PROBLEM-BASED LEARNING APPROACHES IN A DESIGN ENGINEERING CLASS: GRADUATE STUDENT PERSPECTIVES

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Introduction

The global energy demand is growing rapidly along with a rise in environmental concerns. A major issue for the research community is to find environmentally safe and economically feasible energy supplies. These increases pressure on universities to produce more students with sufficient engineering and science skills to solve the current and future industrial problems. However, current technical curriculum in both undergraduate and graduate classes is predominantly sequential and does not adequately prepare students for solving the multidisciplinary problems facing the energy industry. Current experiences of several students show that this sequential approach to education may prevent several students from foreseeing the value of this knowledge in practical applications.[1, 2] Another approach gaining popularity in science education is the problem-based learning (PBL) method.[3]

In traditional design courses, students fulfill certain prerequisites and are educated on the skills necessary to tackle a given problem. Typically, almost all students are from the same academic unit and have completed the prerequisites required by their program. However, solving problems in energy is complex due to the inherently multi-disciplinary nature of the field. The field of energy systems draw students from highly diverse backgrounds ranging from physical sciences, life sciences, and engineering disciplines like chemical, mechanical to name a few. This paper presents the experiences of several graduate students, from three different years, in a graduate level design engineering course that used PBL methods to solve contemporary problems in energy and environmental engineering. In this paper we discuss the advantages and disadvantages of PBL in the context of graduate-level energy education. Finally, recommendations are given for enhancing student learning from PBL in energy education.

Methodology

Students enrolled in the problem-based learning design engineering class came from many different science and engineering backgrounds, but were all working towards an energy-oriented topic. Over two thirds of the students in each year's class were engineers (chemical, mechanical, environmental) and the rest were from physical sciences. These students came from different countries with different levels of research and industrial experience. This is representative of a diverse work force in today's industrial settings too. Table 1 gives an overview of the class topics and team sizes for three years.

Table 1. Class Description of the Three Cases.

Year	Syllabus/ Methodology	Team sizes
Fall 2004	Methane hydrate recovery and utilization (same topic for each team)	5, 5, 6
Spring 2006	Reducing CO_2 emissions from fossil fuel power plants (different topics within same theme)	8, 7, 6
Spring 2007	Implementation of Renewable energy technologies (unrelated topics)	5, 4, 2

Several discussions among graduate students' who had taken this course led to the formation of this paper. In order to get a perspective on the learning outcomes from this course, a questionnaire was emailed to all the students seeking their opinions on these parameters: 1) communication skills, 2) key advantages/disadvantages of each approach, 3) importance of lifecycle analysis in practical applications, and 4) use of PBL style in their research. The learning methodology of each year is discussed in the following section through a brief technical description of the problem in each year along with the main advantages and disadvantages. General comments on other benefits and the (perceived) impact of the class on graduate research are discussed thereafter.

Multiple Approaches to the Same Problem: 2004

This project was on developing strategies for optimal recovery and utilization of natural gas from methane hydrates from Hydrate Ridge, an offshore site approximately hundred kilometers from the Oregon coast. The main challenges for each team were: 1) to develop a model to extract methane hydrates from the ocean floor while estimating the capital and operating costs; 2) to utilize the methane produced to generate value added products which would recoup some of the capital costs associated with hydrate extraction; 3) to ensure that the sea floor remains stable under conditions of methane extraction. However, some of these tasks fell outside the background knowledge of the students in the class. Therefore, team members communicated with professors and graduate students in the field of petroleum and natural gas engineering to understand the various options for extracting and utilizing methane hydrates.

The advantage of having the same topic was that, apart from the healthy competition, it also resulted in excellent cross communication among the teams. Good cross communication among teams resulted in a spirit of camaraderie and led to exchange of knowledge, idea sharing and ultimately better strategies for hydrate utilization. Despite the cross communication among teams, it was interesting to note that the final solutions for all three teams were different. For example: the hydrate extraction models for the teams

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involved steam injection and depressurization. Some of the end-use solutions proposed were off-shore methanol synthesis from methane, power generation from methane in a solid oxide fuel cell, off-shore conversion of methane to methane hydrates and subsequent transportation, and a gas-to-liquids solution.

The main disadvantage of this approach perceived by some students was that the problem was quite vast, in a nascent field and hence a functional approach would have been better. Others disagreed and felt that a wide range of scenarios could be explored only because different teams worked on the same problem. A notable outcome of this project was a poster presentation of the findings of all the three teams at a university wide graduate exhibition.[4]

Different Projects with a Common Theme: 2006

This year, the class worked on the theme of designing various methodologies for reducing the carbon dioxide emission from a 500 MWe scale fossil fuel power plant. Individual teams worked on developing solutions for capturing, sequestering and utilizing the carbon dioxide emitted by the plant. Some flexibility was available in choosing among the larger design problems of capture, sequestration and utilization. There was even more flexibility in division of labor inside the topic. For example: capture team divided the problem into pre-combustion, post-combustion and oxy-fuel technologies, with further sub-divisions in each allotted to individual members. Team members who worked initially on topics that turned out to be non-viable as the class progressed helped contribute to the work in progress. This entailed additional learning efforts by those team members in areas they had not explored before, ultimately resulted in better learning. This project also overlapped with research interests and expertise of several faculty members, so the students could benefit substantially from their collective knowledge, but also faced intense scrutiny at all stages.

The advantage of the 2006 approach was that, because of the common theme, the students were able to give input and ask relevant questions to the other teams. This approach provided some commonality between the teams, and reminded the teams of the global picture and their respective roles. Due to the diversity of the different students in the teams, it was possible to see various design solutions of the overall problem. Inside individual teams, collective management ensured prompt implementation of tasks allotted to members.

One of the main drawbacks of the 2006 approach was that it was difficult for individual teams to gauge relative progress in the class. There was very little interaction between the teams outside of the class. In general this approach did not result in considerable competition between the teams. Another drawback was that the large size (seven/eight members) of some teams made intra-team communication and scheduling quite difficult. Two conference publications resulted in this year.[5, 6]

Different Teams Tackling Unrelated Problems: 2007

The 2007 design course focused around the central theme "Renewable energy utilization for sustainable development" under the three general topics: 1) biomass energy utilization; 2) biofuels production for transportation; 3) geo-thermal energy recovery. A general "problem statement" for each topic was given to the students, and their assignment was to identify key social and technical issues, find and compare options, and then synthesize various methods and results quantitatively in order to make a recommendation.

In general, students were excited to work on renewable energy problems that had received attention from the mainstream population in recent years. The main advantage this year was that students felt that smaller class/team sizes helped them focus better on presentation content. Competition between teams was low since each team worked on a different project and created separate approaches and final goals for their projects. A consequent drawback was that some students whose projects did not depend on the outcomes of others' projects were indifferent to the progress of others.

Students felt that they were making useful contributions to renewable energy technologies, because the topics were contemporary and important to society. The work of one team resulted in a publication with a faculty member not directly affiliated with the class because of overlapping research interests.[7]

General Discussion

Communication Skills. The main written deliverables for this course were literature reviews, progress reports, and a final design document. Students had to learn to work together as a team to combine inputs from different collaborators into cohesive single documents. Therefore, the learning style in this course taught students (as individual and as a team) to write concise technical manuscripts under considerable time constraints. It was a course requirement to give weekly presentations on the team progress, and therefore each student had adequate opportunity to practice public speaking and technical presentation. Students also learned how to approach and consult professionals in the industry when faced with challenges. In addition to obtaining technical information from the industry, this course also provided opportunity to make professional contacts. Finally, students gained project management skills by planning the course of the project, allotting and implementing tasks, and regularly updating team members on progress.

Impact of PBL on Thesis Research. No consensus could be reached whether this course should be taken early or in the later years of their graduate studies. Students who said that this course should be taken in the early years of their graduate studies felt that the problem-based learning approach helped with their thesis work due to a greater understanding of project design and better communication skills. Students who felt that this course should be taken in the later years of graduate studies argued that the required core course work for energy and geo-environmental engineering should be completed before enrolling for this class. Some student felt that this course has little to no impact on their thesis work and therefore can be taken later in later years of their graduate studies. However, nearly all students felt that this course teaches anyone to keep the big picture in mind when working on research projects.

Impact of Life Cycle Analysis. Emphasis was placed by the faculty facilitators on finding the "show stoppers" for each design, which helped the teams to pinpoint the major economic barriers. The consensus was that some insight into identifying roadblocks to the implementation of ideas was achieved, but the time allotted in the course was not enough for a thorough lifecycle analysis of various project designs.

Conclusion

Based on the received responses from the questionnaire, we infer that the overall student experience was similar in all three years. While the methodologies were different in the three years, we feel that the learning outcomes were similar. Students in all years learned how to work in teams with members from diverse technical fields, and reported significantly improved communication skills. Students also learned how to differentiate viable solutions from non-viable solutions for industrial problems, accept failures in some tasks and then shift focus to the remaining tasks at hand. Improvement in individual time management was also commonly reported. We feel that if graduate students are more involved in managing their learning, they are able to connect theoretical concepts to problem solving in industrial settings. We also feel that this course serves as a simulation of the energy industry, where engineers and scientists must work together to solve problems.

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