University – Industry Partnership Projects in a PBL Curriculum

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Conference Key Areas: university-business cooperation, engineering skills, curriculum development

Keywords: project-based learning, professional skill development, professional identity

INTRODUCTION

This system paper focuses on describing a new upper-division project-based learning model, which is centered on university-business cooperation for project development at a U.S. engineering education institution. The model is an adaptation of the Aalborg project-based learning (PBL) model that utilizes industry (business) projects to develop students' technical, professional, and design abilities. Industry partners not only provide projects but also provide their employees to serve as project clients and team facilitators. The intent of the cooperative model is to develop engineers that are better prepared to meet industry expectations upon graduation.

The work completed to date is the development and implementation of the new curriculum with nine graduating classes. At the core of the student experience, a cyclical process of exploration and reflection develops the students' professional identities and thus increases their performance abilities of professional competencies. Specific emphasis is placed on developing the student self-directed learning ability. The development of the model is characterized by the use of industry-sponsored projects with well-defined project scopes and open-ended solutions. The learning activities, or the "lecture component," of the curriculum are a purposefully integrated part of the project work and learning experience for the students. The intent is that students are deeper learners in design, technical, and

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professional domains who have the ability to learn additional competencies in these three domains to support their careers in industry.

The paper describes the PBL model, how students experience the program, and evaluate initial feedback from the industry (business) partners who have hired the program graduates. The paper will include initial conclusions for the program and recommendations for further work.

1 BACKGROUND

The context for this paper and the program development is the significant discussion in engineering education about what should be the “nature, context and curricula of undergraduate education” [1]. The dialogue is being influenced by the rapid expansion of knowledge, changes in engineering practice, concerns for attracting adequate numbers of students into the engineering profession, and change requirements of employers. While the need is evident for transformation of engineering education to match the changes in the engineering profession, very few have actually changed to a new instructional model.

Goldberg and Somerville [2] provide three historical lessons for guiding the transformation. First, needed change will not be accomplished with small changes to existing curriculum. Second, students are “sensitive to the their world of work and to the culture of the education system.” Third, change attempts to date have not been successful. New bold approaches are needed to accomplish the change. The curriculum developed for this program was developed as a bold, new approach, from scratch, to be successful in meeting the needs of the engineering profession.

Throughout the engineering education literature, it is evident that PBL should be strongly considered in the development of a new, or the change of an existing, engineering program. The 2012 Graham report [3] and UNESCO reports [1, 4] identify PBL as an integral part of successful curricular changes and as one of the key steps in the “design and implementation of an effective engineering curriculum,” respectfully. Graham’s study revealed that a majority of the highly regarded examples of change involved the use of PBL within an “authentic, professional engineering context.” Project-based learning is a core theme throughout the 2013 UNESCO report to achieve the Washington Accord graduate attributes and to provide the “personal learning experiences” needed for the transformation of engineering education. It identifies that,

> “*Project Based Learning (PBL) is a widely reported approach to address the need to change engineering education, from the formal presentation of technical material to a student experience model. It provides activities, which simulate the role and responsibilities of practicing engineers, and develops the general graduate attributes that have been identified as essential … Project Based Learning can be organised for individual work, but there is greater benefit from having the project under- taken by a team of students. This relates more closely to a realistic engineering environment, provides an opportunity for students to learn from each other, and assists the development of the essential graduate attributes of team- work and leadership*.”

PBL and PBL theory are an integrated core component of the curricular model for this upper-division PBL program. It began in 2009 as an adaptation of the Aalborg PBL model to meet [5] the need for change in engineering education [6]. It was designed to address the three interrelated domains of design, technical, and professional competence [7]. Design projects became the central theme upon which design learning, technical learning, and professional learning took place [8]. Each semester students select from several options for engineering projects from industry clients based on their interests. Students acquire skills in engineering design, practice ideation, manage resources, and produce products. Integral to the design is the acquisition of technical knowledge required to complete the design. Faculty members scaffold the self-directed learning skills students will need upon graduation to independently acquire the technical competence they will need as practicing engineers [7]. The domain of professionalism is highly integrated into the design work. Specifically targeted are written communication, verbal communication, project management, entrepreneurialism, lifelong learning, professional responsibility, personal marketing, and inclusivity. Students, working with faculty, characterize their initial competence level in each area on a scale from deficient to exemplary [8]. From the Savin-Baden models of PBL [9, 10], the program includes:

- the student learning organized around problems/projects;
- the project as the incentive for the student learning process, which is a central principle to enhancing student motivation;
- the projects that are concrete ones that students are attracted to on the basis of their own experiences and interests; and
- the project reflects the conditions of professional practice.

A program goal is to have all students achieve a desired level for each of the 14 specific learning outcomes within the three learning domains of technical, design, and professional, shown in Table 1. The IRE program is ABET-EAC accredited. As such, eleven of the outcomes are dictated by ABET; commonly referred to as the ABET a-k student outcomes [11]. Based upon economic development needs of the region and the recommendations of the two advisory boards, three additional outcomes were added: leadership/management, entrepreneurialism, and performing in inclusive environments. While ABET identifies the outcome, the individual program develops its own performance indicators (PIs). It is through meeting the PIs for the PBL program that a student successfully meets an outcome. Upon competing all 14 outcomes a student is eligible for graduation.

Table 1. Graduate student outcomes

Technical Outcomes	**Design Outcomes**	**Professional Outcomes**
Technical 1 *An ability to apply knowledge of mathematics, science, and engineering* Technical 2 *An ability to design and conduct experiments, as well as to analyze and interpret data* Technical 3 *An ability to identify, formulate, and solve engineering problems* Technical 4 *A recognition of the need for, and an ability to engage in life-long learning* Technical 5 *An ability to engage in entrepreneurial activities*	Design 1 *An ability to design a system, component, or process to meet desired needs within realistic constraints* Design 2 *An ability to function on multidisciplinary teams*. Design 3 *An ability to lead, manage people and projects* Design 4 *An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice* Design 5 *The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context*	Professional 1 *An understanding of professional and ethical responsibility* Professional 2 *An ability to communicate effectively* Professional 3 *An ability to work successfully in a diverse environment* Professional 4 A *knowledge of contemporary issues*

The PBL program outcomes and performance indicators are made explicit to each entering student as part of the orientation process to the upper-division program.

Each outcome has a rubric that describes levels of performance ranging from 1 (deficient) to 2 (weak) to 3 (acceptable) to 4 (desired) to 5 (exemplary).

2 DESCRIPTION OF UNIVERITY-INDUSTRY PROJECT AND PROJECT EXPERIENCE

2.1 Project Description

The design team, their facilitator, and their clients form a unique learning community. The members share many of the same learning goals, activities, physical spaces, and spend much time together. These communities build anew, each academic semester, and are centered on the design project. Students are given special instruction on how to develop stronger teams through activities and respectful actions. Their success in building strong communities impacts their design success and overall learning.

Prior to the semester start, students are queried about their interests in project types for the upcoming semester. Potential interests include, but are not limited to: industrial mining, industrial general, manufacturing, consulting, biomedical, entrepreneurial, fabrication, or environmental. Based on the results of the student interest, a call for proposals is sent to the program's current and potential industrial (business) partners through the use of the a project solicitation form. Projects vary depending on the needs of industry, but they all have the same characteristics of being a real need for the industry partner, a well-defined project scope, and open-ended solutions. The industry partner commits to providing an employee who will serve in the capacity of the "industry client." The project solicitation form clearly states the purpose of the projects with an "educational scope" statement:

> Student projects are meant to serve two purposes: 1) provide engineering students with an experience that enables them to develop project management skill, technical expertise, design experience, and professional competency, 2) contribute, in a meaningful way, to the client by meeting the client's defined need.

From the industry responses, a projects menu is developed and distributed to all students. Students then select their top three choices. Academic staff then compile all of the student preferences and create teams. Other considerations that staff use when assembling teams include prior student experiences, student personalities, and student education needs. The intent is to create a vertically integrated team with students in different semesters of the program, different skill sets, and development needs. Once a team has been assigned to a project, a project facilitator from the academic staff is selected for the team. The team then progresses through six distinct project design phases (with guidance from the project facilitator):

1. Problem Definition
2. Develop Design Objectives
3. Planning
4. Idea Generation and Selection
5. Modeling and Testing
6. Design Evaluation

Although the process phases are descriptive, the projects themselves are ill-defined which leaves both the approach and the final solution to be determined by the teams and the students though dialogue with the project facilitator and client.

2.2 Project Experience

The student experience in the project can be explained from the perspectives of the student workweek schedule, the progression of the semester, and the progression of their four semesters. The students are registered for 15 credits per semester.

Roughly, this translates to 45 hours of work on task each week. Of the 15 credits, seven are project related and involve the design and professional competencies. The other eight are technical in nature. A goal is to have interplay between the technical credits and the nature of work on the industry projects.

From the technical learning perspective, each student spends eight structured hours per week in contact with faculty in "learning conversations" which are designed to use active learning techniques. They then spend an additional 16 hours per week in “non-faculty contact” learning. This time is spent acquiring new knowledge through reading or video viewing; creating conceptual models of understanding; performing "Deep learning activities" such as experiments or designs; and practicing retention activities, as well as doing some traditional problem sets. For design and professionalism, there are seven hours per week of structured contact, which takes place through professional development seminars, design instruction, and guided design reviews. The remaining 14 hours of non-structured time is spent working on the team project and in documenting professional growth through reflective writing.

The semester progression is 16 weeks. The industry project design process starts with an initial scoping meeting between the team and the client. From this meeting, the team creates the design goals, develops a scoping document, and presents a scoping presentation to the client. From the scoping phase, the team progresses through background research, ideation, options generation, testing, evaluation, and validation. Throughout this progression, the team creates thorough documentation in written form, defends their designs before faculty panels at three points in the semester, makes formal presentations to the student body, and informal update presentations to their clients. The semester culminates with a final design review through a final presentation and a major deliverable delivery to the industry client.

The student goes through this semester evolution four times with formative feedback on their personal development. It includes setting incremental goals for improvement, creating action plans for attending those goals, and monitoring their growth through the next semester. The teams are vertically integrated so that senior students mentor the junior students on the same team. The student graduates after four semesters of successful progression and completion of the program outcomes (credits).

3 INITIAL ASSESSMENT OF GRADUATE AND EMPLOYER EVALUTION

In an effort to understand the essence of university-industry project influence on the PBL graduate abilities, as compared to peers from traditional engineering learning environments, an instrument was developed to gain an initial understanding of how both employers and PBL program graduates interpret their abilities as engineers.

3.1 Methods

For this purpose, an instrument was developed and adapted to a web format [12]. 75 graduates of the PBL program were emailed a request to complete the instrument and to request their supervisor to also complete it. 30 graduates took the instrument (40% completion) and 18 supervisors took the instrument (24% completion).

The instrument asks graduates and their supervisors to rate the ability of both PBL and traditional engineering program graduates using a 7-point scale:

1 - far below expectations,
2 - moderately below,
3 - slightly below,
4 - met expectations,
5 - slightly above,
6 - moderately above, and
7 - far above.

A score of 4 - met expectations was explained to be at the level that they believe a new engineer should enter their company to be effective in their work setting.

The individual instrument items are the graduate's (starting engineer's) ability to:

- Communicate effectively
- Act professionally responsible (prompt, responsive, represent company well)
- Design systems, components, or processes to meet needs w/ constraints
- Engage in entrepreneurial thinking
- Solve engineering problems
- Use the techniques, skills, and modern engineering tools necessary for engineering practice
- Function well on teams
- Display recognition of the need for and ability to engage as an efficient learner
- Lead and manage people
- Lead and manage projects

Respondents were asked to first rate all new engineers in the company who were non-PBL graduates against this scale and then PBL graduates for each item.

3.2 Results

Table 2 displays the results from both the supervisor survey and the graduate survey. The differences between the PBL & Non-PBL means are listed in the third column.

Table 2. Supervisor (n=18) and PBL graduate (n=30) survey results

	Supervisor Mean Score (from 7-point Likert Scale)			**PBL Graduate Mean Score** (from 7-point Likert Scale)		
	Non-PBL Graduate	PBL Graduate	*Difference*: PBL - Non-PBL	Non-PBL Graduate	PBL Graduate	*Difference*: PBL - Non-PBL
Communicate Effectively	4.4	4.9	0.6	4.7	5.5	0.8
Professionally Responsible	4.6	5.2	0.6	3.8	5.6	1.8
Design Systems	4.8	5.0	0.2	4.2	5.1	0.9
Entrepreneurial Thinking	4.1	4.6	0.5	3.5	4.8	1.2
Modern Tools Use	4.6	4.6	0.0	4.0	4.8	0.7
Solve Engineering Problems	4.4	4.8	0.4	4.1	4.8	0.7
Perform on Teams	4.3	5.3	0.9	3.8	5.2	1.4
Efficient Learner	4.4	5.0	0.6	**3.8**	**5.4**	**1.7**
Lead and Manage People	4.2	4.4	0.3	3.4	5.1	1.7
Lead and Manage Projects	4.3	5.1	0.8	3.8	4.8	1.0

The data was compiled; means and standard deviations were calculated. A two-tail t-test was conducted comparing PBL vs. non-PBL means for both surveys. The only statistically significant difference between means occurred in the Efficient Learner category on the graduate survey ($t=2.154$, $p<0.05$).

Further results can be seen through the following trends and perceptions:

- On all 10 of the graduate survey questions and in 9 out of the 10 employer survey questions, the mean score for the PBL graduates was higher than the non-PBL graduates.
- The employers scored all graduates, PBL and non-PBL, above 4 (met expectations) in all categories. The graduates also rated themselves above 4 in all categories, but their non-PBL peers below 4 in 5 of 10 categories.

- Employers found the greatest difference between PBL and non-PBL graduates in “performing on teams,” “lead and manage projects,” and “being professionally responsible.” Whereas, the PBL graduates found the greatest difference in “being professionally responsible”, “leading and managing people”, and “being efficient learners.”
- Employers rated the PBL graduates highest in “performing on teams,” “being professionally responsible,” and “leading and managing projects.” The PBL graduates rated themselves highest in “being professionally responsible,” “communicating effectively,” and “being efficient learners.”
- Employers rated the non-PBL graduates highest in “designing systems,” “modern tools use,” and “being professionally responsible.” The PBL graduates rated their peers highest in “communicating effectively,” “designing systems,” and “solving engineering problems.”
- Employers found the least difference between PBL and non-PBL graduates in “leading and managing people,” “designing systems,” and “modern tools use.” The PBL graduates found the least difference in “communicating effectively,” “modern tools use,” and “solving engineering problems.”
- Employers rated the PBL graduates lowest in “modern tools use”, “leading and managing people,” and “entrepreneurial thinking.” The PBL graduates rated themselves lowest in “leading and managing projects,” “modern tools use,” and “entrepreneurial thinking.”
- Employers rated the non-PBL graduates lowest in “leading and managing people”, “leading and managing projects,” and “entrepreneurial thinking.” Similarly, PBL graduates rated their peers lowest in “leading and managing people,” “leading and managing projects,” and “entrepreneurial thinking.”

4 DISCUSSION

Only one significant result was found in the mean-to-mean comparison: PBL graduates found themselves to be more efficient learners than their non-PBL counterparts. While no significant differences were found in the other 19 comparisons, several initial trends and perceptions are worth noting. First, 19 out of the 20 questions had PBL graduates rated higher than their non-PBL peers and PBL graduates are above 4 (met expectations) for all 20 questions. This provides an initial answer to the questions “are the PBL graduates satisfied with their engineering preparation?” and “are employers satisfied with the engineering preparation of the PBL graduates?” Further evidence that the answer to these questions is yes, comes from a sampling of additional comments made by the respondents:

> “I would say on average the students from IRE we have hired have been more mature and have further progressed along the development curve to be effective in real world industry.” *Employer*

> “By a wide margin, I prefer working with the Iron Range graduates because they are so professional.” *Employer*

> “I think that among my peers I am definitely advantaged in my interpersonal skills and people management. I also think that my ability to juggle tasks or multitask is also superior.” *Graduate*

> “I have found the feedback loop lacking with many of my peers. They seem to find it acceptable to not communicate the results or outcomes of work or

projects. Often if feedback is desired it must be requested using specific details to get the full picture." *Graduate*

The least positive comment made by an employer was:
"I think it's fair to say that IRE graduates come to us with better training in the soft skills (inter-personal), but slightly less thorough training in the hard skills (practice-specific engineering skills). They are excellent overall engineers, but they require a bit more help on the technical side at first. That said, they are quick and eager learners, and I think they understand where their weaknesses are." *Employer*

The least positive comment made by a graduate was:

"At times, I believe there are areas that I am less proficient at in technical knowledge due to the time spent in other areas such as professionalism. However, I have been told how much more valuable I am than the other engineer who has 10-15 years experience, but is not allowed on certain client properties due to his negative unprofessional attitude. He has an obvious advantage from job-specific experience, but I still find that he comes to me for help with technical questions such as statics problems or converting from degree, minute, second to decimal form." *Graduate*

The PBL graduates potentially excel in the areas of leading and managing people and projects, being professionally responsible, being efficient learners, and performing well on teams. The PBL graduates are more evenly perceived with their peers in the use of modern tools, entrepreneurial thinking, and designing systems. Of further note is that graduates showed greater amplitudes when comparing their performance with their peers. They also showed greater levels of dissatisfaction with their peers than the employers noted.

SUMMARY

The new PBL curriculum adapted from the Aalborg PBL model has been continually developing over the past seven years. The history, development trajectory, continuous improvement model, and curricular model have been described. Of particular focus is the university – industry partnership projects that student learning is centred about. A quantitative instrument was initially deployed, analysed, and results reported. The conclusions from this study provide initial indications that PBL graduates and their employers are satisfied with the preparation the PBL model provides graduates.

Further study is needed to increase the n's for both graduates and employers to add more statistical significance to the data. A potential improvement is the addition of a qualitative study of graduate and employer comments to identify trends in the language found in the comments. Consideration of updating the instrument, or utilizing interviews, to identify these trends will be undergone for potential improvement of the study in the future.

ACKNOWLEDGMENTS

The research results communicated in this paper were funded in part by the National Science Foundation (DUE-1060233). The authors wish to thank Anette Kolmos and Erik de Graaff of Aalborg University for their guidance in the development of the PBL model and the research methods.

REFERENCES

[1] "UNESCO, ENGINEERING: Issues, Challenges and Opportunities for Development," ed. Paris, 2010.

[2] D. E. Goldberg and M. Somerville, *A whole new engineer: The coming revolution in Engineering Education*. Douglas, MI: Threejoy Associates Inc, 2014.

[3] R. Graham, "Achieving excellence in engineering education: The ingredients of a successful change," The Royal Academy of Engineering, London, UK2012.

[4] D. G. Beanland and R. Hadgraft, "UNESCO report, Engineering education: Transformation and innovation," Melbourne. 2013.

[5] B. Johnson, R. Ulseth, C. Smith, and D. Fox, "The impacts of project based learning on self-directed learning and professional skill attainment: A comparison of project based learning to traditional engineering education," in *Frontiers in Education Conference (FIE), 2015. 32614 2015. IEEE*, 2015, pp. 1-5.

[6] R. Ulseth, J. Froyd, T. A. Litzinger, D. Ewert, and B. Johnson, "A new model of project based learning," in *ASEE 118th Annual Conference and Exposition*, Vancouver, B.C., Canada, 2011.

[7] R. Ulseth, Self-directed learning in PBL. Aalborg, Denmark: Aalborg University Press, 2016.

[8] B. Johnson, Study of Professional Competency Development in a PBL Curriculum. Aalborg, Denmark: Aalborg University Press, 2016.

[9] M. Savin-Baden, *Problem-based learning in higher education: Untold stories*. Buckingham, UK: Open University Press, 2000.

[10] M. Savin-Baden, "Challenging models and perspectives of problem-based learning," in *Management of change: Implementation of problem-based and project-based learning in engineering*, E. de Graaff and A. Kolmos, Eds., ed Rotterdam, NL: Sense Publishers, 2007, pp. 9-30.

[11] Abet.org. (2015, February 1, 2015). *ABET - Criteria for Accrediting Engineering Programs, 2014 - 2015*. Available: http://www.abet.org/eac-criteria-2014-2015/

[12] V. M. Sue and L. A. Ritter, *Conducting online surveys*, 2nd ed. Thousand Oaks, CA: Sage Publications, Inc, 2012.