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Developing Real-life Problem-based Learning (PBL) Activities through Partnership with Industry

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Deepening student understandings of engineering dynamics principles through industry-inspired, problem-based learning activities

Abstract

This paper describes the development, implementation, and evaluation of project-based learning (PBL) activities in the context of a sophomore dynamics class. The activities were developed in partnership with an industry representative and have thus far been implemented in two iterations. Surveys conducted in Spring and Fall 2016 reveal how students experienced the activities. The survey findings indicate that using PBL activities to complement a lecture-based approach in dynamics provides an opportunity for students to connect abstract engineering principles to real-life situations, thereby increasing student motivation to learn and deepening conceptual understandings.

Introduction

Dynamics is taught as part of what the National Science Foundation [1] describes as the engineering "core" – i.e., the middle two years of the four year undergraduate experience [2]. It is widely recognized that these years are critical to the technical formation of engineers; however, these core courses also present a number of educational challenges around knowledge transfer and integration. For example, many students find it difficult to recall relevant material from previously taken calculus, physics, and statics courses, while others lose interest due to the perceived lack of connection between fundamental engineering principles and "real-world" problems. As a result of these and other "core"-related challenges, the middle two years are a primary attrition point for engineering majors [3]. In this paper, we describe how we are seeking to address these challenges through the development of industry-inspired, real-life, PBL activities.

Literature review

It is now well established that problem-based learning (PBL) approaches to teaching engineering fundamentals courses are more effective than traditional lecture-based approaches [4, 5]. Savin-Baden [4] made a case to distinguish between PBL versus problem-solving learning, stating that the latter is a lecture-based approach. Hmelo-Silver et. al. [5] compared PBL students to lecture instructed students and concluded that although the PBL students made more errors, they also created more elaborated explanations compared to the sparse explanations of students in the traditional curriculum. This finding suggests that PBL can deepen student learning.

In the context of teaching engineering dynamics, prior studies confirm that traditional lecture-based classrooms are ill-equipped to facilitate the development of students' intuitive, visual, and contextual understandings of dynamic phenomena [6, 7]. As Barroso [6] explained, instead of viewing dynamics as "a unified body of knowledge built upon a very limited number of basic equations and principles… many undergraduate students see dynamics is a collection of tricks, one for each type of specific problem" (pp. 1-2) to which, we add, many students simply learn by rote in order to pass an exam. Mativo and Smith [8] further tackled the two basic questions that linger in many engineering educators' minds: Are my students acquiring process skills – knowledge of how to employ factual knowledge in practice? And, are my students acquiring epistemological skills – knowing the validity of the knowledge one has and ability to construct new knowledge in situations where the answer is not immediately known? Their findings indicated that students demonstrated a superior grasp of concepts after designing and implementing their own experiments rather than following rote lab instructions and procedures.

The adoption of PBL and other active-learning and real-world approaches to teaching engineering fundamentals, however, remains limited. Several reasons for this are student discomfort with the initial transition to PBL, the role of the instructor as facilitator rather than teacher, and the value assigned to teaching by the individual and the organization [9]. To address these barriers to the implementation of PBL, Bareveld et al. [9] emphasized the importance of a holistic team approach by involving instructors and administrators to create both professional development opportunities and curriculum innovations that lead to desired results. Our approach is ultimately geared towards this model.

Problem statement and overview

Building on the above summary of prior work, our development and implementation of industry-inspired, PBL activities for an undergraduate dynamics course sought to address the following key challenges that also form the focal points of our discussion of impacts on student learning:

1. Perceived student disconnect between abstract principles and application (relevance)
2. Overcoming student resistance to PBL (motivation)
3. Increasing depth of knowledge of dynamics principles (elaboration and application)

The paper will (i) describe the project context in terms of developing the problems through a collaborative approach between instructors, educational researchers, and industry partners, (ii) introduce one of the three problems that were used in the course, and (iii) present an evaluation of the impacts on student learning organized around the above focal points.

Project context

The project team for this project comprises: Dr. John Mativo the team lead and course instructor; Dr. Nicola Sochacka, researcher in engineering education and instructor in the environmental and mechanical engineering programs; Dr. Joachim Walther, researcher in engineering education and teacher in the environmental and mechanical engineering programs; Doug Brouillard, the industrial partner who is an Engineering Manager at a local car part manufacturing plant that specializes supercharger technologies; and Kathryn Youngblood, an undergraduate student who assisted with qualitative analysis of student responses.

The search for an industrial partner began towards the end of summer 2015. A list of potential partners was established using the criteria below. Of the identified companies, one stood out and was approached for a possible partnership. The company agreed to participate.

i. The potential partner's industrial activities must entail motion and forces.
ii. The potential partner must be within a reasonable radius from campus to allow accessibility by students or faculty, as needed.
iii. The potential partner must be willing to work collaboratively with the research team to identify and develop the problem-based learning activities.

Once a working relationship was established, the industrial partner arranged for a plant visit and tour of the facility for the instructor and educational researchers to familiarize themselves with the production facilities, equipment, and processes. During the visit, the industrial partner provided a detailed tour of the factory floor, with a particular focus on the work flow and equipment used at each stage of the process from start to finish. At each stage, the industrial partner explained why the equipment was needed and how it was expected to perform. He pointed to instances where improvements could be made and others that performed satisfactorily. Together with the industrial partner, the instructor and educational researchers retreated to a conference room after the tour to discuss potential problems that would be created. Two problems that were immediately identified were: 1) A past scenario in which the plant made an error in their initial design of a Gorbel bridge and the G-Force lift assist system to handle two new product lines (their original calculations had only considered static and not dynamic loads) and 2) A dynamic robot arm system for the process of moving loads from one location to another. Development of both problems was started as soon as the instructor received initial parameters from the industrial partner.

The design of the problems and their representation were informed by the details and specifications in the industrial setting and pedagogically informed by principles and best practices in the literature on PBL (e.g., Prince & Felder, 2006 [11]). Ultimately, three problems were developed: the lift assist, robot arm, and a supercharger testing cell. The problems were purposefully ill-structured to depict situations that could occur in industry where information has to be sought from various resources to establish the line of action needed.

The problems were implemented in two iterations of the dynamics course with some incremental improvements to the presentation and facilitation. In both instances, the students were given choices either to design and study their own problem using concepts in dynamics or to engage with one of the three industry-inspired problems. In both iterations, about half the students chose industry-inspired problems. The course instructor and industry partner served as immediate resources.

The following describes the design and class-room implementation of one problem, the lift assist, to illustrate the principles and provide a sense of the materials provided to the students and the process of facilitation.

Example Problem: Gorbel bridge and G-Force lift assist.

The example problem concerning the Gorbel bridge and G-Force lift assist, shown in Figure 1, aims to: i) prompt students to develop an intuitive understanding of the problem and illustrate their knowledge by sketching diagrams of what is expected; ii) provide students with a way to express their conceptual understandings of the problem by reflecting on guiding principles in dynamics, statics, or otherwise that would help them solve the problem; and iii) prompt students to identify, for themselves, from where they need to gather pertinent information to help the formulate the problem and develop a solution.

Brief to hand out to students (2nd iteration)

Supercharger Lift Assist Dynamics Problem

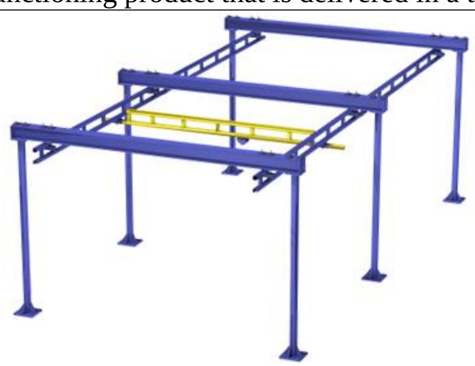
Problem Statement:

The Athens, GA [company name] Supercharger Facility has two new product lines that require the addition of a Gorbel bridge and G-Force lift assist.

One product will use an end effector with a tare weight of 45lbs and capacity of 100lbs while the other has a tare weight of 178lbs and capacity of 50lbs.

Assuming that cost and load ratings increase linearly, what model lift assist and load capacity bridge is most cost effective?

Note: You are in a Dynamics class, so don't forget to factor in the forces resulting from the acceleration of the loads. Seek resources and reference them. Expected results include a functioning product that is delivered in a timely fashion, and is robust and cost effective.



Solve for Load Rating of Yellow Bridge
(20' span) Gorbel Free Standing Work Station

What Size Gorbel G-Force is Needed?

Step 1: Before you start "doing the math", your supervisor has asked you to gain:
i) an intuitive understanding of the problem,
ii) a conceptual understanding of the problem (e.g. in terms of what static/dynamic/engineering principles you will use to solve it), and
iii) an idea of the data you will need and where to get the data.
Work through this problem in groups of three. Please don't hesitate to ask questions!

*Step 2:*Calculate the load rating for the yellow bridge and the required size of the G-force lift assist.

Figure 1: Sample problem.

On the first day of class in Spring 2016, the course instructor provided an overview of the course and announced that a series of real-world, industrial problems would be available for interested student teams. Two weeks into the semester, the industrial partner came to class and presented the company profile and his work as it pertains to engineering dynamics. He explained how the problems affect decision making and sound engineering in day-to-day operations. A week after the presentation, the instructor invited the top 12 students in the course (based on performance at that stage in the semester) to tackle the first problem. Of these 12, 10 agreed to participate (3 teams of 3 or 4). Following an initial introduction to the problem, the course instructor met with each team to ensure the problem was well understood and to establish that they knew where to seek resources. Based on the lessons-learned from the first problem, the project team developed two additional problems, which were offered to all students in the class.

For each problem, which were rolled out at different times during the first iteration (Spring 2016), the instructor provided the problem assignment and due dates while the student teams established their own schedules in between those dates. In the first iteration, students were given four weeks to tackle the problem and submit a preliminary report. Thereafter, students were given the opportunity to keep refining the problem for the rest of the semester. During the second iteration, in Fall 2016, students were given the last half of the fall semester to address the problems. The next section provides examples and excerpts from student work, drawn from the first iteration, which highlight particular features of how the students approached this ill-structured challenge and, at the same time, provide the reader with further insights into the details of one of the three problems.

Examples of student work

Project planning: To varying degrees, the student groups approached the ill-structured problems in an independent and self-directed manner. The groups that were most successful made a concerted effort to work continuously on the problem throughout the allotted time in the semester. This approach gave these groups the time to make mistakes, and incrementally gain an appreciation for the social, technical, and economic aspects of the problem. The groups that created a project timeline were also more successful in scheduling a time to meet with the industry partner. The need to consider the availability of a third party, industry stakeholder was arguably the greatest motivator for the students to think seriously about project planning. Exhibit 1 shows a student-generated time-line for their project, including a proposed meeting time with the industry partner.

Exhibit 1: Project schedule (excerpted from final group report)

Date	Task
2/18/2016	Establish report format and outline task
2/23/2016	Turn in report rough draft to [the instructor] for comments
2/25/2016	Turn in revised 2 page report on how to approach problem
2/25/2016	Assemble as a group to discuss project progress and next steps
3/01/2016	Meet with [the industry partner] to discuss the problem and see the existing structure
3/03/2016	Assemble as a group to discuss project progress and next steps
3/15/2016	Assemble as a group to discuss project progress and next steps
3/17/2016	Turn in set of solutions

Process: The assignment encouraged students to draw on both the instructor and industry partner as resources for their project, thus situating the engagement with a dynamics problem in a realistic stakeholder context. In various forms, students made use of these resources to enrich their understanding of the physical problem and again an appreciation for how such problems are situated in the organizational and economic context of engineering companies. Exhibit 2 shares a portion from one of the group's final report, in which they describe how they engaged with the industry partner to gather the information they needed to solve the problem.

Exhibit 2: Excerpt from final group report describing process for engaging industry partner

"In order to fully understand the problem, a tour was scheduled with [the industry partner], the engineering manager at the [company name] supercharger plant. A list of discussion questions was emailed to him prior to the meeting. During the tour, [the industry partner] was able to provide a general overview of the problem from his perspective. It was discovered that this problem had actually been solved several years ago when the current lift assist had originally been designed. He stated that the structure and components were only designed statically, and that dynamics were not fully analyzed with the original design. Since this error had cost the company thousands of dollars, he stressed the importance of taking into account the effect of the dynamic movement of the lift assists. Figure 2 below shows one of the three lift assists currently in use in the factory. Due to the proprietary information of the superchargers, the quality and angle of the pictures is substandard. Figure 3 below shows the structure that holds the three lift assists and where the fourth lift assist to be designed would be placed…The information obtained from the meeting with [the industry partner] was very useful. He provided information on the weight of the two superchargers and the end effectors, which are discussed in the analysis of this report. He also advised using a specific lift assist manufacturer's site to learn more about the possibilities of the lift assists."

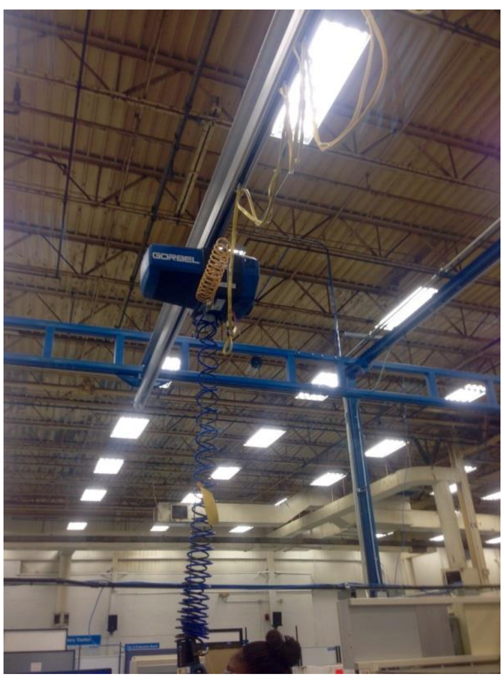


Figure 2: Lift assist

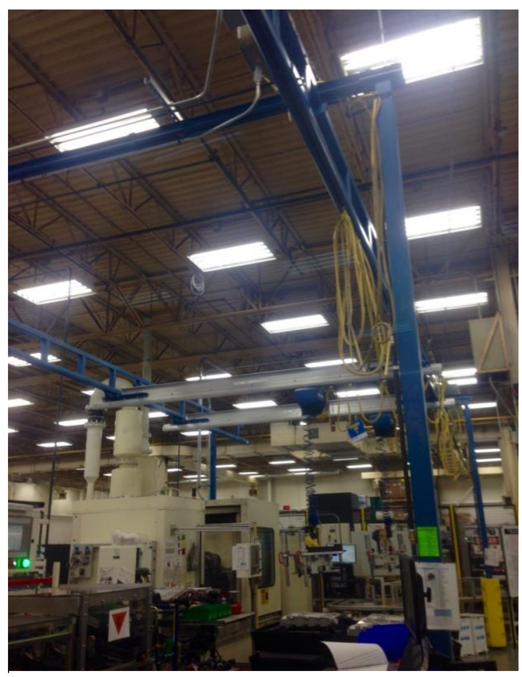


Figure 3: Lift assist structure

Learning outcomes: One of the most striking learning outcomes from this activity was the fluency that students gained in describing static and dynamic engineering concepts. This was particularly evident in several of the final reports that extensively described the problem solving process using both words and equations. Exhibit 3 shows one group's narrative account of the engineering principles that they applied to solving the problem.

Exhibit 3: Excerpt from a group report describing application of engineering principles to the problem

"The first step in analyzing the problem was to look at the bridge structure as a rigid, non-moving system statically. After that analysis was complete, the structure was analyzed dynamically to account for the moving components of the bridge and the lift assist…Once we had collected the specifications required to perform calculations, the group started by calculating the applied force of the entire mechanism on the track and supported structure during the transfer. This force needed to be calculated using knowledge of dynamics because it will include the weight of the supercharger, the weight of the mechanism, and the upward acceleration of the mechanism."

Evaluation of impact on student learning

In addition to examining the course artifacts for evidence of students engaging differently with the industry-inspired problems, the impact on student learning was evaluated using an end-of-semester survey. This section describes the survey design and analysis, and findings. The Discussion section then examines the evaluation results in relation to the three key learning challenges that were identified in the prior literature.

Method

At the end of both the Spring and Fall 2016 semesters, a survey was administered to students to explore their experiences with the problem-based learning exercise. The survey comprised the following three questions:

1. What did you like most about working on your project problem and why?
2. Please describe how your project problem helped you to better understand one area/concept of engineering dynamics.
3. What could be done to improve the project problem experience for future cohorts?

In the first iteration (Spring 2016), 46 students submitted surveys. Of these, 34 had completed one of the three industry-inspired problems while the remaining 12 had developed their own problem to study a concept in dynamics.

In the second iteration (Fall 2016), 85 students submitted surveys. Of these, 50 had completed one of the three industry-inspired problems while the remaining 35 had developed their own problem.

The survey responses were coded using the qualitative data analysis software NVivo 11. An open-ended process was used to establish emergent themes in the student responses so as to not limit the insights gained from the data to the project goals and the key learning challenges identified in the prior literature [12].

Emerging themes in student feedback

Table 1 shows an overview of the emergent themes identified in the qualitative analysis. The paragraphs under the table briefly describe key features of each theme.

Table 1: Emergent themes, subthemes, and example quotes from the qualitative analysis

Emergent themes	**Sub-themes**	**Example quotes**
Real World Applications	First Hand Exposure to Professional World	"It made me feel like we worked on something that we would actually use outside of college. A lot of example problems done in class and for homework are sometimes a bit far-fetched. An industrial robot is a very familiar and relevant object likely to be seen or used outside of college."
Open-Endedness	Necessity of Research, Lack of Adequate Information	"It was a unique problem compared to most textbook problems that didn't have a specific answer, which I liked because it gave us **freedom to do what we wanted** with it." "I feel like we were just **tossed into the mix** with little to no clue where to begin. It felt overwhelming at times."
Problem Solving Process	Problem Constraints	"This project helped me **understand the process of engineering design**. Starting from scratch and having to work at a solution that would be applied to a real life machine was very new to me. It opened my eyes to see how important detail is in the design process."
Increased Understanding of Concepts	Statics and Dynamics, Energy, Kinematics (Centrifugal Forces, Rotational Dynamics), Kinetics (Newton's 2nd Law, Tension, Torque), Pulley Systems, Robotics, Superchargers.	"Our project helped me with **understanding the kinematics of rigid bodies** because I did multiple examples and could understand how different angles and angular velocities and accelerations could affect a problem." "Researching about the project helped me understand more about **mechanical systems and how materials affect its functions**: Belt friction, Wrap angle, Centrifugal force, Torque, Tension."
Group Dynamics	Positive Experiences, Negative Experiences	"I really enjoyed solving the problem in a group. I think we worked really well together and were able to finish efficiently because **we all had different strengths**." "Meeting more often would help a lot more. **We weren't successful in cooperating as a team** because our time did not match."

<u>Real world applications</u>

Students commented most comprehensively on the "real-world" nature of the industry-inspired problems. Many students appreciated the opportunity to work on a problem they might actually solve in their professional careers. As one student stated:

> "It provided a realistic scenario similar to a problem which could be encountered on the job."

Other students explained how the real world example helped them "to learn the material better":

> "By working on a real life problem with [company name] Superchargers, it allowed me to see real world problems and how we can solve them with dynamics."

One student stated that the experience helped them to value what they are learning in class:

> "It was nice to get a taste of what real world problems are like. Because it helps me see the value of what I am, or should be learning."

Open-endedness

Students expressed both excitement and frustration at the open-ended nature of the problems. For example, one student wrote:

> "The industry problem helped me understand that problems are often open ended in the real world. By this I mean there is not a set of information given for every problem."

At the same time, multiple students suggested that more information would have been helpful, as illustrated in the following two quotes:

> "It would be helpful if the design problems were less open ended. It was so easy to get lost in trying to solve the problem because there were no constraints. We had to make our own, and it was challenging because there are an endless amount of possibilities to consider."

> "A little more explanation of the project details itself. Our group spent a lot of time researching dead ends using wrong formulas that we had assumed were correct at the time."

While these two quotes point to student dissatisfaction with these aspects of the exercise, we note the benefits of learning to think through appropriate constraints and navigate "dead ends". The instructor used such feedback from the first iteration to reassure students in the second iteration of the *value* in facing and overcoming these challenges.

Problem solving process

Some of the students noted the differences between solving classroom and real-world, or "workplace" problems [13]. As one student wrote:

> "This problem helped me see how one goes about solving an engineering problem in the real world."

One of the students articulated specific differences between classroom and workplace problems:

> "When we get a real life problem, we will encounter real obstacles that need solution. Ex: Pulleys are real with real friction."

In the second iteration of the exercise, the instructor invited students to be aware of, and discuss with their teammates and the instructor, similarities and differences between classroom and workplace problems.

<u>Increased understanding of concepts</u>

The second survey question asked students to describe one area or concept of engineering dynamics that the industry-inspired projects helped them to better understand. Students' responses covered statics and dynamics, energy, kinematics, and kinetics as well as pulley systems, robotics, and superchargers. Most importantly, students made connections between engineering principles and real-world applications:

> "My group had a real-world concept where statics are typically considered, but dynamics was needed as well. We were able to take into account the moving components in order to best select an appropriate life assist that is cost effective and could carry the load capacity. This was important to save the company money in the futures, as well as improve production."

> "Our team had not covered tension in pulley systems in that manner. We had to understand that the tension on one side did not equal the tension on the other and work through the system."

<u>Group dynamics</u>

Students who discussed group dynamics as a positive feature of their experience referred to the different strengths that team members brought to the project, including for example, disciplinary backgrounds and inter-personal skills. In both iterations, concerns with respect to group dynamics were limited to scheduling issues. For example, one student commented:

> "we had issues with a group member who was unable to meet the whole time. So maybe a chance to work in class?"

Discussion

The following paragraphs examine the evaluation findings in the context of the key learning challenges that were identified in the prior literature

Perceived student disconnect between abstract principles and application (relevance)

The survey findings indicate that the industry-inspired problems enabled students to make connections between abstract engineering principles and their application in real-world settings. As discussed above, students appreciated the opportunity to see the relevance and value of what they are currently learning in class and were excited gain insight into what their future professional lives may look like as practicing engineers.

Overcoming student resistance to PBL (motivation)

Despite students' appreciation for the opportunity to experience a real-world engineering problem, many of the students still pushed back against the open-ended nature of the problem. For some students, the perceived lack of information was initially overwhelming and demotivating. While for others, the "freedom to do what we wanted" was one of the most motivating factors. These mixed responses underscore the importance of facilitating PBL activities in a way that empowers students to view obstacles as opportunities for learning. In order to do so, it is critical that instructors anticipate the scope of obstacles that students may face and, at the same time, resist the temptation to make students feel *too* comfortable by providing either too much information or too much guidance. A timeline for deliverables would put in place intermittent checks to reduce lots of wasted time in PBL. Further, industry inspired problems seemed to be better understood when given during the second half of the semester after students had confidence in the fundamental concepts of the course, in other words, they could relate to the framing of the ill-structured question.

Increasing depth of knowledge of dynamics principles (elaboration and application)

As illustrated in depth in Exhibit 3 and through the quotes presented under the Increased Understanding of Concepts theme and sub-themes, one strength of this exercise was how it encouraged students to experiment with and articulate engineering principles in different ways. The fact that there was no one correct answer or problem solving procedure seemed to release students from the tendency to look for the "trick" to solve a particular type of problem. Instead, students started with concepts, discussed them in their groups, and only then started to explore appropriate problem solving methods and equations. The real-life nature of the problems also seemed to allow students to have a better grasp of what answers seemed right or wrong. While some students framed these explorations as "dead ends", we argue that such dead ends facilitated deep learning of engineering principles [14].

Conclusion

This paper described the development, implementation, and evaluation of a set of ill-structured, industry-inspired problems to support student learning in an undergraduate engineering dynamics course. The intervention addresses a number of key problems that prior literature identified around instruction in engineering fundamentals courses, particularly from a problem-based learning perspective. The description of problem development and implementation was complemented by exhibits from student work that illustrate particular features of the learning experience. The impact of the project on student learning was evaluated using a qualitative analysis approach to develop emergent themes from students' feedback solicited in an open-end survey at the end of the semester. In the aggregate, the findings demonstrate a positive student response and emergent themes illustrate particular aspects of the initiative's impact on student learning. The emergent themes also shed light on the key challenges identified in the literature and point to the potential for future work in this area.

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