AC 2010-917: SPECIAL SESSION: ASSESSING STUDENTS' LEARNING OUTCOMES DURING A COMPLEX AND REAL-WORLD PROBLEM-BASED SERVICE LEARNING (PBSL) PROJECT IN A SOPHOMORE ENGINEERING DESIGN COURSE

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Special Session: Assessing Students' Learning Outcomes during a Complex and Real-world Problem-based Service Learning (PBSL) Project in a Sophomore Engineering Design Course

Abstract

Authentic and real-world problem solving is an integral part of the engineering profession. Yet, current research indicates that engineering education is primarily focused on well-defined and well-structured problems, which do not provide students the real-world relevance, context, nor experience in solving the types of problems required in the engineering profession. The addition of *problem-based learning (PBL) methodologies* to the engineering curriculum provides engineering programs the opportunity to introduce students to a variety of real-world projects. Just as important to these PBL methodologies, though, is the type of projects to which students are exposed. Numerous studies have shown the importance and impacts (including learning, retention, motivation, etc.) of integrating *service learning projects* into engineering education. Herein, we present the assessed learning outcomes of integrating a *problem-based service learning (PBSL)* experience in a sophomore design course. The implications of such an effort in utilizing *PBSL methodologies* and *learning outcomes assessment* are that the strategies and tools developed herein can be used by engineering programs nationwide, independent of discipline or academic level.

Keywords **–** problem based learning, service learning, engineering design, learning outcomes.

Introduction

There has been much criticism about undergraduate engineering education not focused on ***real-world and authentic problem solving***. In fact, the type of authentic and real-world problems that engineers often face in the workplace are ill-structured and complex; yet, such problems are not integrated into engineering curricula and coursework. Rather, engineering courses mainly focus on problems that are well-structured with known, correct solutions often acquired from preferred solution methods and an implicit methodical approach[1-2]. Particularly because engineering practice is more suffused with complex and ill-structured problems[1], it is imperative that engineering students begin the real-world practice of problem solving during their undergraduate education.

Problem-based learning (PBL), a powerful student-centered pedagogy, offers a strong framework upon which to build a curriculum that will allow our students to learn essential and globally competitive problem solving skills[3-4]. Some of the benefits of PBL include: (1) improving students' problem solving and critical thinking skills, (2) promoting high motivation for students, (3) increasing the ability to integrate and apply engineering skills with fundamentals of math and science, (4) enhancing the acquisition and retention of knowledge, and (5) facilitating collaborative learning. Yet, although widely used in engineering, particularly during the senior year, PBL practices have not extensively been integrated throughout engineering curricula, and limited studies exist to provide sufficient support for PBL. There are two main pitfalls of PBL practice: (1) a poor classification of what constitutes PBL practice and how such experiences can be integrated throughout the curriculum, and (2) limited assessment studies exist, mainly because PBL enables students to develop skills that are difficult to measure.

Similar to PBL, ***service learning (SL)*** or service-based efforts have been impacting undergraduate education and certainly undergraduate engineering education as well. Service learning enables students to not only learn important real-world knowledge and skills but also provide a service to the community. Similar to PBL, although service learning is gaining momentum in educational settings and is seen as an important pedagogical tool, there are limited well-grounded studies on the impacts and learning outcomes of students who participate in such experiences. In engineering education settings, a few previous studies have described the use of service and some of the impacts [5-8].

Herein, we present an assessment of students' learning outcomes during a ***problem-based service learning (PBSL) experience*** in a sophomore engineering design course. The design course, the first of six courses in a ten-credit engineering design sequence, was meant to introduce students to a broad variety of topics in engineering design, including creative engineering design concepts and practices, design history, sustainability, cognitive processes and design problem solving, basic design skills, and project management. The PBSL project was designing a device to enable a professor (and also the client) with cerebral palsy the ability to strengthen his lower and upper body as well as to exercise outdoors. In fact, the exact problem statement that students were given the second week of class is shown in **Figure 1**.

Semester Project Description
"Design of a Pedaled Cycling Vehicle for a Client with Cerebral Palsy"

A professor of adaptive physical education is interested in the design and construction of a unique **pedaled cycling vehicle**. As an individual with cerebral palsy, the customer would like to expand upon his fitness activities, which have primarily focused on swimming and strength training, to include outdoor activities such as the utilization of a cycling vehicle, which can also be used for training for cycling events and muscle strengthening. The customer's ultimate goal is to ride to raise money and awareness for programs that provide opportunities for physically-disabled children and adults to be more active.

Despite extensive research of the adaptive bicycle market, the client has been unable to identify a cycling vehicle to suit his specific needs. He cited the prohibitive cost of custom design work, ineffectual designs for training and racing, and designs incompatible for his stature as primary difficulties encountered in his search.

In assisting the customer, your task this semester is to provide numerous cycling vehicle designs that are viable to meet the specific user needs of the customer. Ideally, these cycling vehicle designs should provide sufficient adaptability to accommodate others with some similar and some different needs and requirements.

Figure 1: Problem statement of PBSL project given to students in a sophomore engineering design course.

Further, the following list shows the learning objectives that were set for the project. More specifically, by the end of the semester students were expected to:

1) Identify, describe and discuss the needs of the customer which are to inform the conceptual designs
2) Understand, research, and establish design specifications to meet the needs of the customer
3) Generate multiple conceptual designs using sketching, CAD, and Solidworks skills
4) Explore and evaluate the multiple conceptual designs using a number of methods (performance testing, decision-making strategies, sustainability principles)
5) Work effectively in a team setting
6) Develop a framework in selecting the conceptual design that is to be presented to the customer
7) Address and analyze the conceptual designs for basic sustainability characteristics
8) Effectively document and present the process used during this design project

As can be seen from the problem statement and project objectives of this PBSL design project, this is not only a real-world problem with a "real" customer, but certainly one that is open-ended and fairly ill-defined. In fact, it is a project that some would find in a capstone design experience. Our motivation in integrating such an authentic and complex problem in a sophomore design sequence was to expose students to not only real-world problem solving but also a project that enabled students to help a member of our university community. In assessing students' learning outcomes during this PBSL design project, we were guided by the following ***research question:***

> What were students' learning outcomes (knowledge, skills, and attitudes) as a result of participating in a real-world PBSL design project?

Methodology

As was stated previously, the setting for this effort was a sophomore engineering design course, in which students (N=64, ~ 15% female and 85% male) were given a semester-long PBSL design project. Prior to this course, students had received a very basic introduction to design in the context of a freshman engineering course, so this sophomore design class was the first course that exposed students to in depth instruction in design.

In regards to methodology, the research question was answered by using primarily qualitative assessment methods and limited quantitative tools. We felt this research design approach to be more relevant given the nature of our research questions as well as our desire to gain in depth insight into students' learning. More specifically, we collected data from: (a) a series of open-ended questions that were a part of a *project evaluation questionnaire* that was administered at the end of the semester, (b) a couple of Likert-scale items, which were a part of the end of semester *course evaluation* and were designed to measure the value and difficulty of the project, (c) *observations* made by two assessment specialists, which served as external evaluators to this effort.

The data analysis of the open-ended questions began with the iterative development of a coding framework [9]. Two researchers independently reviewed the open-ended survey responses and derived codes based on the common thematic threads emerging from the data. Thematic network analysis [9] was used as the framework for exploring the patterns and themes that emerged from the data. This approach enables a researcher to organize and condense the data.

Results and Discussion

In this section, we present data and findings that provide insight into students' learning outcomes as a result of participating in the PBSL design project. As described previously, data from three sources are presented: (1) several open-ended questions from an end-of-semester project evaluation questionnaire, (2) Likert scale items from an end-of-semester course evaluation survey, and (3) observations conducted from two assessment specialist, serving as external evaluators.

At the end of the semester, students (N=64) were administered a project evaluation questionnaire, which included several open-ended questions about the project and provided us some useful insights about students' perceptions, learning outcomes, and satisfaction with this real-world design experience.

In the project evaluation questionnaire, students were asked: ***"In your own words, how would you describe this project to your parents or peers?"*** Overall, in reviewing students' responses, it was evident that students highly valued the real-world nature of the project as they described the value of having a specific client or customer with unique needs. In the context of this project, students seemed to also understand the design process and understand the practice of design which led them to identifying a problem and ultimately providing multiple conceptual designs to the customer. The team-nature of the project was also valued by students, who also acknowledged the pros and cons of working in a team setting. Overall, students' responses illustrated an enthusiasm in being able to design a device that would help their customer and also portrayed a sense of ownership. The following quotes are representative student responses:

> *"We are working in teams to design a bicycle for a customer, who suffers from cerebral palsy and has many limitations, such as weak lower body strength and poor balance that need to be accounted for in our design."*

> *"We went through a process of designing a bicycle for a client. We were paired up in teams and had to create a report of this process."*

> *"This semester project was a fun and I learned how to use a design process to come up with a design that would fit the needs of the client."*

> *"I thought this project was an excellent project for the design course this semester. I think it really forced us to dig deep into design ideas and work on our teamwork skills as well. I think that having an actual client made it that much more exciting for the presentation."*

"The engineering students have been chosen to design a bike that a professor with Cerebral Palsy can ride and exercise his upper and lower body."

"Our main project this year was to design a bike for a client with a disability called cerebral palsy. There is so much more involved in the process of designing than one may think. We have to know the client's strengths and weaknesses in order to figure what kind of design would be convenient for the client. Also there are many factors of the cycle that needs to be thought of when designing such as cost, safety, materials, weight, alternative propulsion, gear system and so on. This project was a great experience for us in college because this is getting us ready for jobs after college."

Students were also asked about the ***learning outcomes (knowledge, skills, and attitudes) they gained*** as a result of working on this project. Their responses focused on gaining: (1) design skills and understanding the design process, (2) team working skills, (3) gaining domain knowledge, (4) communication skills, (5) project management skills, (6) problem-solving and creativity skills, (7) self-awareness. **Table 1** below serves to show typical quotes from student responses for each of these seven themes. From these seven organizing themes, the most prevalent responses dealt with learning design skills, team working skills, and gaining domain specific knowledge. More specifically, students' responses pertinent to design skills dealt with understanding the steps of the design process, understanding the complexity of design and that there are many solutions, understanding the customer needs, acknowledging the many trade-offs that must be made during design, coming up with possible solutions, using concept selection strategies, etc. Also, in regards to team working skills, although the majority of students' responses were positive and students seemed to recognize the value of team work, several responses also pointed out the difficulties (scheduling issues, team management, team member contributions) of learning how to work collaboratively. As for the domain specific knowledge theme, students' responses revealed the specific knowledge about bicycles, cerebral palsy, design, etc. that students learned during this experience.

Table 1: Themes and corresponding student quotes/responses for open-ended question dealing with learning outcome gains during the PBSL design project.

Overarching Theme	Typical Responses/Quotes
Design Skills and Understanding the Design Process	*"I learned how to take a problem and look at each piece before jumping to a solution. Learning the design process help me see how much time it takes for real-world solutions to be developed."* *"I learned how complex some projects really are and all the steps of the design process."* *"I learned more about the design process. I learned how to properly approach a problem and how to assess certain customer needs, how to evaluate the customer needs, how to compare and select a design."* *"I learned that the design process is a little more complicated that just making a drawing. I also learned it is ok to research the problem because you don't know what the answer is."* *"I gained a lot of design skills and a lot of process recognition skills."* *"I learned how to evaluate customer needs and turn them into target specifications.*

	Then, learning how to determine the trade offs for the project. Overall, I learned about the design process."
Team Working Skills	*"I learned a lot about working efficiently in a group. It was often difficult to get all of the members to participate and get the work done efficiently."* *"I learned about how I worked in a team."* *"Teamwork is very important."* *"I learned that it is not easy working in teams. I also learned a lot about how the design process actually works and why certain steps come at certain times in the process. I also learned how to present technical subjects in a professional manner."* *"Working as a team is very important. Each member's contribution builds upon the next member's contribution."*
Gaining Domain Knowledge (i.e. cerebral palsy, bicycles, etc.)	*"I learned a lot about bicycles in general and the cerebral palsy brain disorder. I also learned how to apply the design process into a real life situation."* *"I obviously gained a much greater amount of knowledge of bicycles, their subsystems, and how they work."* *"I learned about many available bike designs, and a great deal about how bicycles work. I also learned about cerebral palsy and it's limiting factors to those like our client."*
Communication Skills (Oral and Written)	*"It was the first time we had to communicate to the customer face to face and communication skills are only learned by practicing, I improved some in this aspect."* *"I learned how to effectively write a progress report and present designs to a group."*
Project Management Skills	*"Working on this project, I learned how to manage my time with a group better. When we made our timeline, I realized that by following the timeline, we do not get behind and we stay on schedule. This also made it less stressed when assignments were due for class because we had it done before hand or if we did not finish it when we were suppose to we realized that we would have to meet again to finish it. So the best skill that I gained from this project is time management."* *"Some of the skills I gained were to efficiently and effectively work with a group, present and write a great final report, and how to accurately determine the best choice of a bike with the specific needs."*
Problem Solving Skills and Creativity	*"I learned basic problem solving skills, as well as how to take an organized approach to engineering tasks and complete them effectively. … Lastly, I learned how to be more creative and think with an open mind and consider all ideas for solutions, even ones that I knew would not be practical."* *"I've learned more about the design process and problem solving and have developed more cognitive skills that help with creativity."*
Self-awareness	*"I learned about some of my strengths and weaknesses, especially in comparison to my peers."*

Students were also asked to reflect on ***what aspects of the project were most and least valuable***. Overall and in agreement with responses on learning outcome gains (Table 1), students felt that the most valuable aspects during the project were learning and applying the design process (e.g., developing ideas, meeting customer needs, generating concepts, sketching and drawing concepts, concept evaluation and selection) to a problem with a real client. It is important to point out that many students seemed to particularly value creative concept generation. Further, a less common but not unusual response to another valuable aspect of the project pertained to teamwork. In regards to aspects of the project that were least valuable, students' responses primarily focused on the writing of reports (midterm and final), which students perceived as time-consuming, at times repetitive, and too ill-defined. Such a response is not atypical in undergraduate engineering courses.

Students were also asked ***"how do you think this project prepared you for becoming an engineer?"*** Some examples of typical responses are:

> *"By giving me experience in actually being presented with a problem and having to go through the steps of the design process and present a final design that I think will best solve the task at hand. This project allowed me to better see how engineers deal with problems that they are given."*
>
> *"It helped me understand how to approach a customer with real needs and propose a solution. Professional work was very important trough out the project so it also prepared me for working situations."*
>
> *"Many engineers work in groups, this project helped me realize how to work in a group more efficiently. You learn that you do not know everything all the time and that sometimes it is best to let others take the lead and show you how to do some things."*
>
> *"I can now utilize the design process and work in a team very well. This will help me as an engineer because I will know how to develop the most successful designs."*
>
> *"As an engineer we will have to prepare documents for a client and work under a project manager. Many of these documents will not have outlined instructions and will have strict deadlines we will have to meet. These documents will be in pieces that we, as a team, will have to pull together at maybe the last minute for our client."*
>
> *"I learned very thoroughly the engineering design process, how to work effectively in a team, and how to prepare technical documents and presentations, and definitely time management."*
>
> *"I believe that the project helped show that engineering isn't just sitting in a shop taking an hr to design something then spend weeks building it. It also consists of many layers of planning, revising, and preparation. This project also helped me focus more because it was a real client instead of a made up one which isn't as appealing to design and plan for. Also, working with groups helped because it's an integral part of the real world."*
>
> *"It dumped me completely headfirst into the muddy waters of design. I was up to my ears in confusion and somehow our group came out to the surface with a plan. It forced me to help the client even though it was way beyond my ability and it put me closer to helping me get there."*

"The real life aspects of this project as well as getting some personal experiences on how to deal with problems."

"I feel like this project has helped prepared me for becoming an engineer by bringing the following skills to my attention: attention to detail and documentation, research, using the design process, professionalism, presentation skills, and having to expand upon my comfort zone and research a topic I was not familiar with at all to complete the project."

"It somewhat resembled the process that I saw when I competed in the FIRST robotics competition. I worked with Army engineers to design our robot and they were all somewhat structured."

From these responses, we see that students found this design project to be relevant to engineering practice and on becoming an engineer. The students mentioned a variety of factors, including the design project being "realistic" and having a "real" client, to design being integral to engineering practice and also being complex, to the team process modeling workplace practices, to the importance of preparing documentation, to real life problem solving, etc.

Further, in digging deeper to ***gain insight into the complexity of this project***, students were asked to identify the aspects of the project that they found to be challenging and those they found to be easy. Overall, aspects of the project that students perceived as challenging included most every component of the design process (determining customer needs, project-specific knowledge, generating design concepts, drawings, concept selection and evaluation, documentation, lack of technical skills, etc.), working collaboratively (scheduling issues, team management), as well as project management (meeting deadlines, time constraints, etc.). On the other hand, aspects of the project that students listed as being easy included research skills, teamwork, writing reports and making presentations, drawings, etc. Although not predominant, some steps of the design process were also identified by some students to be easy.

In the ***end-of-semester course evaluation***, students were asked to rate not only how valuable the design project was in learning and mastering the course subject matter and content, but also how difficult. Both questions were based on a 5-point Likert scale, very valuable (5) to not at all valuable (1) and very difficult (5) to very easy (1). With one of the highest ratings, compared to other PBL activities in the course, this design project received a mean value rating of 4.0, which corresponded to about 80% of the students rating the project as very valuable or valuable. In terms of difficulty, this design project received a mean rating of 3.9, which corresponded to about 78% of the students rating the project as very difficult or difficult. These results suggest that even though the project was perceived to be difficult, the fact that students rated it to be valuable (in fact one of the highest valued activities in the class) reflects that it was a rewarding and worthwhile experience for students.

Two assessment specialists, who served as external evaluators, also conducted ***observations*** during the final semester presentations with the customer, student peers, and engineering faculty as the audience. Observations focused on gathering notes on learning outcomes, the learning environment, and interactions amongst students with peers, the customer, and the engineering faculty instructors. The assessment specialists' observation notes revealed that the project allowed students to demonstrate their knowledge of engineering design concepts and it was apparent that many of the students were able to apply design concepts to a real life problem. Many of the designs were very thoughtful and students seemed to be able to integrate their knowledge of the client's needs, knowledge of engineering concepts, and their own creativity. Further, whereas most groups displayed good presentation skills and seemed confident in what they were presenting, there were students who were not confident and who also had designs that were not as developed or thoroughly conceptualized. Also, from the questions and constructive feedback that students received from their peers, it was evident that there was an overall comfort and trust within the learning environment. Moreover, having the client present to provide feedback was undoubtedly very rewarding and memorable for students and their learning experience. It was evident that students recognized the relationship between completing the project for a grade and providing a service to a client. Whereas in most classroom design environments the customer is not present, during this experience students responded to questions, feedback and criticisms of their work in a very positive way which brought about another learning opportunity for the students. Lastly, during these presentations, the students seemed to carry themselves more as engineers offering a service to their client than sophomore engineering students. This might suggest that they recognized and acknowledged the responsibility they have as engineers to provide a service to a client or to society as a whole.

Conclusions, Future Work, and Lessons Learned

Considering that engineers in real-world engineering practice very often deal with problems that are complex, ill-defined, unstructured, integrating many disciplinary knowledge domains, meeting a need for society and our community, etc., it is imperative that engineering educators also expose engineering students to real-world and authentic problems. Although most often, the closest we (as engineering educators) come to this is during capstone projects, it is critical that engineering students begin to learn complex problem solving skills earlier on (in both traditional engineering science courses as well as the more project-driven courses like capstone design).

Further, service learning projects have been receiving much attention in recent years for the real-world problems and community-driven solutions that it enables our students to work on. Having integrated an authentic problem-based service learning (PBSL) project in a sophomore engineering course, we focused our efforts herein in assessing students' learning outcomes during this experience using primarily qualitative tools (open-ended questions and observations).

Overall, our findings show that students not only valued this real-world PBSL experience, even though they were challenged by the complexity of the project, but also gained much valuable knowledge and skills along the way. In summarizing some of the key findings, the data revealed that exposing students to a "real" PBSL problem with a "real" customer truly motivated students:

(a) to learn and apply new domain-specific domain knowledge,
(b) to understand and implement a design process and design skills,
(c) to value and be challenged by working in a team setting,
(d) to gain much needed project management skills,
(e) to recognize the need and importance of research,
(f) to deliver a solution to their physically-disabled client,
(g) to recognize the relevance and connection of this project to real-world engineering practice,

(h) to understand the responsibility and importance of providing a service to a client,
(i) to see themselves as engineers or at least becoming engineers,
(j) to value and be challenged by real-world PBSL experiences,

In the future, we will continue our efforts in assessing students' learning outcomes during PBSL projects by evaluating student work, conducting focus groups or interviews, developing and using surveys, etc. Also in the future, we will continue to fine tune and improve this PBSL experience as well as think of ways to incorporate PBSL in other engineering courses.

We truly believe in using PBL pedagogies to integrate service learning projects into the engineering curriculum. More specifically, though, we have come to recognize that there are many flavors to PBSL (community-based, customer-driven, design focused, short-term vs long term, local/regional/national vs international, technical vs non-technical, simple vs complex, multidisciplinary vs not, etc.) and one must choose the flavor that is best suited to meet the course objectives, student learning outcomes, faculty time constraints, student time constraints, resources available, etc. Certainly, integrating a PBSL activity and a PBSL-driven curriculum requires more time than just planning a typical lecture, so well thought-out planning is critical. Like any long-term endeavor, especially one that deals with a real-world problem and a real client, integration of PBSL is a learning process and one that requires patience, an ability to adapt, and continuing to look for improvements in the process. In regards to scalability, it is important to select appropriate PBSL experiences that align with the goals of the course or the program and for the customer (whether it is an individual client, an industry partner, a community partner, etc.) to be aware of the learning outcomes that students need to meet.

Further, although it is more accepted and more common to integrate real-world complex problems (PBL or PBSL) in project-driven courses like design, it is also important to integrate such experiences and teach such skills to the more traditional engineering science courses. The key, as stated previously, is to align the PBL or PBSL experience with the goals of the course. Moreover, it is not easy to achieve integration of complex problem solving throughout the curriculum (from freshman to senior year), but it is critical that this be started early in order to instill a culture and mindset of solving such problems. If it is not done early, as is often the case, students may resist such experiences because such problems are much more challenging and time-consuming than they are used to.

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