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PROJECT-ENHANCED LEARNING IN CHALLENGING ENGINEERING SCIENCE COURSES

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ABSTRACT

Many sophomores and juniors perform poorly in traditional lecture presentation of challenging engineering science courses, and this may present either a threat or opportunity for retention. Examples of such core ‘gateway’ courses in mechanical engineering and electrical engineering curricula include Thermodynamics, Signals and Systems, Probabilistic Methods, Statics, and Dynamics, among others. Test scores, surveys, and classroom assessments indicate that many students completing these courses did not really understand the fundamentals, even if they could apply the ‘formulae’.

A supplemental or alternative approach such as project-enhanced learning has been effective. The authors have implemented project experiences in three different courses, based on initial experience in a course on Thermodynamics. In Fall 2011, project-enhanced learning was introduced in two other courses: Probabilistic Methods In Electrical And Computer Engineering, and Dynamics in mechanical engineering. One or two major projects based on systems, objects, or activities that are familiar to the students are designed and assigned to apply key course topics. The goals are to motivate and improve learning of abstract concepts and to provide a realistic application that anchors and helps retain learning. Teamwork and professionalism were also emphasized. This paper will present the projects developed and the experience of the instructors in conducting the projects. Observed student reactions and learning will be discussed. Online discussion forums helped in project guidance and peer discussions. Each student team was required to submit a final project report at the end of the semester.

1. INTRODUCTION

The middle years of college are critical for retention of engineering students. In the freshman year, many programs now provide exciting introductions to engineering design and applicable science by dedicated and experienced instructors. But in sophomore and junior years, they

encounter traditional lecture presentation of highly analytical engineering science courses, sometimes given by tenure-track faculty members under pressure to prioritize research over undergraduate teaching. Many students who struggle through these courses go on to enjoy engineering design courses and activities that may be encountered only in their senior year. But many drop out just before they have design experience because they did not succeed in or see the relevance of the analytical courses.

Retention of students in engineering is connected to learning and self-efficacy in core courses that appear to be abstract, challenging, and not meaningfully connected to their professional aspirations. Many researchers and engineering educators report that project assignments, if designed appropriately and if widely adopted by faculty have significant impact on enhancing student learning and ultimately retention and graduation.

One example of a core engineering science course is introductory Thermodynamics, which must introduce to students both a new branch of science and an unfamiliar abstract method of scientific reasoning. Even those students who learn to apply the ‘formulae’ rarely understand the laws of thermodynamics. Another example is a course related to probabilistic methods using difficult mathematical concepts that the students may not connect to real-life applications. Courses on topics such as statics and dynamics, for which students may have relatively better physical intuition and familiarity from high-school studies, can also quickly become mathematically abstract in advanced college-level presentations.

Active learning methods and problem-based learning (PBL) approaches are known to be effective learning approaches (Acar and Newman, 2003; Denayer, *et al.*, 2003; Frank, *et al.*, 2003; Hsieh and Knight, 2008; Perrenet, *et al.*, 2000; Said, *et al.*, 2005; Sheppard, *et al.*, 2008). The project-enhanced learning (PEL) approach was developed at Indiana University – Purdue University Indianapolis (IUPUI) and implemented in an introductory Thermodynamics course over a period of twelve years (Krishnan and Nalim, 2009). PBL and PEL are somewhat different approaches. PBL refers to approaches where the structure of the course is driven by an open-ended problem posed to the students. PEL refers to approaches where a project is integrated with a traditional lecture-based course, and can be implemented in a supplemental manner, with manageable workload and among multiple sections and instructors.

The requisite characteristics of project implementation in PEL evolved with experience. Instructor willingness to add a project component in addition to traditional methods depends on project attributes that must be carefully constructed to minimize additional workload to the instructor as well as the student. A project component of analysis courses at the sophomore and junior levels cannot be as open-ended as a senior level design project. The PEL approach resulted in enhanced peer-to-peer interactions, revealed student misconceptions, improved student motivation and learning, as reported previously (Krishnan and Nalim, 2009).

The major benefits are improved learning in target courses, and potentially greater retention of students in engineering. Attendant learner benefits are improved self-efficacy in target courses, sense of belonging in the discipline, peer-to-peer learning, enhanced communication and team skills, professionalism, and project management skills. Benefits for the instructor include early feedback on student difficulties and misconceptions, and the relatively low workload required for

the structured project. Despite evidence of the benefits of active learning, engineering schools and faculty members have inadequate incentives to experiment with non-traditional approaches (Sheppard *et al.*, 2008).

In 2010, IUPUI received a grant from the National Science Foundation (NSF) to implement and disseminate PEL in engineering science courses, as well as to identify barriers to adoption and to train faculty members. The grant activity aims to expand the PEL model to multiple courses at IUPUI and other institutions. One or two projects are assigned and discussed at the beginning of the semester, so that it naturally motivates the learning of needed concepts throughout the semester. This paper describes the PEL approach, applications in three courses, and experiences at two urban research universities.

New instructors were initially reluctant to add the project to an already packed syllabus, but soon found that the tightly integrated project required very little extra grading effort. They also observed improved learning of the subject matter. Students were motivated to learn how to complete the project without errors, asking questions when something did not seem right, unlike with traditional piecemeal homework. Often, an online discussion forum for the project revealed student misconceptions and prompted early intervention to correct the errors.

2. PEL IN THERMODYNAMICS

The abstract nature of an introductory Thermodynamics course is inherent in the nature of the topics covered where many new concepts, laws, definitions, and variables are introduced sequentially throughout the course. Unlike concepts in mechanics, thermodynamic concepts have probably not become intuitive through visual and tactile senses in daily life or primary education. Students are typically required to master these new ideas as they move from chapter to chapter. In the preface to his thermodynamics textbook, Levenspiel (1996) quotes Andrews (1971), who in turn quotes a student: “To me, thermodynamics is a maze of vague quantities, symbols with superscripts, subscripts, bars, stars, circles, etc., getting changed along the way and a dubious method of beginning with one equation and taking enough partial differentials until you end up with something new and supposedly useful.”

The project involved applying the basic principles of thermodynamics learned in class to real-life need for shelter and comfort. The PEL approach in Thermodynamics is intended to apply key topics to a familiar domestic problem of heating, ventilation, and air conditioning (HVAC) system design for a residential application, based on fundamental principles such as energy conservation, manufacturer’s specifications, and actual climate data.

The first part of the project involved using the energy balance to calculate the winter heating and summer cooling requirements for a house based on actual historical climate data for the region and accounting for various energy sources such as solar radiation, electrical equipment, and human metabolism. The second part of the project involved market research and analysis to select the most efficient and cost-effective HVAC equipment to meet the heating and cooling needs of the house.

This thermodynamics project was implemented for a number of years at IUPUI by about six different instructors. In 2011, PEL was adopted in the Engineering Thermodynamics course at Virginia Commonwealth University (VCU) and was continued at IUPUI by a new assistant professor. The aim remained to provide a bridge between the theoretical framework (laws of thermodynamics) covered in the course and their application in senior design courses. The traditional structure of the course is laid out such that the majority of the time is dedicated to sequentially covering the three laws of thermodynamics, and then devoting a few hurried lectures towards the end of the course to some applications (refrigeration and power cycles). The students do not see the usefulness or practical application of these laws until the end of the course. PEL was introduced with the primary objective of promoting better parallels between learning the theory and its practical applications, making the learning experience more meaningful. The secondary objective was to make a challenging course like Thermodynamics less daunting by promoting peer-to-peer learning, communication and teamwork.

2.1 Implementation of PEL in Engineering Thermodynamics at VCU in Fall 2011

Engineering Thermodynamics is a sophomore level required course for undergraduate students enrolled in the Mechanical and Nuclear Engineering Department at VCU. This is one of the first courses taken by the students in the core area of thermo-fluid sciences, followed by fluid mechanics and heat transfer. Traditionally, these core courses emphasize fundamental principles and build on the minimal introductory material covered in the freshmen-engineering course. The students apply the fundamental principles learnt in these core courses as a part of a capstone design project and thermal systems design course in the senior year.

(a) Project Implementation

The project was assigned at the beginning of the semester. The first part of the project was required to be completed soon after the relevant instruction on the first law of thermodynamics was completed.

The project constituted 10% of the overall course grade, significant enough so the students take it seriously. The project was accompanied by a reduction in weekly homework assignments such that the overall workload for the student does not exceed what is typically expected for a three credit undergraduate course. In other words, the workload was kept the same while replacing closed-ended weekly homework problems on individual topics with more open-ended problems that must be solved as components of an integrated design project.

(b) Challenges

Although the principle of energy conservation (energy is neither created nor destroyed) was generally well understood, one of the challenges faced by the students was correctly identifying and accounting for all energy sources and transfer processes taking place in the house, along with simplifying assumptions that must be made to make the analysis manageable while still maintaining a reasonably accurate model. This required the students to be familiar with the mathematical statement of the first law for open systems, and how to use it correctly.

Students were required to gather information from a number of different sources (e.g. looking up climate data using an online database, comparing different heat pump or gas furnace models from manufacturer's product brochures). This initially posed a challenge about half of the students, who had been accustomed to finding all information in the statement of the problem itself, with occasional need to look up a property value always available at the back of the textbook.

Gathering information from multiple sources was challenging because the data from different sources were in different system of units. All data had to be converted to a common system of units before plugging them into an equation or making comparisons. Roughly 25% of the class had one or more unit conversion errors in their calculations.

(c) Student Response

The increased teamwork resulted in greater effort from the students since the task appeared less daunting and more manageable as a part of the group. The project resulted in roughly 75% of the class visiting the instructor office hours at least once during the duration of the course. The increased interaction was not only beneficial for the students, but was also beneficial for the course instructor as it provided early feedback on students difficulties and misconceptions that were cleared in subsequent class lectures. Based on the feedback, it was evident that students immediately saw a practical application of what they were learning. For example, the first law of energy conservation was not just a theoretical principle, but had a very direct application in choosing the right equipment for heating or cooling of their house. Towards the end of the project many students analyzed if the calculated heating and cooling cost were making sense (at least in terms of order of magnitude) by comparing it to their annual utility bills. The project kept the students engaged in the subject matter. They viewed learning and application of thermodynamics laws and several other topics as a means to a common end (as opposed to a series of individual topics that must be crammed the night before a test).

2.2 Implementation of PEL in Thermodynamics at IUPUI in Fall 2011

The PEL approach to thermodynamics instruction was continued at IUPUI in Fall 2011. The class of about 60 students formed 30 teams in pairs. The project grade was based not only on the written reports, but considered oral presentation (20%), written reports (70%), presentation attendance (5%), and forum discussion (5%). The discussion forum was provided on the course website which uses the Indiana University course management software, Oncourse. This allowed students to share their concerns, problems, and experience, and to help each other. The 5% forum discussion grade was awarded to the entire class if more than half of the teams were active on the forum.

The performance of the students in the presentations was particularly outstanding, relative to the expectation of the instructor. All students attended and participated actively. The presentations were orderly and well orchestrated despite a tight schedule, with smooth transition between teams given 7 minutes each for presentation and answering questions. The instructor was very pleased with the evident team work, slide layouts, presentation style, smooth delivery, and time management. This indicated a level of creativeness and professionalism that was commendable

for sophomore students, and appears to reflect their enthusiasm for the PEL approach as well as the effectiveness of the structured grade incentives. Students played three roles in the presentation: as a speaker presenting their own work, as a judge to score others presentation, and as and an audience to ask questions.

When the project was assigned the instructor was concerned about the time available to complete the project and did not expect all teams to have completed all the work. In this first experience teaching the course, the instructor was pleasantly surprised by the project completion, and by the effectiveness of the presentation by these sophomore students.

Further, more than half the teams were active on the discussion forum, with 170 posts covering many different topics regarding to the project. These exchanges helped students learn and to achieve commendable results in both oral and written work.

3. DEVELOPMENT OF PEL IN PROBABILISTIC METHODS AT IUPUI IN FALL 2011

In Fall 2011, a new PEL component was added to the course Probabilistic Methods in Electrical and Computer Engineering. This probability course is a part of the curriculum for majors in both electrical engineering and computer engineering. It aims to introduce the concepts of probability, statistics, and random process, and to discuss their applications to engineering problems. Many students find it difficult to understand the mathematical concepts in the course. Furthermore, perhaps the majority of students struggle to make connections between concepts and equations learned in the course and the engineering applications for which they are being prepared. Therefore, an appropriately designed project was expected to enhance students' understanding of the subject material.

To develop the project was itself a challenging task. For this purpose, suggestions were sought from all faculty members in the department who had previously taught this course. The faculty members had different experiences and views on the project topic. The proposed topics included biometrics, signal systems, image processing, and communication systems. After careful considerations, two projects were developed and assigned. The first project related to a dice game and the second project was related to a communication system. The dice game project was expected to be effective, firstly because students enjoy playing a variety of games of chance. A topic related to a dice game can help them make connections between course subjects and their experience. Further, because we asked students to develop their own strategies of winning the dice game with their peers, this may motivate them to think based on what they learned from the course.

The second project was chosen because the probabilistic methods course is a prerequisite for a required senior-level course on "Transmission of Information," which is related to communication systems. A topic related to communication systems is thus beneficial in the curriculum. Further, their success in the later course, compared with other students who have not done the project, may be used as an indication of the effectiveness of PEL. In this way, we may obtain preliminary data for the analysis of the benefits of the course project.

One difficulty in developing the project is the topic coverage. As the course covers a variety of topics related to probability, it is nearly impossible to cover every single topic in two projects. In this regard, the project is designed in several steps, with each step covering part of the important concepts. The project designed in this way is easily expandable and major steps could be added or deleted based on the interests of instructors and student feedback.

The project contribution towards the total course grade score was specified as 10%. This was considered a reasonable incentive for students to work hard on the project, but not so much as to ignore learning the fundamentals and theory taught and tested in the course. The two projects were equally weighted at 5% each. The students are asked to form a team of two for each project. Each student is asked to turn in a final report on the project; evaluation of their performance is based on the individual report.

The first project requires students to develop a winning strategy for a dice game, that is a variation of the popular dice game “The Pig”. The students are asked to develop their own strategies for the game and play the game several times with their teammate using the strategy that they have developed. They are also asked to observe the outcomes and record the results. Then they are asked to exchange their strategies with their teammate and discuss whose strategy is better. All the games are recorded and the analyses on the strategies are included in their final reports.

The second project is to ask students to design a digital communication receiver that meets specific requirements. The students design an appropriate digital receiver in the presence of transmission noise. This project has real-life applications related to cell-phones and communication networks. Each project team was assigned a different set of parameters. The students are asked to determine the signal that was mostly likely being transmitted given the noisy observed signal and to calculate the bit error. The topic in the project covers most important concepts in the course including conditional probability, total probability, Baye’s Theorem, and others.

Both projects have received very positive feedback from students. After the projects were assigned, students visited more often during office hours and asked a variety of questions related to the projects. Their final reports also contain very interesting comments, from which I can see these projects really helped them think and learn the concepts. For example, one student wrote “I have played the dice game with my teammate five times, he won four times. However, I think my strategy is better. If we play more games, I will win more times than him because my expected value of scoring is better than his.” This is an excellent analysis with the true understanding of the concept “the expected value”. Similar analyses can be found in many of their final reports. In addition, students commonly feel these projects help them learn the subject. In the course evaluation, when asked whether the course assignments help them learn the subjects, the average score is 3.65 out of 4.0 and the median is 4.0. One student commented “The instructor was effective in establishing a good balance between teaching, assignments/projects, and exams in a way that I consider enhanced learning and understanding.”

From what we have observed so far, the course projects have made positive impact on students and helped their learning. We may consider in future semesters how to expand the projects to

cover more topics and concepts; how to make the projects more scalable; and how to minimize the workload of the instructor on developing, modulating, and implementing the projects. Taking all these factors and student feedback into consideration, and revised version of course projects will be implemented in Spring 2012.

4. DEVELOPMENT OF PEL IN DYNAMICS AT IUPUI IN FALL 2011

Dynamics is a required course in the mechanical engineering curriculum, and is the second course in a sequence on mechanics, the first being a course in statics that is a prerequisite to this course. Although students have had some mechanics instruction previously in a college physics course, and may have developed some intuition for the concepts of force and motion, many struggle with the mathematical analysis and advanced topics.

There were two common projects statements introduced in the class after about the first four weeks of classes. The originally assigned project was on elevator design. One of the teams proposed an alternative project on roller coasters. Both systems transport people from one level or elevation to another. Both systems involved a great deal of the subject matter of dynamics in their design. The design objectives and constraints of the two systems differ quite remarkably.

To reduce the amount of work to be reviewed by the instructor the students worked in teams of 2 or 3 people. Each team was asked to keep a journal of their design work and activities. The journals were reviewed and signed off by all group members before each submission to the instructor for review of the progress of each team. The teams made 5–10 min presentations of their work on the last day of class in lieu of a final exam. On the day of the presentation each team submitted a project report, a journal and their presentation slides.

The PEL activity enhanced interaction between the instructor and the students. There were more questions from students regarding the class discussions, and also more outside-classroom discussions than in a traditional course delivery. Peer-to-peer interaction was significantly increased among group members and also among the entire class as each student researched the topic of the project. There was enough variation between each team's assigned parameters and constraints to allow for discussions without having a single solution to the project. The project was somewhat open-ended and choices had to be made by each team after computations were done. The experience of solving a common dynamics problem helped create a sense of ownership of the class materials and projects.

The project required immediate application of material learned, which seemed to help cement better understanding of some of the topics. This was different from students simply solving problems from a text book, which generally involve applying formulas, solving equations and 'number crunching' without improving conceptual understanding. At times the instructor highlighted some concepts and information in class that would be useful for the project. This appeared to motivate the students to pay closer attention to what was being discussed, and stimulated more questions during classroom discussions.

The use of design journals assisted the instructor in keeping up to date with the progress of each team. The documentation process (all team members were required to participate) is very likely to help prepare them for other design projects in later semesters. By doing research on the topics of elevators and roller coasters, the students and instructor learnt a lot about such systems. Questions about how to accomplish certain requirements of the project gave the instructor the opportunity to help students recall and to reinforce topics that had been discussed in class. In some cases it was as if the proverbial light bulb was turned on in a student's mind. They were able to see the connection between a project-required analysis and the course topic without the instructor giving them the answer.

The students prepared for and delivered a final project presentation to their peers at the end of the semester. That meant each one had to understand what was to be presented and then portray a measure of understanding of the subject. There were questions to be asked by the audience and the instructor during the presentation. The class required more commitment and effort from the instructor than in a traditional none-PEL class, but not an overwhelming effort. The relative return in student learning justified the limited additional effort.

5. CONCLUSIONS AND RECOMMENDATIONS

Project-enhanced learning and instruction is an effective approach to enhance learning and may promote retention, especially in challenging engineering science courses in the middle years of undergraduate engineering education. While keeping student motivation alive in these courses, project-enhanced instruction also achieves multiple benefits:

1. PEL motivates the study and learning of course concepts in order to carry out challenging projects successfully.
2. The concepts and their meaning become clearer with concrete applications that appear meaningfully connected with the students' professional aspirations.
3. If assigned at the beginning of the course and the projects are designed to integrate the course topics, the learning objectives are understood better even before the topics are introduced in the lecture and results in better assimilation of the subject material.
4. The project provides avenues for feedback from the instructor, both during the discussion of project activity and in the students presentations and writing.
5. The project enhances teamwork and peer-to-peer interaction, especially if an on-line project discussion forum is provided. Student-driven but instructor-guided interactions help address student misconceptions on the topics of instruction and enhance instructor motivation.
6. The project can inspire the student interest in the course and increases their self-confidence at a time when they are about to enter serious professional career training.
7. Learning retention and student performance in follow-on courses may be enhanced
8. Students express satisfaction and may ultimately be retained in engineering in greater numbers.

These conclusions are reached from instructor's anecdotal experiences, rather than quantitative research. It is very difficult to obtain reliable assessment data in such learning interventions, especially because it is almost impossible to provide an 'untreated' control group and to avoid

sample bias. Students generally self-select for course enrollment, and it is unethical to force students into course sections that may even appear to provide unequal learning opportunity.

Some mixed qualitative and quantitative methods will be explored in the future to evaluate PEL effects. Possible approaches include evaluating student performance in topics tested in related follow-on courses in relation to the actual concepts and applications taught in the course project. We may also examine retention in engineering and the long-term impact on the professional lives of graduates. The extent of interactivity between the instructor and the students is important for the success of project-based or project-enhanced learning approaches. Qualitative and other approaches to assess this factor may be another topic for future studies.

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