Professional Competency Development in a PBL Curriculum

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Abstract

Substantial dialogue exists regarding the needs of the engineering profession and the changes in engineering education necessary to meet them. Important to this change is an increased emphasis on the professional competencies as identified by the Washington Accord and the ABET professional skills for engineering graduates and how to educate for them. This paper will explore the potential for a project based learning engineering curriculum model to meet this need. It will summarize a newly developed upper-division undergraduate project-based learning (PBL) engineering program in the U.S. engineering educational system and its approach to professional competency development. Based on the ABET intent, students graduate with integrated technical/professional knowledge and competencies. The program does not have formal courses; instead learning activities are organized and indexed in industry projects where they are solving complex and ill-structured industry problems. The program started in January 2010 and has 75 graduates to date and has earned ABET-EAC accreditation.

A mixed-methods research approach will address the research question: "What is the professional development trajectory of students in the new project based learning (PBL) curriculum?" Quantitative method includes the development of an instrument to measure student growth in professional competencies. Qualitative measures include an interview protocol to understand which components of the PBL model affected the student professional development trajectory. The paper will provide initial results and analysis for the quantitative study, which indicated a positive impact on student attainment of the professional competencies in the PBL curriculum as compared to students in a traditional curriculum.

Keywords: professional competency, professional skills, PBL, assessment

1 Introduction

Two recently commissioned reports from UNESCO [Beanland and Hadgraft, 2011 & 2013] identify that engineering education has not responded in a significant enough fashion to the rapid expansion of knowledge over the past 50 years that has changed the way engineers perform their role of providing solution for their societies' need for change. The lack of response has resulted in both an undersupply of engineering graduates around the world and in "engineering graduates (who) are deficient in the capabilities ... required of engineers."

The engineering education community around the world is engaged in dialogue regarding the needs of the engineering profession, what should be the nature, context, and curriculum for undergraduate education, and the engineering education transformation process to meet these needs (Beanland and Hadgraft, 2013; Sheppard, et. al, 2009; National Academy of Engineering, 2005; National Science Board, 2007; National Research Council, 2004). Within the international community, a landmark point in this dialogue commenced in 1989 with professional organizations and institutions from Australia, Canada, Ireland, New Zealand, United Kingdom, and the U.S. forming what would become the Washington Accord. The Accord was later joined by several countries from around the world (Beanland and Hadgraft, 2013). It sought to establish standards for professional competencies and graduate attributes for engineering students graduating from an accredited institution. In 1996, ABET introduced a new set of engineering accreditation criteria, ABET Engineering Criteria 2000. Of greatest significance towards changing engineering education was the General Criterion 3 Student outcomes, generally known as the ABET Criteria. Programs had to define student outcomes for the attainment of the professional skill and competency aspects of engineering.

Despite these efforts, Sheppard's, et. al., (2009) *Educating Engineers: Designing for the Future of the Field* identified that the curricular design in the engineering education system still had not changed much in regards to meeting the professional development needs of the profession. It was still heavily biased towards analysis to the detriment of professional skills development and other areas of engineering, despite students and employers, alike, expecting a higher degree of synergy between the classroom and what is needed in field (Passow, 2012).

In response to this dialogue, a Midwestern community college and university collaborated to develop a two-year, upper-division, 100% PBL model of engineering education (Ulseth, et. al., 2011). It began in January 2010 as an adaptation of the Aalborg PBL model (Johnson and Ulseth, 2014). The program has 75 graduates to date and has earned ABET-EAC accreditation. A program focus is the student attainment of professional competencies.

2 Professional Development in Engineering Education

A pair of 2005 studies by Shuman (2005) and Loui (2005) focused on the ineffectiveness of the traditional lecture format for teaching the ABET professional skills and argued that a modern engineering education focus on active and cooperative learning approaches. The Loui study identified that students primarily learn about professionalism from relatives and co-workers who are engineers and rarely from their technical courses, and proposed that engineering education should have a focus of "socializing students to become professional engineers."

A promising approach in developing the professional competencies is a curricular focus on professional identity formation. Ibarra and Barbulescu (2010) identified professional identity as an important factor in the student adaption to the workplace. Sheppard, et. al. (2009) describes professional identity in terms of standards of the professional community, "to serve the public with specialized knowledge and skills through commitment to the field's public purposes and ethical standards." Eliot and Turns (2011) define it as the "personal identification with the duties, responsibilities, and knowledge associated with a professional role," developed through a social process where students are connecting expectations with their own needs, wants, and attitude.

The development of the PBL model in this study focused on creating the professional identify for students as engineers with the purpose of their acquiring professional competencies. In the development, three core curricular foci emerged: first, the recognition of the social nature of engineering education and the importance of students developing their professional identity as an engineer; second, the importance for the learning to be embedded in professional practice; third, the potential a PBL curriculum has to support the first two foci.

2.1 Role Acquisition

Thorton and Nardi (1975) proposed that professional role identification is a four-stage developmental process where individuals go from having idealized perceptions of the professional role to a more personalized role aligned with their own values and goals:

1. Anticipatory Stage: Individuals start with a highly idealized understanding of the role of the professional, which is often incomplete. "Social and psychological adjustment" to the professional role is initiated in this beginning stage and is only of value to the extent to which the individual's understanding of the profession is accurate.
2. Formal Stage: Individuals undergo a formal learning experience with the purpose of learning the duties, responsibilities, and knowledge for a professional role. Expectations at this point are generally formal and explicitly stated and focus more on the "behaviors, knowledge, and skills" of the individuals in the role than the actual attitudes held by the individual. Individuals are conforming to the professional role.
3. Informal Stage: Individuals encounter the unofficial or informal expectations associated with the professional role which may align or contradict the formal expectations. Peers and colleagues have the greatest credibility. Expectations are more "implicit and refer to the attitudinal and cognitive features of role performance." This stage is where the individual starts shaping or adjusting the role to fit his individual perspectives and desired outcomes versus the conforming to the role.
4. Personal Stage: Individuals begin internalizing the professional role expectation and attempt to align or adapt it with their values and goals.

2.2 Professional Practice

Passow's (2012) study of ABET competencies identifies the need for utilizing the "context of professional practice" for competency. Sheppard, et. al, (2009) also identifies the need for a professional practice "spine" where students experience "practice-like" experiences as a central component to the educational process; enabling students to "move from being passive *viewers* of engineering action to taking their places as active participants or *creators* within the field of engineering." This professional practice develops the student engineering professional identity.

2.3 Project Based Learning

As professional practice is sought in developing the professional identity of engineering students, a curricular model that supports this is necessary. Felder and Brent (2003) identify PBL as an instructional model that can be readily adapted to achieving the professional competency development desired in engineering students. Several other prevalent publications identify the use of PBL as a critical component of transforming engineering education and developing the necessary professional skills and identities of engineering students: Beanland and Hadgraft, in their 2013 UNESCO Report: Engineering Education, Sheppard, et. al. (2009) in Educating Engineering: Designing for the Future of the Field, and Litzinger, et. al. (2011) in Engineering Education and the Development of Expertise.

3 PBL Curricular Design for Professional Competencies

The new PBL curriculum purposefully incorporates the Thornton and Nardi four stages of role acquisition model and embeds them in a four-semester design sequence professional practice spine. It was specifically developed to address the alignment gap between the desired outcomes for engineering graduates and those attained by traditional program graduates (Ulseth, et. al., 2011). The new PBL model starts every semester in the anticipatory stage for each student with a professional development plan to identify where they are in their understanding and abilities of the professional role for an engineer. Based on this faculty-guided self-assessment, each student identifies: their current professional performance abilities; their professional growth goals for the semester; and their planned activities they will participate in for the coming semester to achieve their professional development goals.

Each semester students experience the formal and informal stages of role development. The formal stage is centered on the PBL program's weekly professional development seminars that formalize the expectations for the week's specific professional engineering competency. The first day of the week starts with the "seminar," a session where all students and staff attend a seminar on a relevant professional development topic. On Wednesday, this topic is a structured part of each team's two-hour meeting with their engineering design project mentor. In this meeting, a discussion is conducted on the development of the team's project, but just as importantly, the discussion also focuses on the professional development of the individuals in the team. Every week ends with students reflecting in their journals regarding their development for the week, including their professional development on the topic of the week.

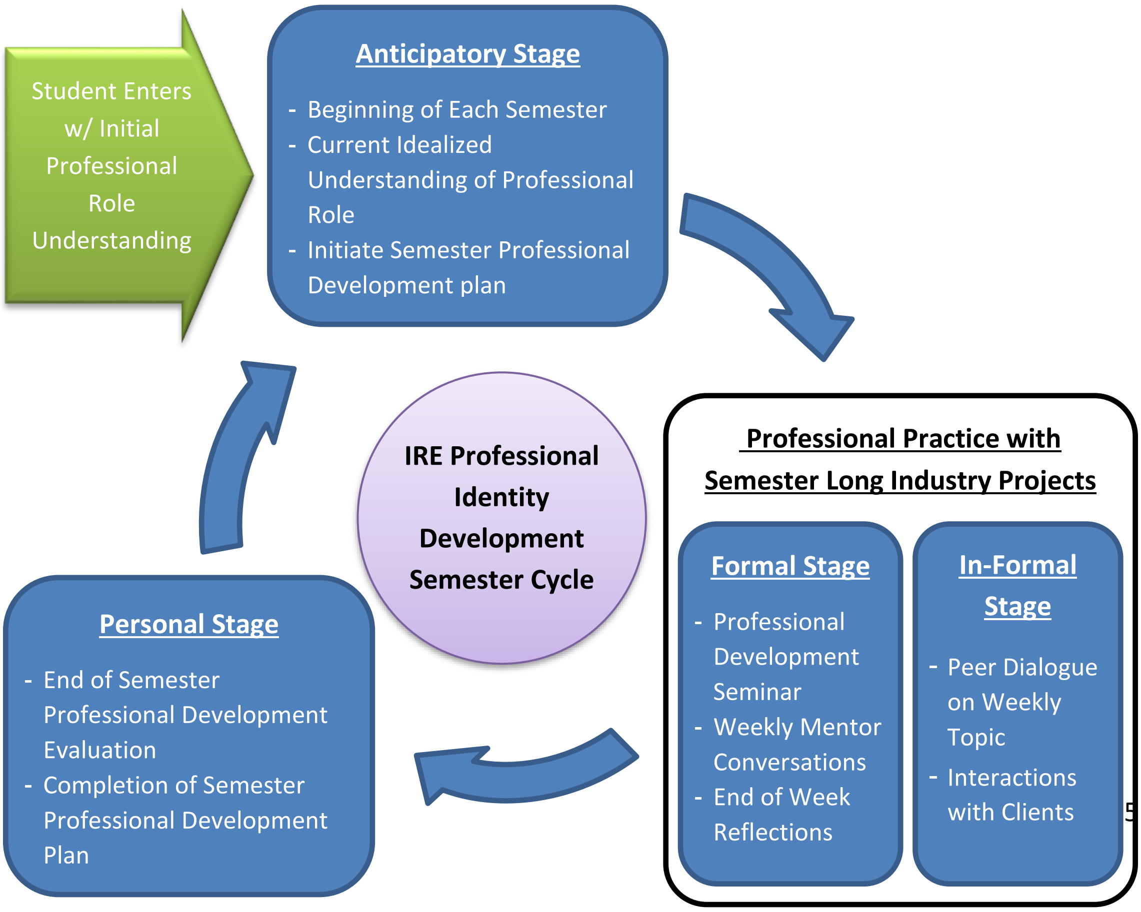
The formal structure and the team structure are both designed to set up the informal stage. As students are adapting the expectations of that week's professional topic to fit their own individual perspectives, their peers have all heard the same message around the professional competency, which guides and provides common language for informal peer conversations. The mid-week meeting with their project mentor facilitates and coaches the adaptation in a professionally supportive atmosphere. The end of the week reflection activity provides the opportunity and expectation for students to identify how they will accept that week's professional topic within their own professional identity.

Vertically integrated teams provide a professionally supportive collegial atmosphere; students who are at the beginning semesters of the program benefit from peers on their teams who are further along in their professional development, which provides them a positive peer perspective on the value of professional competencies. Thorton and Nardi identify these types of interactions as ones that students place the most value on. In addition, students further along in the curriculum benefit from having to guide the younger students. They must first reflect on their own understanding and experiences before they can guide the younger student with a particular professional competency. Student interactions with their clients and faculty leaders also provide multiple opportunities to practice the use of their professional skills and get formative, non-graded feedback on how to improve.

The personal stage is an integrated part of the end of semester assessments and grades for each student. Mentors evaluate each student on performance in all the professionalism areas through a performance evaluation similar to what practicing engineers undergo in the professional setting. These experiences culminate in a chapter of the student's individualized personal development plan (PDP) with a summary of the learning activities during the semester, the level of attainment of the goals from the previous semester, and a summary of the feedback the student has gotten during the performance evaluation. These inputs lead to the development of new goals and detailed action plans for the next semester.

The four-stage cycle is repeated each of the four semesters of the upper division program, with required substantial progress toward the desired graduation level professional outcomes. The revisiting of the professional development topics with increasing level of sophistication each semester reflects the intent of the spiral configuration of the Networked Components Model proposed by Sheppard, et. al. (2009). It better reflects what is understood about learning and role acquisition than the more traditional linear "one-time" through from theory to application model. Professional competencies account for three credits of student work each semester. The model is illustrated in Figure 1.

Figure 1: PBL Professional Development Model



4 Research Methodology

This study looks specifically at how students in the PBL curriculum develop professional competencies compared to students in a more traditional program. An explanatory sequential mixed method approach will be used to address the study's research question:

> "What is the professional development trajectory of students in the new project based learning (PBL) curriculum?"

The first phase of the study, and the focus of this paper, is an initial quantitative study to understand the effect of the PBL curriculum on the student professional development trajectory. It includes the development of an instrument to assess the growth of the student importance for and performance of professional competencies, followed by collection of data from study participants, and an analysis of the results. A future, second phase, qualitative study focuses on understanding how the PBL curricular aspects affected the student professional development trajectory. The explanatory sequential mixed methods approach will provide for a third interpretation of the study results focused on expanding the understanding of the professional development trajectory in the PBL curriculum.

The quantitative study seeks to identify if a difference exists between PBL and non-PBL students in their self-reported growth of importance and performance in their professional abilities. The study will focus on the following four directional hypotheses:

1) PBL students will have an increase in their self-reported importance for professional skills
2) This importance increase will be greater for PBL students than for non-PBL students
3) PBL students will have an increase in their self-reported performance for professional skills
4) This performance increase will be greater for PBL students than for non-PBL students

Currently there are limited well-established resources for assessing student attainment of professional skills (Shuman, 2005). As part of the quantitative study, two instruments were developed to evaluate the professional growth of students in the PBL model as compared to students studying in a more traditional model. The first part focuses on the individual professional abilities and the second part focuses on these professional abilities in a team context.

4.1 Instrument Development

4.2.1 Individual Professional Development Instrument

The individual professional development instrument is based on the ABET student outcomes in Criteria 3 itself. The criteria of specific focus in the study are: an ability to function on multi-disciplinary teams (3.d); an understanding of professional and ethical responsibility (3.f); and an ability to communicate effectively (3.g). In the fall of 2012, a group of the PBL students participated in a workshop where they were first trained on the ABET student outcomes and then developed a list of 19 individual professional behavioral expectations that reflected these outcomes in their own language as students. They were used to develop the items in Table 1. Each expectation is presented in the instrument to participants with the following statement:

"Engineering students are expected to act professionally with one another, with mentors, and with people external to the program. Below is a list of important professional behaviors that engineering students and graduates should follow."

Students are then asked to rate (1 = Low, 5 = High) each expectation item on both:

a) Its importance to your personal and project success & b) Your current level of performance

Table 1: Individual Professional Development Instrument Items

Function on Multi-Disciplinary Team (3.d)	Understanding of Professional and Ethical Responsibility (3.f)	Ability to Communicate Effectively (3.g)
• Arrive at all meetings on time • Treat all others with respect • Meet the needs of your team by completing work on time and of high-quality • Give proactive feedback to others • Do not take frustrations out on those around you	• When told something, record and act upon it • Dress and groom appropriately • Work hard to create an environment free of harassment and conducive to learning • Willingly help others inside and outside of University • Meet all deadlines • Schedule time to better yourself through reading current events • Act ethically in all respects • Continually seek to improve yourself • Maintain a positive attitude • Act safely while completing all tasks	• Read memos and respond appropriately • Speak professionally, free of vulgarities and with appropriate grammar • Pay close attention to your emails and respond to requests in a timely manner

4.2.2. Team Professional Development Instrument

The second instrument is a professional development survey that identifies students' beliefs on the importance of professional development and their current performance level within the context of functioning as a member of a team. This 1-5 Likert-scale instrument is an adaptation of TIDEE professional development work of Davis and Beyerlien (2011). Each expectation is presented in the instrument to participants with the following statement:

"Many engineering projects challenge and stretch the abilities of people involved. This exercise guides you through steps to identify knowledge or skill deficits in your project team and to create a plan for growing your abilities to meet these needs. With instructor feedback and focused effort on your part, you will increase your ability to perform as a professional and become a better independent learner. The first step in planning professional development is to identify abilities needed to be successful. The twelve abilities listed throughout the survey are a good place to begin."

They are asked to rate each ability (and associated behaviors listed) (1 = Low, 5 = High) for:
a) Its importance to your personal and project success & b) Your current level of performance

Professional Ability Expectations In Team Setting

- **Analyzing information** Applying analysis methods/tools to understand & explain conditions
- **Solving problems** Formulating, selecting, and implementing actions for optimal outcomes
- **Designing solutions** Producing creative, practical products that bring value to varied stakeholders
- **Researching questions** Investigating, processing, interpreting information to answer important questions
- **Communicating** Receiving, processing, sharing information to achieve desired impact
- **Collaborating** Working with a team to achieve collective & individual goals
- **Relating inclusively** Valuing and sustaining a supportive environment for all knowledge & perspectives
- **Leading others** Developing shared vision & plans; empowering to achieve individual & mutual goals
- **Practicing self-growth** Planning, self-assessing, & achieving goals for personal development
- **Being a high achiever** Delivering consistently high quality work & results on time
- **Adapting to change** Being aware, responding proactively to social, global, & technological change
- **Serving professionally** Serving with integrity, responsibility & sensitivity to individual & societal norms

4.2 Experiment

The study began with both instruments being administered to students entering the PBL upper-division program, as juniors, for the fall of 2013 and the fall of 2014. This group is identified at the PBL pre-treatment group. The instruments were also administered to 2013 and 2014 graduates of the program. These graduates are the PBL post-treatment group.

At the same time, a comparison, non-PBL pre-treatment group was identified and comprised of junior year students entering traditional upper-division engineering programs in the upper Midwest Region of the U.S. The instruments were also administered to 2013 and 2014 graduates of these programs. These graduates are the non-PBL post-treatment group.

Both instruments were adapted to a web format utilizing Survey Monkey (Sue & Ritter, 2012). Results from the instrument were downloaded into a spreadsheet for data analysis. For each data set, averages and standard deviations were calculated. Using a Z-score > 2 for statistical significance was sought for growth from prior to upper-division experience to after upper-division experience. Table 2 details the number of students completing the instrument.

Table 2: Number (n) of Students Completing Both Instruments.

	Comparison Group		PBL Group	
	pre-nonPBL	post-nonPBL	pre-PBL	post-PBL
Number of students (n)	87	43	46	30

5 Results

Results, summarized in Table 3, indicate that students who experienced the PBL curriculum indicate growth in self-reported performance for both parts of the instrument with an increase of 0.3 and 0.4 respectively. The current results indicate no significant growth for non-PBL students in performance overall for these 30 professional abilities. The results for both PBL and non-PBL students indicate no growth for the importance for professional abilities.

Table 3 Composite Pre-Post Professional Responsibility Growths

		PBL Group Mean Scores				Non-PBL Group Mean Scores			
		Pre	Post	Growth	Z-score	Pre	Post	Growth	Z-score
Individual Professional Responsibility	*Performance*	**4.0**	**4.3**	**0.3**	**2.7**	4.1	4.2	0.1	1.0
	Importance	4.7	4.7	0.0	-0.1	4.6	4.6	0.0	-0.3
Team Professional Responsibility	*Performance*	**3.6**	**4**	**0.4**	**4.9**	3.7	3.9	0.2	0.6
	Importance	4.6	4.6	0.0	1.0	4.6	4.6	0.0	-0.1

The results were also analysed at the individual item level. The PBL students showed significant growth in 15 of the 30 instrument items and the non-PBL students showed significant growth in only one instrument item, as displayed in Table 4.

Table 4 Individual Instrument Items of Growth

PBL Group Growth Items	**Pre-Score Mean**	**Post-Score Mean**	**Growth**	**Z-Score**
Importance: Pay Close Attention to Email & Timely Response	4.70	4.93	0.23	2.69
Importance: Act Safely	4.67	4.90	0.23	2.13
Importance: Researching questions	4.39	4.77	0.38	2.87

Performance: Pay Atten. to Email & Timely Response	3.96	4.47	0.51	2.90
Performance: Act Safely	4.24	4.60	0.36	2.32
Performance: Meet Needs of Team	4.04	4.37	0.32	2.04
Performance: Willingly help others in & out of Eng. Env.	4.22	4.70	0.48	3.06
Performance: When Told Som., Record & Act Upon It	3.76	4.17	0.41	2.17
Performance: Analysing information	3.38	3.97	0.59	4.04
Performance: Solving problems	3.39	3.97	0.58	3.06
Performance: Researching questions	3.45	4.00	0.55	2.83
Performance: Communicating	3.59	4.23	0.64	3.65
Performance: Relating inclusively	3.66	4.17	0.51	3.39
Performance: Leading Others	3.55	3.93	0.38	2.22
Performance: Practicing Self-Growth	3.41	3.90	0.49	3.03
Non - PBL Group Growth Items				
Performance: Read Memos and Respond Appropriately	3.87	4.16	0.29	2.15

6 Discussion

From the current quantitative analysis, there is statistically significant evidence to indicate support for hypotheses three and four that engineering students subjected to the PBL curriculum do indicate a self-reported growth in the professional ability performance. This growth is greater in comparison to the students in the non-PBL control group; which showed no statistically significant growth in performance. Both the Individual Professional Development Instrument and the Team Professional Development Instrument support this initial finding. Given the similarity of the results from both instrument, the use of only one instrument will be explored as the study continues.

The current evidence does not appear to support hypotheses one and two. The students in the PBL curriculum group and the non-PBL curriculum group did not show statistically significant growth in the overall importance for professional abilities. These results give some indication that the student importance for the professional skills that were established prior to the start of upper division and do not appear to change over the two-year time frame regardless of the curriculum mode. One potential reason is the instrument does not have the capability to detect the growth in the way it is currently structured. Another potential is that there is little room for growth in importance regardless of the curricular model because the importance for the professional competencies is already know and valued by the students from their experiences prior to starting their upper division programs.

7 Conclusion and Future Works

The results do indicate that the growth in the ability for students' performance of professional competencies increases for students who experience the PBL curriculum as compared to the non-growth for students experiencing the traditional engineering curriculum. This provides an initial indication that a PBL curriculum incorporating the described "professional development model" has the potential to provide the called for change in engineering education and meeting the professional competency need of the engineering profession.

Although the quantitative data shows promising results, it does leave a couple aspects of the trajectory to be explained further. The first aspect is why the students in the PBL group do not show the expected growth in importance for professional competency proposed in hypotheses one and two. The quantitative study also gives little insight to a second aspect of understanding how the curriculum affects the student professional performance development trajectory.

A future, second phase, qualitative study of the PBL student professional development trajectory will focus on explaining these two aspects further. It will be administered to a subset of quantitative participants and the results will be analysed to further explain the results of the quantitative study. The first aspect is to provide some understanding of why students in the PBL curriculum did not identify growth in the their importance for professional competencies; growth in importance for professional competencies was an expected outcome of the students in the PBL curriculum. The second aspect of the qualitative study is to further explain the growth seen in the self-reported performance of professional competencies. It goes deeper into the research question, "What is the professional development trajectory of students in the new project based learning (PBL) curriculum?" to identify how the curricular elements affected the student trajectory.

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