3) mathematical modeling of a phenomenon. Approximately 200 first-year students were enrolled in this course, which were divided into PBL groups of approximately 8 students each with one facilitator per group. Facilitators were either faculty or engineering postdocs, though their experience with PBL pedagogy ranged from first experience to several semesters of experience. Five groups (i.e., the students and the accompanying facilitator) were selected for this study. The primary selection criteria was, that all students in these groups consented to participate in the study. The eight students in each of the five selected groups are assumed to be a representative sample from the course, where the variation across groups is the facilitator. Students from all the PBL groups attended the same weekly one-hour lecture/seminar, addressing topics ranging from professional skill development, to the occasional lecture on content, such as a statistical methods refresher that helped the students with the analysis of their experimental data. Additionally, each PBL group met with their facilitator twice each week for 90-minute sessions in designated PBL rooms. The PBL rooms were closed spaces designed to facilitate group work. Each room had a single table surrounded by chairs and ample whiteboard space for collaboration. The students were given three problem statements throughout the semester; each corresponded to one of the three content topics and lasted approximately six weeks in duration. This study was conducted during the second problem (i.e., experimental design) where the students were presented with a problem statement and were given six weeks to complete their work on the problem.

4.3.2 Data Collection

The primary data for this analysis includes observations of the five PBL groups, with five different facilitators. The observations were conducted during the biweekly 90-minute PBL sessions of the participating groups and included the collection of recordings (both audio and video) and field notes. With the exception of one group, each group was observed six times over a six-week period, with data collection occurring in Week 1, Week 3, and Week 6. The one exception was the Petersen PBL group that only had five observations, because during one of the scheduled observation periods they met in a different location without notifying the observer. This longitudinal perspective enabled me to observe the facilitators and students as they worked through one complete problem, from problem statement to presenting their solution. The observation recordings were later transcribed verbatim. The observation transcripts and field notes were organized into five cases; each case corresponds to one PBL group (i.e., facilitator plus students) and includes up to six observations. In Table 4.2, I provide an overview of the observation data collected, where a check mark indicates that observation transcripts and field notes were available and used for analysis; F indicates only field notes were available and used in this analysis; X indicates that an observation did not occur and field notes were not taken; and P indicates dates when the PBL groups gave presentations and did not have a typical PBL meeting. For this analysis the observation of the presentation days were not included, because on these days there was limited interaction between the group and their facilitator and other students and facilitators from course were present. For the exception group (e.g., Petersen), their first Week 1 meeting was observed but only observer field notes were recorded and then in Week 3 the observer was unable to locate the group for the observation. In comparison to the other cases, this gap limits this case to two recorded observations and one observation with field notes alone out of a possible four observations; the impact of less than a full dataset for this case is described in limitations.

Table 4.2 - Available observation data of the PBL group meetings here the shaded boxes represent data that was used for this analysis.

	Week 1		**Week 3**		**Week 6**	
PBL Group	**Tuesday**	**Thursday**	**Tuesday**	**Thursday**	**Tuesday**	**Thursday**
Tostig	√	√	√	√p	√	√p
Harper	F	√	√	√p	√	√p
Kahn	√	√	√	√p	√	√p
Sennett	F	√	√	√p	√	√p
Petersen	F	√	**X**	√p	√	√p

Key: p – presentation day, X – no observation, F – field notes only, √ – field notes and recordings

4.3.3 Data Analysis Methods

Using multiple-case study analysis methods (Miles & Huberman, 1994; Stake, 2006; Yin, 2009), I analyzed the observation transcripts of five PBL groups. Each case was coded using the PBL-FIEC model, and through an analysis of the coded segments and field notes, a facilitator profile was written for each case. Based on the facilitator practices highlighted in each profile, the cases were arranged into groups determined by similar characteristics. This step resulted in a typology, where each group defines a facilitation type and together the types define a typology of facilitation strategies.

In Phase 1 of the analysis, the observation transcripts were coded with the PBL-FIEC model developed by Hunter (Manuscript 2) to develop facilitator profiles. Phase 1 included many steps, the first was to organize the observation transcripts by case and import them into MAXQDA—a qualitative data analysis software—for analysis. Next, the transcripts were coded with codes from the PBL-FIEC model, which included the six facilitator methods and 27 facilitation strategies. Each case was coded separately, and then checked for inter-rater agreement with two other researchers (Creswell, 2008; Ritchie et al., 2013).

Next, to develop facilitator profiles, I conducted a within-case analysis of the coded observation transcripts using MAXQDA visual tools and tables to assist with summarizing each case. Within-case analysis means that the cases were analyzed relative to the PBL-FIEC with no comparisons made between cases (Ayres, Kavanaugh, & Knafl, 2003). The visual tools in MAXQDA that were used include, Document Portrait, Code Matrix Browser, and Code Relations Browser. The Document Portrait allowed for a visual representation of the amount of interaction between the facilitator and the students, as well as a high level view indicating which facilitation methods the facilitator was enacting and if there were patterns in the use of facilitation methods. The Code Matrix Browser provided a more detailed view of how often a facilitator enacted each facilitation method and strategy during a session; this gave insight into which methods were used most frequently by a facilitator, as well as if there were changes in the use of facilitation methods or strategies throughout the six weeks. Lastly, the Code Relations Browser allowed me to identify patterns in the use of facilitation methods and strategies (i.e., an *Articulate* strategy was used 15 times and in 10 of those instances it was followed by a *Monitor* strategy). I created a table and recorded insights from these tools for each observation transcript of each case. Additionally, I read through the coded transcripts and noted in the table details of the facilitators methods and strategies, as well as, if and how they paired strategies. In the last column of the table I recorded pertinent information from the field notes regarding the facilitator's behavior. Lastly, a description of the level of interaction between the facilitator and students and was determined from both the Document Portrait display and triangulated with the observer field notes. Where level of interaction is specified as the frequency in which the facilitator is engaging in the conversation. A low level of interaction is when most of the dialogue is between the students with occasional interaction with the instructor, as opposed to a high level of interaction where most of the dialogue is between the instructor and students. From this table, I wrote a case summary for each facilitator, which included facilitator demographics (i.e. experience with PBL facilitation, position at the university, and gender), a description of the facilitator's overall facilitation behaviors, a description of how the facilitator enacted facilitation methods and strategies including which strategies were used most regularly, a description of which strategies were paired with other strategies and how, a description of the extent of the facilitators interaction with the students, and if the facilitation behaviors changed over time. The summaries were then compiled into a data display that depicts facilitation profiles for each facilitator.

In Phase 2, I used the data display for the cross-case analysis to compare the facilitator profiles across the five cases and distinguished commonalities and variations in facilitator behaviors. Once commonalities and variations were distinguished, patterns were identified across cases to develop a typology of facilitation, the patterns helped to identify distinct descriptions used to discriminate and categorize the five summaries, and resulted in a typology of facilitation methods and strategies (Ayres et al., 2003; Ritchie et al., 2013). Each profile within a type is related to the others within the type by the facilitator behaviors described by the PBL-FIEC Model. A representation of the multiple-case study method used is shown in Figure 4.2.

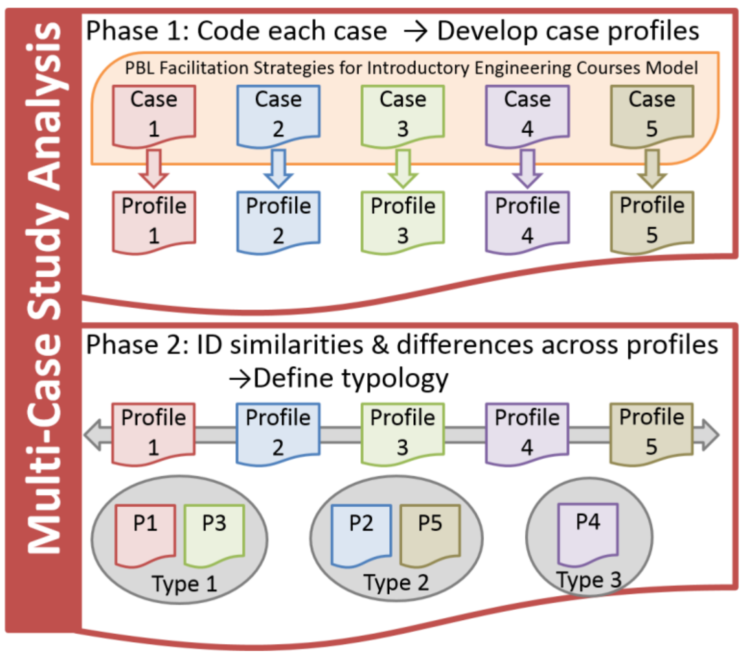


Figure 4.2 - Multiple-Case Study Analysis Method

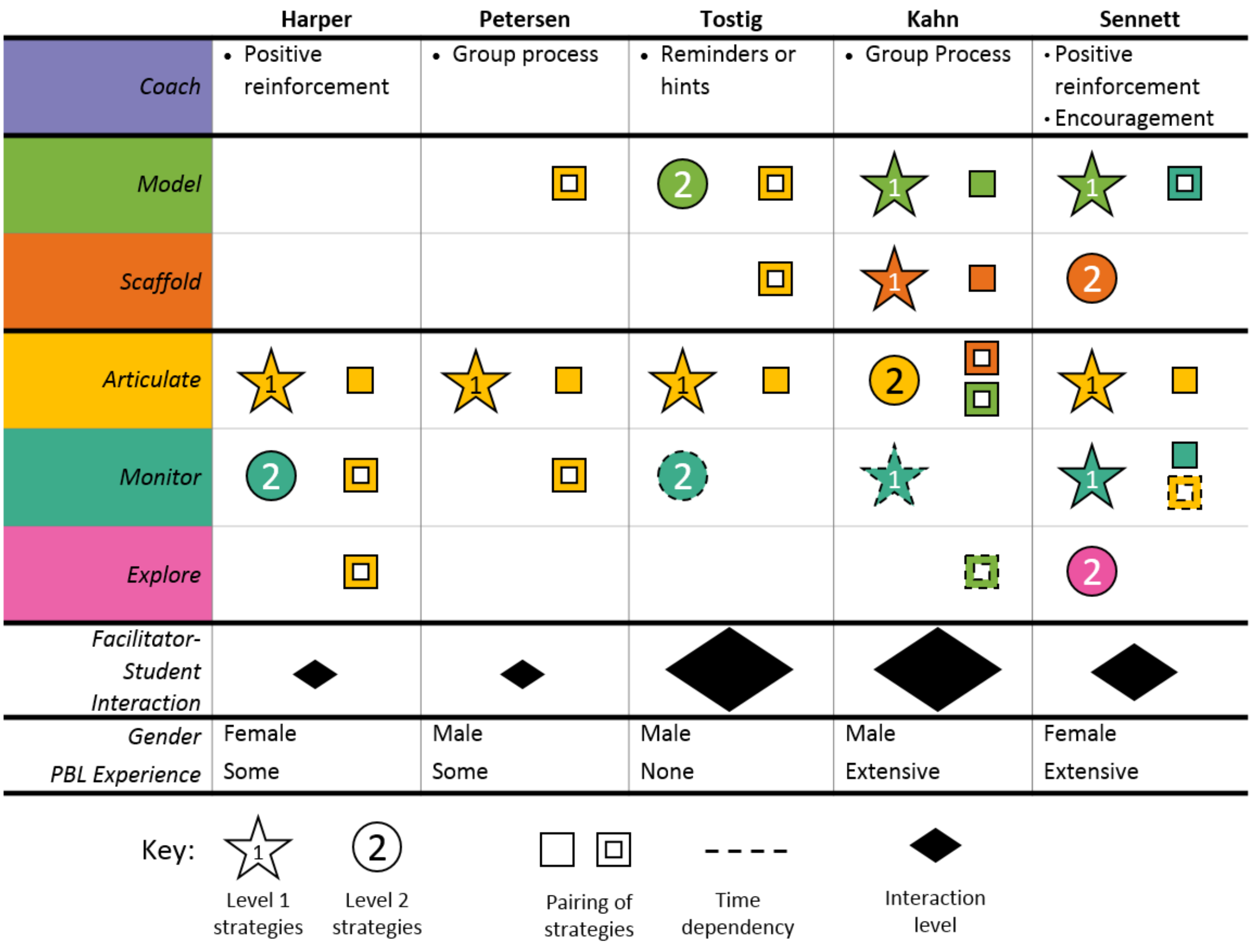
4.4 Results

Using the methods mentioned above, I was able to describe practices of PBL facilitators in an introductory engineering course with the PBL-FIEC model as a lens. There are two key outcomes that help to describe these facilitation practices and are reported here—facilitator profiles and a typology of facilitation. Because the typology depends upon understanding individual facilitation profiles, the individual profiles are presented first, followed by the summarizing and comparative typology. In summary, the analysis resulted in a typology with two identified groups, where each group includes facilitators with similar facilitation strategies.

4.4.1 Facilitator Profiles (Case Summaries)

The facilitator profiles described herein include demographic information, descriptions of coaching style, descriptions primary and secondary facilitation behaviors, and the amount of interaction between students and facilitator. I have summarized the facilitator profiles in the form of a table (Table 4.3). For each case (e.g., facilitator), the demographic information is listed, how the facilitator enacted various strategies is indicated by symbols and colors, and a scale indicates the amount of interaction between the facilitator and students. The facilitator's main (i.e., Level 1) and secondary (i.e., Level 2) facilitation strategies are highlighted and marked respectively with a star or a circle. In some cases, the facilitator used multiple Level 1 strategies and one did not stand out above the others. In those cases, all relevant strategies are likewise indicated with a star to designate them equally at Level 1. If a facilitator had a pattern of pairing two facilitation strategies, this is indicated by a square, where the solid-colored square indicates the first strategy in and the open-centered square indicates the follow-up strategy. If the enactment of a strategy seemed to have a time dependency (i.e., used primarily during the first meeting, etc.), it is indicated by a dashed line around the symbol. In the last row the amount of student-facilitator interaction, where the largest diamond indicates a high level of interaction throughout the meetings and the smallest diamond low interaction. Lastly, each facilitator enacted strategies from each of the six facilitation method categories; however, the goal of this table is to draw attention to the strategies that define the most common facilitation practices of each facilitator.

Table 4.3 - Summary of Facilitator Profiles



Dr. Harper

Dr. Harper was engaged with the students; she was constantly observing the students and participating in the conversation, though she restrained herself from constantly interjecting. Dr. Harper used pertinent questions or statements at seemingly pivotal moments to direct conversation. Dr. Harper's questions and statements were conversation starters and generally she did not have to push much further, which left more space for the students to work through the problem on their own. Additionally, Dr. Harper's coaching style was that of *positive reinforcement*, where she encouraged students to follow through with their ideas.

The facilitation strategies enacted the most by Dr. Harper fall into the group of constructs that are facilitator prompts that call the students into action (e.g., *Articulate*, *Monitor*, and *Explore*), she enacted facilitation strategies from the other constructs (e.g., *Model* and *Scaffold*) less frequently, but when necessary. *Articulate* was the strategy most used by Dr. Harper. Something that was unique about Dr. Harper's use of *Articulate* prompts, was that she rarely asked follow-up questions, instead the students were the ones most often asking the follow up questions or explaining to each other what they think Dr. Harper was wanting the students to consider. When students were unable to give an appropriate response to Dr. Harper's prompts to *Articulate*, she generally followed-up with strategies from the *Monitor* and *Explore* constructs. As an example of an *Articulate* prompt followed with a *Monitor* prompt: in preparation for their data collection Dr. Harper asked the students to walk her through their data collection process, but the students indicated some uncertainty of their process, thus she followed with a *Monitor* prompt asking, "Have you done it, gone through your own protocol?" this prompt required the students to go through their protocol and self-evaluate or monitor their work and adjust if needed.

Next to *Articulate, Monitor* strategies were key ways she guided the students' problem solving process. Dr. Harper tended to observe the students working for extended times without her input; when she sensed that they had skimmed over something, were headed down a wrong path, or had a misconception she generally prompted the students to *monitor* their knowledge, understanding, or reasoning. An example of how Dr. Harper enacted a Monitor prompt following an extended period of observing the students, she stated,

> *"I think you should back up before you… [F1: Okay.] So you're talking about all this accuracy and you're talking about repeatability, right, as two things you can test? Is that what you guys are saying? [A few students: Yes.] Okay. Do you feel you need to pick one of those and/or pick a device before you move further?"*

In this statement, she caused the students to pause, take stake of where they are in the problem solving process, and then make an informed decision about how to proceed.

Dr. Petersen

Dr. Petersen was engaged with his group; he actively observed, but was reserved in interjecting statements or questions into the conversation. Dr. Petersen generally joined the conversation after students had struggled for a bit. At first glance, the limited interaction might be perceived as a lack of concern for the students learning, but to the contrary Dr. Petersen exhibited care and concern for the students by his confidence in the students to work through the struggles of learning and become more self-sufficient learners. Additionally, Dr. Petersen's coaching style was supporting *group process*; he consistently assisted the team in working together, as an example he made plans to meet with the group outside of the PBL meetings, even staying into the evening hours to work with them. Dr. Petersen's facilitation practices provided ample room for the students to discuss, build knowledge, and work toward a solution.

The group of facilitation strategies enacted most frequently by Dr. Petersen come from the *Articulate* construct, but only after the students had spent some time struggling. Dr. Petersen frequently enacted *Articulate* strategies in combination with *Model* or *Monitor* strategies. These strategies were enacted when the students were unable to accurately communicate an appropriate answer to an *Articulate* prompt. He occasionally enacted other strategies (e.g., *Scaffold* and *Explore*), but much less frequently. When Dr. Petersen joined the conversation, he typically used *Coach* strategies (e.g. Group Process) to facilitate the group, making sure all student voices are being heard and considered.

Dr. Petersen enacted *Model* strategies following *Articulate* strategies when the students needed more help with a concept or process. With *Model* strategies, Dr. Petersen set up controlled mini-cases as models then prompted the students to *articulate* their knowledge, understanding, or reasoning of a concept or process within the controlled example. The *model* worked to disrupt their misconceptions. Dr. Petersen was a willing investigator; he openly admitted to not knowing all the answers and used *Model* strategies to make visible to the students his thought process for how he would approach learning the necessary knowledge for the situation.

With *Monitor* strategies, Dr. Petersen often prompted the students to reconcile differences between each other regarding their knowledge, understanding, or reasoning of concepts or processes. As an example, after one student gave an explanation he would ask, “Does everyone agree with that?” In this way, he facilitated the students in *monitoring* and checking each other’s understanding and then collectively coming to a more accurate understanding.

Dr. Tostig

Dr. Tostig was very involved with his students in the problem solving process; he often injected comments or questions into the discourse to provide reminders or guide the students. Most of the group discourse was between Dr. Tostig and the students, as opposed to the discourse being among the students. Through all of Dr. Tostig’s interactions with the students, he is consistently urging them to “be scientists” and ground their decisions in science. Consistent with this action, Dr. Tostig’s coaching style was to offer *reminders and hints*, where he would remind them to emulate a scientist or provide them hints such as, ‘A scientist might consider what other researchers have done before designing a study.’

Similar to the two previous facilitators, Dr. Tostig used *Articulate* prompts as his primary strategies for facilitation, and occasionally paired these strategies with other strategies. For Dr. Tostig, he generally paired *Articulate* prompts with providing *Models* or *Scaffolds*. When students were unable to provide an appropriate response to an *Articulate* prompt, Dr. Tostig provided a *Model* or *Scaffold* in an effort to assist students in transferring knowledge from one context to another. He called on his extensive laboratory experience to describe similar circumstances, in this way Dr. Tostig would demonstrate how knowledge was applied in one setting to help students build a conceptual model.

Additionally, Dr. Tostig enacted two secondary strategies (e.g., *Model* and *Monitor*); Level 2 strategies are strategies used less frequently than Level 1 strategies, but are also used individually and not necessarily in combination with a Level 1 strategy. After observing students and noticing they were headed in an unproductive direction, Dr. Tostig would provide a *Model* for the students as a suggestion for an alternate way to view the problem.

The *Explore* strategies emerged as secondary strategies for Dr. Tostig in the last week of the problem. In the Tuesday meeting of the last week the students were preparing to present the results of their data analysis and were working through their interpretation of their results and how it would be presented. During this meeting, Dr. Tostig enacted *Monitor* strategies to assist the students in evaluating their interpretations; additionally, in preparation for the presentation he enacted *Monitor* prompts to help the student think about what questions they might be asked after their presentation and if they were prepared to give responses.

Dr. Kahn

Dr. Kahn was very involved with the group throughout the problem solving process; he often initiated and guided the discourse. For example, at the first meeting for problem two Dr. Kahn directed the students to read the problem statement then initiated discourse by asking for student responses to the problem statement, and proceeded to guide the next steps and determining research tasks. Dr. Khan's coaching style was to support *group process;* he did this by consistently directing questions or prompts to specific students, calling them by name, in such a way as to ensure all voices were being heard.

Dr. Kahn enacted a great variety of facilitation strategies. He relied heavily on his engineering background to provide examples and models for the students; however, he rarely provided students with direct answers. Instead, the *Models* or *Scaffolds* he provided the students were to guide the students' discovery of new knowledge. Dr. Kahn had a unique way for enacting the *Articulate* strategies, he generally initiated with *Model* or *Scaffold* facilitation strategies and then followed up with an *Articulate* prompt. This pattern of *Model* or *Scaffold* followed by *Articulate* was consistent throughout, though at times Dr. Kahn use other strategies (e.g., *Explore*) in combination with *Model* or *Scaffold* strategies.

Another unique aspect to Dr. Kahn's facilitation strategies was his timing for enacting different strategies. For example, in the first meeting Dr. Kahn often used a paired strategy, where he started by providing a *Model* then an *Articulate* prompt and followed-up with an *Explore* strategy. The prompt for the students to *Explore* was a result of them being unable to answer the prompt to *Articulate*. This combination of strategies assisted the students in making a list of research tasks and scoping the problem. Another example is, in the last meeting prior to the final presentation—where the students presented the results of their analysis—Dr.

Kahn enacted *Monitor* strategies to engage with the students. During this meeting, he was assisting the students to evaluate their analysis methods and check the results prior to the presentation. One other time-dependent aspect to Dr. Kahn's facilitation practices was that as the weeks progressed, the types of *Articulate* and *Model* strategies he enacted progressed from knowledge to understanding to reasoning; thus prompting and providing deeper levels of cognition as the problem progressed.

Dr. Sennett

Dr. Sennett was engaged with her group of students throughout each meeting; while observing the students' problem solving process she balanced times of remaining quiet with times of providing support and prompting the students. In general, Dr. Sennett's goal seemed to be for her students to approach problem solving and the group process like professionals and to "think like engineers." This was evident in her occasional mini-lectures about professionalism and cognitive reasoning. Throughout, Dr. Sennett displayed two coaching styles, *positive reinforcement* and *encouragement*; she consistently cheered her students on by letting them know she had confidence in them to succeed and helping to reflect on how far they have come and their potential for how much farther they could go. She may have set a high bar for them, but her encouragement along the way and reinforcing that they could succeed in what they had set out to accomplish.

Dr. Sennett enacted a great variety of facilitation strategies across all six facilitation method constructs, with little preference for one over another. The strategies that she enacted most often came from the *Model*, *Articulate*, and *Monitor* constructs and were regularly supplemented with strategies from the *Scaffold* and *Explore* constructs. Additionally, Dr. Sennett enacted strategies in combination with each other. One combination Dr. Sennett used regularly was a *Monitor* prompt followed by providing a *Model*. As an example, in the last meeting Dr. Sennett returned the students' graded report from the previous problem and they reviewed the report together in preparation for the report they would write for the current problem. During the review of the graded report Dr. Sennett used *Monitor* prompts to guide the students in evaluating their performance on the prior report, and followed-up by providing Models of how that might have written the report differently to help the students build conceptual models they can apply to writing the next report.

4.4.2 Typology

I grouped the facilitators into facilitation types based on the facilitation strategies they used and the way the used them (e.g., Level 1, Level 2, or paired). Two types were identified: Type 1 where facilitators predominantly prompt students to take action and Type 2 where facilitator had diversified strategy use. Type 1 included Drs. Harper, Petersen, and Tostig and Type 2 included Drs. Kahn and Sennett. Though only two types were identified in this data set, it is possible that there could be a third type that is a transition between Type 1 and Type 2 that did not emerge because of the limited cases. Note there was no pattern to the use of the *Coach* strategies or the facilitator-student interaction level.

4.4.2.1 Type 1 – Predominantly Prompting Students to Take Action

Facilitators in Type 1 used *Articulate* prompts as their primary strategies in guiding students in the problem solving process. These facilitators often paired *Articulate* strategies with one or two other strategies, such as *Monitor* and *Explore*, or *Scaffold* and *Model*. In addition to the primary strategies and the paired strategies, in general, these facilitators used one or two secondary strategies, such as *Monitor* or *Model*. Most of the facilitators' actions started from an *Articulate* prompt, which is a facilitation method from the group of constructs where the facilitator prompts the students to take action. Often a simple *Articulate* prompt was enough guidance for the students to adjust their problem solving path. The three facilitators in Type 1, had either no or limited prior experience with PBL. A summary of the Type 1 characteristics are shown in Table 4.4.

Table 4.4 - Summary of the characteristics for Facilitator Types

	Type 1	Type 2
Level 1 Strategies	One Level 1 strategy, Articulate	Three Level 1 strategies
Level 2 Strategies	Up to two Level 2 strategy, generally Model or Monitor	One or two Level 2 strategies
Paired Strategies	Up to two pairings, where the paring is initiated with the Level 1 strategy, Articulate, and is followed-up with up another strategy	A variety of possible parings, where the paring is initiated from any of the Level 1 strategies and often more than one Level 1 strategy initiates pairs
Prior PBL Experience	Some or None	Extensive

4.4.2.2 Type 2 – Diversified Strategy Use

Facilitators in Type 2 generally used a greater variety of strategies and had three facilitation strategies that were Level 1 (i.e., primary strategies). In addition to multiple Level 1 strategies, these facilitators also used one or two secondary strategies. Similar to the Type 1 facilitators, Type 2 facilitators also paired facilitation strategies. Unlike the Type 1 facilitators, *Articulate* was not the central strategy for their facilitation methods, thus the pairing of strategies by Type 2 facilitators was not solely initiated from an *Articulate* strategy as it was with the Type 1 facilitators. As an example, a Type 2 facilitator may pair a *Monitor* strategy with a *Model* strategy where *Monitor* was the initiating strategy and *Model* was the follow-up strategy. Similar to Type 1, each pair was initiated from a Level 1 strategy; however, because Type 2 facilitators had multiple Level 1 strategies, their paired facilitation strategies were initiated from more than one strategy. As an example, Kahn had *Model* and *Scaffold* as Level 1 strategies, and he used both individually to initiate paired strategies (i.e., *Model* was paired with *Explore* and *Scaffold* was paired with *Articulate*). The two facilitators in Type 2, had extensive prior experience with PBL. A summary of the Type 2 characteristics are shown next to the Type 1 characteristics in Table 4.4.

4.5 Discussion

Through this study, I have investigated the facilitation methods and strategies of five instructors individually and then compared the facilitators profiles to each other; this resulted in the development of the Typology of PBL Facilitation Strategies. This typology for facilitation provides actionable ways for PBL-FIEC to be put into practice by instructors. The PBL-FIEC model contains six facilitation methods and 27 facilitation strategies; the typology provides examples of how a sub-set of these methods and strategies can be used to effectively facilitate engineering students in introductory PBL courses. In asserting this effectiveness, I draw on other findings from this NSF-funded project that showed similar student motivation outcomes from all of the PBL groups, and that students in this course when compared to students in a traditional engineering design introductory course were more learning focused than grade focused (Matusovich et al., 2011). Both of these findings indicate some measure of success for this course and each facilitator.

4.5.1 Facilitation Strategies

In this data analysis, two types were identified: *Type 1 – Predominately Prompting Students to Take Action* and *Type 2 – Diversified Strategy Use*. A Type 1 facilitator uses limited facilitation strategies and primarily relies on the *Articulate* strategies to prompt students to take action. Comparatively, a Type 2 facilitator uses a greater variety of facilitation strategies, having three Level 1 strategies, where they use strategies that prompt the students to take action or strategies where they provide actions for the student to observe. The Type 1 facilitator's reliance on Articulate as a primary strategy indicates that the facilitator may not be able to accurately judge students' level of comprehension by only observing them, instead the facilitators use *Articulate* prompts to uncover gaps in student knowledge. In contrast, the Type 2 facilitators generally enact *Model*, *Scaffold*, and *Monitor* as Level 1 strategies, and each of these strategies indicate a prior facilitator perception of students' knowledge, understanding, and/or ability to reason. Type 2 facilitators seemed more able to predict the needs or learning gaps of their students through observation, and thus could rely on strategies other than *Articulate* to provide their students with *Models* or *Scaffolds* or to prompt the students to *Monitor* their cognitive processes or to *Explore* new knowledge. Between the two types of facilitators, the Type 2 facilitators seem to have a better perception of their students learning.

For the Type 1 facilitators, in addition to *Articulate* as their Level 1 strategy, they generally use one secondary facilitation method from the PBL-FIEC model as well as pairing *Articulate* strategies with up to two other facilitation methods, one of which is typically their secondary method. Overall this means that a Type 1 facilitator regularly uses less than half of the facilitation strategies from the PBL-FIEC model. However, when they perceive students lack of knowledge or understanding, they do follow-up with a paired strategy to push the students to *Monitor* their cognitive processes or to *Explore* to expand their current knowledge and understanding. The Type 2 facilitators similarly used paired strategies to push students to deeper levels of cognition and metacognition, in a way that supports students in developing self-directed learning skills. However different from Type 1 facilitators, Type 2 facilitators regularly enacted facilitation strategies from each of the PBL-FIEC methods, including strategies from the Methods that call on the facilitator to provide (e.g., *Model* and *Scaffold*). These two Methods help the students build knowledge in ways that are different from *Monitor* and *Explore*, as they help the student to build conceptual models and transfer knowledge.

4.5.2 Facilitator Experience Level

The Type 1 facilitators in this study are all post-doctoral researchers with less than two semesters of prior PBL facilitation experience. These facilitators are early career professionals, and compared to more senior faculty likely have fewer experiences that would help them to use other facilitation methods. The facilitators in this study that were Type 2, are both faculty members with several semesters of prior PBL facilitation experience. Compared to the Type 1 facilitators, the Type 2 facilitators have more experiences that they can call on, that likely help them in using a variety of facilitation strategies. Additionally, these facilitators have experience in working with students, particularly in this course, and they know the problems and learning sequence typical of this course quite well. This experience makes it plausible that the facilitators are able to anticipate what the students' needs will be or where the students will get stuck. It seems that there is a possible connection between facilitator type and their prior PBL facilitation experience; however, it is difficult to know for certain because there is not a facilitator in this data set with a moderate level of prior PBL experience.

4.5.3 Transitional Type

Although, a third type did not emerge from the given data set it is possible that there could be a third type that is a transition between Type 1 and Type 2 as the two identified types are significantly different from each other. Type 1 appears to be a beginner or entry level facilitator type, using limited strategies, but doing those well. Then Type 2 looks more like an advanced facilitator type regularly using nearly all of the facilitation strategies. This separation in the two types gives space for a possible third type that would be a transitional type. A transitional type would probably enact two Level 1 strategies and one or two Level 2 strategies, along with a few paired strategies. It is not certain that a transitional type would exist as one did not emerge, but that could be caused by a limited data set.

4.6 Limitations

There are two methodological limitations that should be considered when interpreting the results of this study. Though these limitations do not invalidate this study, they do constrain the conclusions that can be drawn. First, of the five cases in this study, only facilitators with little-to-no or extensive prior PBL facilitation experience were represented; there were no facilitators with moderate yet not extensive experience. As previously mentioned, this may be a limiting factor in the emergence of the types. However, the facilitators did have diverse demographics in other ways (i.e., male and female, post-doc and faculty, engineering and non-engineering degrees). Therefore, the Typology of Facilitation Strategies accounts for different facilitation styles based on varied demographics. Second, Dr. Petersen's case had relatively limited data in comparison to the other cases (i.e., only two recorded observations and one observation with only field notes), which was beyond my control. Dr. Petersen's case had the fewest variety in the strategies enacted and only one Level 1 strategy. Although it is possible that a secondary strategy for Petersen might have emerged if the case had a complete data set, given that the time between the observations was at the maximum possible (i.e., Week 1 and Week 6), there was the best possible opportunity to observe possible changes in facilitation strategies. Additionally, since Petersen falls into a type with two other cases, it is unlikely that a complete case would have resulted in the emergence of a new type.

4.7 Implications

This study has important implications for practice. By providing a Typology of Facilitation Strategies, which include pragmatic examples of facilitation practices of facilitators from a variety of backgrounds, future PBL practitioners have concrete guidance on how to enact facilitation in engineering contexts regardless of their background or prior experience. This provides the PCK that was lacking and was a barrier to sustained PBL practice with fidelity. Prior investigations of PBL facilitation strategies in engineering provided a large and comprehensive model for based on the facilitation practices of many facilitators. The

Typology digests this model into two fundamental ways a practitioner could enact a set of these facilitation strategies in their course. Additionally, this Typology should be considered when developing facilitator training programs as it represents that there can be differences in the way the PBL-FIEC model is enacted in practice.

4.8 Future Work

While this study served its purpose to translate a research-based model into PCK that is actionable (e.g., Typology of Facilitation Strategies) for PBL practitioners to use to improve their facilitation strategies in engineering courses, there are areas of future research that could help to expand the Typology or improve our understanding of the different types. First, we conduct a similar study with more facilitators who have a wider diversity in demographics. For example, including facilitators with a range of prior experience with PBL facilitation (i.e., none, some, moderate, and extensive) and a range of professional experience (i.e., post-docs, and assistant, associate, and full professors). This would allow a broader investigation into the potential of a transitional type as well as if or when a facilitators might transition from one type to another. Second, we could investigate whether there is a relationship between the facilitation style and the students' development of skills commonly associated with PBL pedagogy. This could be accomplished by observing and analyzing PBL facilitator behaviors using the PBL-FIEC model and the Typology of Facilitation Strategies to determine the facilitator type; in addition to measuring student learning outcomes by collecting and analyzing written reports (as grades in and of themselves are not appropriate measures) and oral presentations to look at things such as complexity of the solution. Third, we could investigate fading of facilitation and to what extent and when students start to learn how to self-facilitate their group. This could be accomplished by observing PBL groups over a longer period of time, preferably an entire semester. Using the PBL-FIEC model and the Typology of Facilitation Strategies, but segment each case into three pieces corresponding to beginning, middle and end of semester to see if the facilitator type changes between these segments. Additionally, the PBL-FIEC model can be used in a similar way as in this study, but to develop a typology of student self-facilitation strategies and likewise see if there is a change in student self-facilitation type between the three semester segments. Lastly, we could investigate the facilitator's intentions (or lack of) in their facilitation strategies by interviewing them concurrently with the observations. Such a study could reveal whether a facilitator was limited to a Type 1 by their facilitation skills and experiences, if was an intentional choice, or if it is more based on their personality (or authentic teaching-self).

Chapter 5. Discussion and Conclusion

5.1 Introduction

The purpose of this dissertation study was to use the Innovation Cycle of Educational Practice and Research (ICEPR) as a lens to investigate the challenges with facilitation practices in introductory PBL engineering courses (Jamieson & Lohmann, 2009), and to develop a pragmatic research-based model that provides insights aimed at improving PBL facilitation practices. In order to achieve this purpose I answered the following research question:

How can the Innovation Cycle of Educational Practice and Research be realized for problem-based learning (PBL) in engineering?

To answer this question, this dissertation study included three phases and completed one loop around the ICEPR, enabling me to focus on both practice and research of PBL facilitation in engineering. Using the ICEPR as a lens allowed me to investigate educational practices of PBL to inform a research study, the results of which could in turn be used to inform and improve facilitation practices in PBL. The preceding three chapters each corresponded to a phase of the study, sequentially addressing the following aims:

1. to identify challenges in training PBL facilitators and in the transition and practices of new PBL facilitators in introductory engineering courses,

2. to develop a research-based model for PBL facilitation methods and strategies in introductory engineering courses, and

3. to develop a typology of PBL facilitation strategies with pragmatic examples of how the facilitation model is used in practice.

In Phase 1, I studied a new PBL implementation in an engineering course to identify challenges with facilitator training and practices (Manuscript 1). Results from Phase 1 provided ideas and questions for research that became the impetus for Phase 2 (Manuscript 2). In Phase 2, I studied a well-established PBL course in introductory engineering to develop a research-based model, PBL Facilitation Strategies in Introductory Engineering Courses (PBL-FIEC). The model developed in Phase 2 was then used in Phase 3 (Manuscript 3), where I studied the same well-established PBL course to develop a typology of facilitation strategies that provides pragmatic ways to implement PBL-FIEC into practice. In summary, using the ICEPR I investigated PBL practice to identify questions and ideas which led to research study on PBL that resulted in answers and insights that I believe are ready to be used for improving PBL practice. A mapping of the outcomes from each phase of my dissertation as they relate to developing research that can impact improved innovative practice is shown in Figure 5.1.

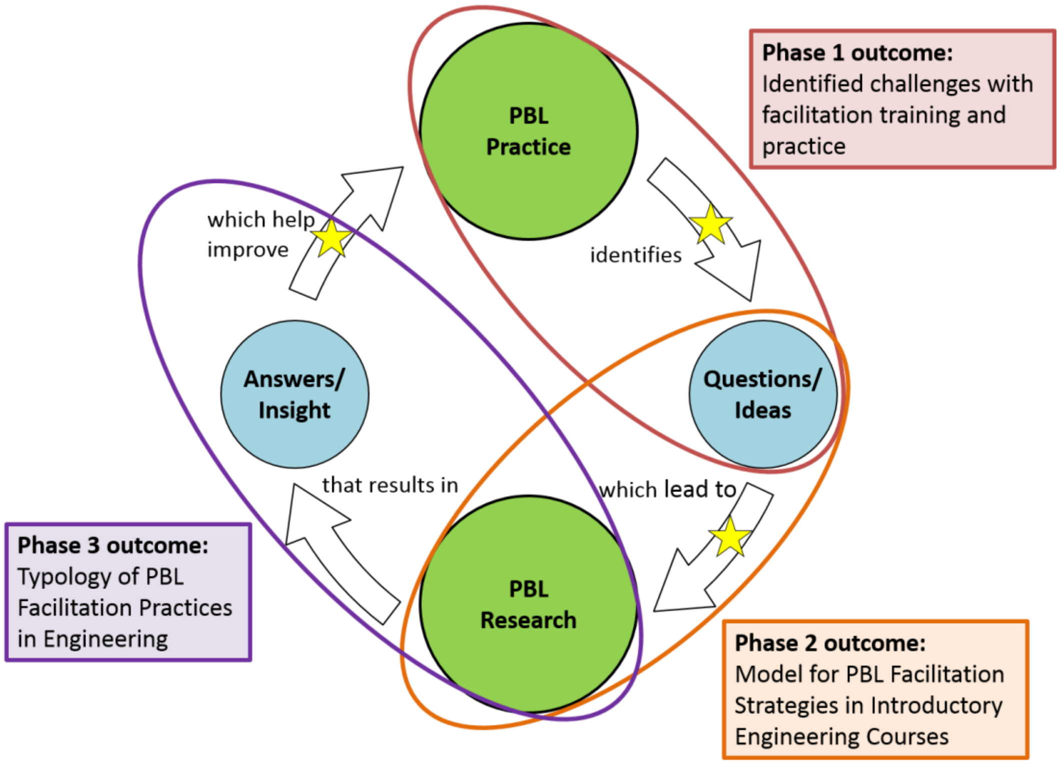


Figure 5.1 - Dissertation outcomes superimposed on the Innovation Cycle of Educational Practice and Research

5.2 Implications

Persistent gaps in the ICEPR for engineering education have limited the impact of education research on the use of PBL pedagogy in engineering. In that regard, the implications of my dissertation results are two-fold related to both facilitation practices in engineering courses and educational research and consider the interplay between the two. Implications for practice include using the PBL-FIEC model and more specifically the Typology of Facilitation Strategies for developing facilitator training programs and evaluating facilitation practices. Implications for research involve the use of the PBL-FIEC model for further study of PBL facilitation practices. Additionally, the use of the ICEPR in this study has implications for both educational practice and research.

5.2.1 Implications for Practice

My dissertation research has implications for practice in the areas of preparing instructors to become PBL facilitators in engineering and on the reporting of both successes *and* failures of pedagogical implementations. In Chapter 1, I identified that lack of PCK situated in engineering is reported in the literature as a barrier to attempt implementations of learner-centered pedagogies (Beddoes et al., 2010; Finelli et al., 2013; Henderson & Dancy, 2007). Additionally, in Chapter 2 (Manuscript 1) the results of an investigation of a new PBL implementation further identified the lack in understanding of facilitation strategies for an engineering context as a challenge in training instructors for PBL facilitator roles in engineering.

In response to the lack of PCK, PBL-FIEC provides pedagogical-content knowledge, specifically for PBL facilitation situated in a relevant context that engineering instructors seek when considering implementation of new pedagogies. The PBL-FIEC includes six broad methods for facilitation and a total of 27 strategies related to the methods, with three to six strategies per method. For each method and strategy there is a clearly stated pragmatic definition. Additionally, included with each strategy are examples from practice, in the context of engineering education, of how each strategy can be implemented and the student response each strategy intends to elicit (i.e., fostering self-directed learning, helping students build conceptual models, or guiding students to evaluate performance and adjust learning goals or tasks). The PBL-FIEC model provides a pragmatic and tangible way for engineering instructors to understand PBL methods and strategies and to implement into their courses with ease. Furthermore, this model is not limited to PBL in introductory engineering courses, although that is the context in which it was developed. PBL-FIEC can contribute more broadly to the understanding of learner-centered instructional strategies regardless of the specific pedagogy. As an example, for engineering capstone design contexts a model for instructional strategies was developed based on workplace mentoring strategies (Kram, 1985), where the instructor acts as a mentor that supports the student learning process. Notably, there is some overlap between cognitive apprenticeship (and thus PBL-FIEC) and the Model for Mentoring in Engineering Capstone (Pembridge, 2011), such as the methods/functions of coaching and role modeling. This intersection provides an opportunity for the PBL-FIEC model to further inform instructional strategies in engineering capstone. Furthermore, instructors teaching in more traditional primarily lecture-based courses can use strategies from the PBL-FIEC model to initiate discourse that encourages deeper cognitive development and metacognitive skills in students.

In regard to facilitator training, the facilitator training and thus the facilitation implementation in Manuscript 1 suffered from the lack of pragmatic models for facilitation in engineering. The Typology of Facilitation Strategies developed in Phase 3 provides a foundation for training instructors who are new to PBL facilitation and for training facilitators with some PBL experience in advanced facilitation strategies and will be beneficial to future PBL implementations, specifically for the facilitator training. Additionally, reconsidering the outcome of the training and implementation of Manuscript 1, where the novice facilitators relied mostly on questioning strategies, a similar pattern was identified in the Manuscript 3 for Type 1 facilitators. The Type 1 facilitators were also novices and relied on *Articulation* as their primary strategies. This gives an indication that enacting *Articulation* strategies is an appropriate place for novice facilitators to start, as long as they are supported with pragmatic examples of how to implement the strategies. Considering that the PBL-FIEC model contains 27 different strategies in six different facilitation method constructs it can be overwhelming or burdensome for an instructor new to PBL facilitation. However, the Typology provides examples from practice of actionable ways that facilitators can leverage a sub-set of the strategies or methods to effectively facilitate students in PBL. In the Typology, there are two types with a potential for a third transitional type between the two. Where Type 1 only requires knowledge and use of a few strategies and Type 2 requires use of nearly all of the strategies. However, PBL-FIEC and the Typology should not be used a merely checklists, but should be part of transforming teaching and learning, where PBL-FIEC and the Typology are simply a starting place that can open the door for new practices.

Lastly, this dissertation is an example of publishing findings from a less than successful implementation of an innovative pedagogy, in a way that informs future research that can in turn improve future implementations. This step feeds the ICEPR and helps to improve pedagogy and leads to further innovation in the future. Not only did Manuscript 1 provide a path to improve PBL facilitation in engineering, it also provides an example for implementers of all pedagogical innovations to publish their findings whether successful or not in an attempt to inform research that better informs practice.

5.2.2 Implications for Research

The research presented in my dissertation has implications for research on PBL facilitation strategies and the development and evaluation of training programs. The PBL-FIEC model expanded the instructional methods component of Collins' Cognitive Apprenticeship framework (2005) to include six instructional methods defined for an engineering context and 27 facilitation strategies associated with the six methods. The PBL-FIEC model provides a new lens for studying PBL facilitation strategies in engineering as opposed to prior models that were designed in the context of medical education. This model is just the beginning as it sets a path for future investigations that could expand on this model, or use this model to better understand facilitator practices, or how students develop self-facilitation skills.

Additionally, the PBL-FIEC model and more specifically the Typology provide a foundation on which to develop PBL facilitator training programs for engineering instructors. The Model and Typology provide facilitation strategies, which address nuances specific to engineering contexts and will adequately prepare engineering instructors to use PBL facilitation strategies in their courses. Moreover, the Typology is a valuable research tool for evaluating facilitation practices of instructors, and for understanding the impacts of different facilitation types.

Lastly, developing the Typology from the PBL-FIEC model is an example of how to translate educational research into a form that is useful for improving education practice. This is an example for other instructors to follow when considering how his or her research fits into the ICEPR and how they might develop research-based insights that can have a direct impact on practice.

5.2.3 Summary of Implications

In summary, the results of my dissertation have implications for both research and practice. Each of these implications is a direct result of the intentional connection between practice and research by using the ICEPR to guide the design of the studies throughout.

5.3 Future work

While the findings of this study advance our understanding of PBL facilitation strategies in engineering courses and are important in and of themselves they also open the doorway to future and important research. A natural next step would be to continue cycles of the ICEPR and implement the research insights from this study and improve a current or implement a new more robust PBL practice. We need to take what we learned through all three manuscripts (e.g., the challenges with implementation and training, the needs for training improvement, the PBL-FIEC model, and the Typology) and support engineering instructors in developing PBL implementations for their courses. This will provide more sites for future studies related to PBL facilitation. Additionally, the implementing instructors should report their findings both the successes and failures as this will shape future research aimed at improving PBL practice. Specifically, I suggest 5 areas of future work related to the findings in my dissertation.

5.3.1 Validation of the PBL-FIEC Model in Other Engineering Courses

We could use PBL-FIEC to investigate facilitator strategies in PBL implementations within different engineering courses (preferably well-established PBL courses) to address the limited scope of my study, which only included a single course. Such a study would allow us to validate and possibly expand the model for engineering courses in general. Additionally, these subsequent studies should include interviews with the facilitators to address the limitation of my study that resulted from me only including observations of facilitator and student interactions during PBL sessions. Conducting facilitator interviews following each PBL session would enable confirming facilitator intentions in using different strategies.

5.3.2 *Investigate Relationship Between Facilitator Type and Student Learning Outcomes*

We could repeat the study in Manuscript 3 with new participants and include measures of student learning. The measures of student learning should illuminate the learning outcomes often associated with PBL pedagogy (i.e., advanced problem-solving skills, deeper understanding of course material, increased ability to work cooperatively in groups, increased communication skills and engagement in self-directed learning) and possibly include items such as, final reports, presentations, and interviews, but not grades as they might not be an accurate measure. This investigation should reveal student learning outcomes for PBL engineering courses using appropriate measures as well as to see if there are connections between facilitator type and student learning outcomes.

5.3.3 *Development and Study of Facilitator Training Course*

We could develop and evaluate a facilitator training program for engineering instructors based on the PBL-FIEC model, Typology, and the lessons learned in Manuscript 1 as part of a new PBL implementation. This would allow us to create a robust training course that could be implemented across the country in engineering colleges.

5.3.4 *Stages of Development for PBL Facilitators*

We could expand the Typology, by including a larger sample size of facilitators with a wider diversity of backgrounds (i.e., mid and late career faculty with no prior PBL facilitation experience). Doing so would address the limitation of variation in facilitator rank and experience, and allow us to investigate the stages of development for PBL facilitators and possibly provide more support in training programs for facilitators at all levels.

5.3.5 *Fading of Facilitation and Student Development of Self-Facilitation Skills*

We could investigate student development of self-facilitation skills and strategies, by using the PBL-FIEC model as a lens to evaluate student behaviors. Previous studies have suggested that facilitators should fade their facilitation roles as students gain experience in PBL and can begin to take over these roles (Hmelo-Silver, 2004; Hmelo-Silver et al., 2007). This would allow us to understand the necessary supports for developing these skills and the role of the facilitator in the process. Moving students toward this type of self-facilitation is the start of transformative pedagogy and students transforming as learners.

5.4 Researcher Reflection

The larger NSF-funded project, which funded this current study, was in its second year when I joined the research team. The first year of the project included the observation and data collection of the well-established PBL course at State University 1 (SU1), of which I did not take part. In the second year when I joined the project, I was involved with 1) reviewing the PBL observations from year one, 2) designing the PBL implementation course and resources for SU2, 3) preparing the facilitators, 4) observing and collecting data on the implementation, and 5) conducting interviews with student participants. Though I was not involved with the direct observations of the PBL course in year one, I watched many hours of recorded PBL sessions and had the unique opportunity to sit in on a PBL session at SU1 during the second year of the study.

Through participating in designing and implementing a PBL course in engineering at State University 2, I directly experienced the challenges that come with such an undertaking. It was easy for me to understand why many faculty would give up on an implementation and not try again. I doubted through much of the implementation and more so after if the students were any better off based on their experiences. Yet, there was a glimmer of hope; I saw what was possible in the PBL course at SU1 and I knew there was something to be learned that could help to ease the transition for others. It was this experience and sentiment that grew my interest in understanding the PBL facilitators' roles and strategies in an engineering context. I wanted other students to have the opportunity to have the same experiences the students at SU1 were having.

This experience resonated with me in my role as an instructor and connects with my philosophy toward teaching. I believe that what is learned is more valuable than what I teach and that learning can happen without me teaching. I believe that each of my students has the ability to be a learner. That it is an inherent in their nature to be curious about the world around them, to have desires to discover new things, and have dreams to leave their mark on this world; everyone wants to be passionate about something. I think my biggest role in the classroom is to not get in the way of this nature and I think that being a facilitator as opposed to a lecturer is one way to accomplish this. This starts with engaging in pedagogy that transforms the way students approach learning, and allowing my teaching practices to be transformed as I learn from my students.

As a facilitator, I recognize that I am not the holder of all the knowledge and that I have the opportunity to learn as much as my students. I see my role as a guide or a facilitator, to provide scaffolds in ways that make knowledge more accessible and to assist students in practicing cognitive tasks and metacognitive skills. It is my job as a teacher to uncover the natural characteristics in my students and bring them to life in the classroom. Thus, my philosophy on teaching is: in all things do not be a barrier to my students' learning and in all things make knowledge more accessible for my students and aid them in the meaning making process (i.e. cognition). My goals in the classroom are (1) to remove barriers to students learning and to not be a barrier, (2) to build agency in my students, and (3) to create structures that make knowledge more accessible.

5.5 Concluding Remarks

While I began the study with appreciation for learner-centered pedagogies, completing my dissertation has strengthened my vision for PBL in engineering. Drawing on my teaching and research experiences, I have formulated a vision for how PBL facilitation could impact the future of engineering education, and more specifically my future work. I would like to see more classrooms move toward learner-centered and facilitated learning environments. If we invested the resources for facilitation in the early years of higher education, then we can develop learners who are self-directed and self-facilitated, that work in groups with shared responsibility and challenge each other both cognitively and meta-cognitively. My first job post-dissertation will take me to Mexico, where I will work with under-educated youth in non-traditional learning environments. My goal is to use my knowledge of facilitation strategies to foster a deep desire for learning and discovery as I help to prepare these youth for their vocations. Most of these youth have been failed by the educational system, and deeply seeded negative beliefs about their abilities to learn. I believe that learning in a collaborative and facilitated setting can help students regain confidence and restore their natural curiosity, sense of discovery and passion.

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APPENDIX A. Problem Statement

Improving Ambulance Safety

Emergency Medical Services (EMS) plays a vital role in our society. They are called on to respond to medical emergencies; provide life-saving medical care in the field, stabilize patients and transport patients to hospitals. EMS personnel work in high stress situations where seconds can mean life or death for the patients in their care. EMS personnel are under pressure to respond quickly to emergencies and to quickly transport patients to hospitals for advanced medical care.

Unfortunately, the need for rapid transit to and from the scene of an emergency, has many potentially negative consequences for both patients and EMS personnel:

i) In the rush to arrive at the scene of an emergency, and to transport a patient to the hospital, the ambulance driver will often exceeded posted speed limits and drive through red lights and stop signs. It is estimated by the US department of labor that 74% of EMS staff fatalities are related to transport. EMS personnel in the U.S. have a fatality rate of 12.7 per 100,000 workers; this is more than double the fatality rate of the general population.

ii) The speed of transit often causes significant vibrations and motions in the patient-care compartment, which can cause severe discomfort for the patient. In addition, the paramedic, who is unrestrained while caring for the patient, is at considerable risk during transit. Both of these factors can also contribute to the lack of a stable environment in which to perform sensitive medical tasks.

Your team has been challenged with the following design task:

Design a device, system and/or process that improves the safety and effectiveness of the EMS personnel and/or the safety and comfort of the patient during transport to the hospital.

APPENDIX B. Student Resource: Distributed Facilitator

Workshop #1 – Understanding the Problem

Workshop Outcomes:

By the end of today's workshop, your teams should:

i) Develop a detailed description of the problem that identifies what you know and what you don't know at this point.

ii) Develop a *research plan* for your team that will enable you to expand your understanding of the problem. Each team member should be tasked with further researching a specific aspect of the overall problem.

Phase 1: Individual Analysis of the Problem Statement

Individually, take 5 minutes to briefly write down responses to the following questions:

- What are your initial thoughts of the problem statement?
    - What immediately jumps out to you as the crux of the problem?

- What is the context of this problem?
    - Who are the stakeholders in this problem? Who is affected by your design decisions?
    - How could they be affected by your final design?
    - In what environments does this problem occur?

- What are the sub-problems of the overall problem? (*Note: there are always multiple!*)
    - What are the critical roadblocks of this problem?
    - What problems must your final design solve?
    - Why are these difficult problems to solve?

- What are the tradeoffs in this problem? What conflicts are inherent in this system? i.e., what component of the system suffers as result of the improvement of another component?

- What questions do you have about the problem statement?

Workshop #1 – Understanding the Problem

Deliverable #1: Create a Shared Google Document

Your team will use a shared Google Document to collaboratively take notes during the Design Module's workshops. See "ENGE1114_S11_OnlineCollaborationTools.pdf" for help.

- Log on to docs.google.com
- Create a new document (one team member should take the lead here)
- "Share" the document with your teammates *and your Workshop Leader* (by entering their email addresses).
- By following the link in the resulting email, you team will be able to collaboratively (and simultaneously) take notes (and even write your project report!).

Phase 2: Team Analysis of the Problem Statement

Appoint one person as the recorder for this portion of the meeting.

- Each person should take a few minutes to share their overall ideas and questions about the problem (from Phase 1) with the group while the recorder takes notes.

Change to a new recorder. As a team, review the notes and answer the following questions:

- What do you know about the problem and its context?

- What is unknown about the problem?
    - As a team, brainstorm a series of questions about the problem statement.
    - The goal is to identify as many questions (about all aspects of the system) as possible.

- Group the questions into categories related to the various sub-problems you identified earlier.
    - What aspects of this problem need to be researched?

Workshop #1 – Understanding the Problem

Phase 3: Formulate a Research Strategy

Change to a new recorder

- Review the categories and questions, and identify who is interested in researching each area. If multiple people are interested in an area, develop an equitable way to distribute the work.

- As a team, brainstorm potential resources that can be consulted to assist in answering each question. Make sure the recorder captures both who is responsible for each area and what potential resources the team has identified (though each person will likely have to expand his or her search resources).

Deliverable #2:

As a group, assign each member an aspect of the problem to research, using the categories identified earlier. Present these assignments to your workshop leader before leaving.

Workshop #1 – Understanding the Problem

<u>Phase 4: Reflect on the Meeting</u>

Change to a new recorder. Take notes of this discussion in the group's Google Doc.

- Does the Google Document clearly record everyone's input? If not, what's missing?

- Does the Team Analysis (defining the questions and categories) capture the critical issues identified by each team member? If any issues were left out, why?

- Is everyone on the team satisfied with their research assignment? If not, how can the team distribute the work more effectively – either today or for future portions of the project?

- Does everyone on the team have a clear idea about how to start their assigned research task (i.e. resources to consult, search terms, people to contact)?

- Are there opportunities for improving your team's performance in your next meeting?

<u>Before the next workshop meeting:</u>

- Complete your individual research assignment.
- Record & document research results on a separate Google Doc that is part of the group's "Collection"
- Do your best to provide answers to the questions identified within your assigned category.
- The more concrete and definitive (and quantitative, if appropriate) the answer, the better.
- Remember to cite your sources!
- Be prepared to share your results with your team members and your workshop leader.

APPENDIX C. Floating Facilitator Resource

General Strategies

1. Make sure students have completed each Phase before moving onto the next.
2. Circulate about the classroom. Make sure you are giving equal attention to all the groups. Guide them when they are stuck or heading in the wrong direction.
3. Listen to the students. Be slow to speak. Use the questions below to guide the students, but don't just give the questions or answers. Model for them the behaviors of Inquiry, Problem Solving, Knowledge Building and Team Skills.
4. When the students use qualitative terms like: a lot, more, most….get them to think in quantifiable terms (e.g. lbs, feet) which might require them to do some research. When the students give data….ask them to state the source.
5. When students say "I think" or "I believe"…ask "what is your reason and evidence?"
6. When they start using specific terms probe them to define that term in a way that is agreeable to the group. Operationalizing the terms (e.g. What do you mean by time? What do you mean by safer?)

PBL Questions to help <u>guide</u> the students

Phase 1:

1. What is the root of the problem? [injury, death, discomfort, safety]
    a. Get the patient medical care in a timely fashion, while keeping the patient and others safe.
2. Get them to identify the real problems and away from solutions.
    a. What causes the discomfort? [movement in a vehicle, vibrations]
    b. What causes the deaths? [collision with other vehicles, accidents]
    c. What causes the injuries? [near miss accidents, quick changes in direction]
    d. What are the safety concerns? [movement of the providers and patients]
    e. If they are identifying solutions, ask them 'What problems does that solve?'
3. What is the context?
    a. Who are the users? [EMTs, patients]
    b. Who else do the design decisions effect? [manufacturer, salesman, doctors, hospital, public at large]
        i. Who are the purchasers? [local governments, fire stations, EMTs]
    c. What are the implications on these people?
        i. In what ways could they benefit?
        ii. In what ways could they be negatively impacted?
    d. Where will the solution be implemented? [Blacksburg, town, rural, dirt roads, small alleys, during natural disasters (flooding, high wind, snow)
4. What are the sub-problems?
    a. The users? Patient restraint, EMT restraint
    b. The transport? Vibrations, motion, equipment motion, roadways and routes
    c. The urgency? Patients need medical attention quickly. Does that mean we have to speed to get to the hospital?
5. What are the tradeoffs?
    a. Speed vs. Cabin motion
        i. The patient needs medical attention quickly thus there is a need for fast transportation.

        ii. If we decrease transportation speed then we can have a smoother and safer ride. But we put the patient's health at risk.
   b. EMT maneuverability vs. safety
   c. Time vs. Patient's health

Phase 2:

1. What are the unknowns?
   a. What do you need to know about how the patient is transported?
      i. What is the size/weight of the gurney?
      ii. How is the gurney attached to the vehicle?
      iii. How are they strapped to the gurney?
      iv. Does it have to be a gurney?
   b. What do you need to know about the motion of the ambulance?
      i. How much vibration is there?
      ii. How much motion is there?
      iii. What are the transport speeds?
      iv. How long is the average transport (time/distance)?
   c. What do you need to know about the EMT?
      i. What are his jobs during transport?
      ii. Where is he located relative to the patient?
      iii. How much equipment does he need access to?
      iv. How much range of motion does he need?
      v. Does he currently use any restraint system?
      vi. What are the current protocols/rules that guide how the operating procedures for the EMTs?
   d. What are the causes of collisions?
      i. In what ways are the vehicles damaged?
      ii. What are the impact forces?
      iii. Are rollovers a big problem?
      iv. Side collisions, head on, single vehicle?
   e. What more do you need to know about where an ambulance is used and the context?
   f. What are the causes of patient discomfort? What is the level of discomfort?
   g. What are the causes of injury/death?
      i. Who is injured/killed?
      ii. How?
   h. What are the current "safety features" for the EMTs? the patients?
   i. What are all the things you know about the vehicle? What do you want/need to know about the vehicle?
      i. What are some of the measureable things?
         1. Size of the vehicle?
         2. Weight of the vehicle?
         3. Height?
         4. Width?
2. Get them to stay away from solutions, however if they are "stuck" on a solution push them in other directions:
   a. Do you have to design an entire new vehicle?
   b. Do you have to design just augmentations to the current vehicles?
   c. Does the solution have to involve a vehicle/transport?
   d. Could there be a "procedure" approach to the design solution?
      i. What if we didn't change the vehicle, how might we approach this design?
3. Research strategies:

a. Google?
    i. What are the search terms that you will use?
    ii. Who are the current manufactures?
b. Have you thought about researching existing solutions?
    i. Existing solutions in other contexts.