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Challenging Students' Values and Assumptions Through Project-Based Learning

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"*Computationally, I learned how to really start at the basis of $E_{in} = E_{out}$ and work up from there. Overall though I learned how much potential the earth has to provide if you just look creatively"* [student's words].

Background

Learning through the exploration of problematic situations is not a new educational approach. If we trace the origins of problem-based learning back to early educational forms we will see that Socrates presented students with problems that, through questioning, enabled them to explore their assumptions, their values, and the inadequacies of their offered solutions. Literature shows that this kind of increased understanding and examination of perspectives and frameworks is encouraged through problem-based learning because it offers students opportunities to examine their beliefs about knowledge in ways that lecture-based learning and narrow forms of problem-solving learning do not [1]. John Dewey, the father of modern educational philosophy, argued more than century ago that instruction should be based on students' interests with students involved in real-life activities and challenges [2].

In problem-based learning (PBL) students are confronted with an ill-defined problem [3] and work in teams to find a solution [4]. Instructors act as facilitators and problems are situated in a real-world context that can require single or multidisciplinary collaboration [3,4]. A more complex form of PBL is project-based learning in which students are either given, or choose, a project and design solution. Evaluation of this method of learning shows that, "relative to traditionally-taught students (lecture-based), students who participate in project-based learning are more motivated, demonstrate better communication and teamwork skills, and have a better understanding of issues of professional practice and how to apply their learning to realistic problems" [5, p. 131]. Project-based learning has the same attributes as PBL, but projects can span several problems resulting in a larger scope, thus providing an emphasis on integrating previously acquired knowledge [5].

Scholars suggest that problem-based and project- based learning in engineering education is more effective than traditional forms of instruction [3, 6, 7]. The pedagogical importance of inductive learning methods such as a project-based approach can create an environment in which students are driven by their passion, curiosity, engagement, and dreams [8].

It has been argued that project-based learning is an effective means of meeting ABET criteria [4]. In the traditional engineering classroom, students focus almost solely on the technical aspects of engineering problem solving. Project-based learning can provide opportunities for students to be exposed to the broader context of engineering problem solving [7, 9]. Perkins [10] suggests that students learn best when they experience the "whole game" associated within a content area. Situated in real-life examples, Perkins idealizes seven principles to engage students in their own learning process. These principles range from exposing students to the entire context of a subject area, to working on so-called hard parts of the problem, getting students outside of the classroom, and gains in peer learning from team tasks. Using this integrative approach toward instruction, the technical content and pedagogy come together to align with the final student assessment (the project). Pellegrino's "Assessment Triangle" [11] comprehends this model of instruction with a three-legged stool of interconnected elements. These three key elements scaffold student cognition and learning, while at the same time providing evidence of students' competencies, and relate the learned material for instructor evaluation. Project-based learning however, still hasn't gained widespread acceptance in engineering education [6].

This paper elaborates upon how a project-based approach to engineering education can address a wide spectrum of learning objectives including both individual course objectives as well as ABET objectives and concurrently encourage students to look beyond surface technical aspects of engineering solutions. Through this paper we demonstrate how one (of several) projects in a course can meet these multiple objectives, in a comprehensive, integrated fashion.

Purpose of this study

The study presented in this paper examines the outcomes of a real-world design project used in a foundational course in engineering thermodynamics. Outcomes identified by students are linked to course objectives as well as ABET criteria to demonstrate the breadth of outcomes reported by students.

Method

Participants and setting

The participants were eighty-eight sophomore engineering students enrolled in a one semester, entry-level engineering thermodynamics course during the Fall 2013 semester at a large, research-based, public university in the United States. This Thermodynamics course is the only course students have in their undergraduate curricula. Students enrolled in the course representing mechanical, aerospace, and petroleum engineering majors were divided into 16 groups (of 5 or 6 students each) to work on a real-world design project for 10 weeks. At the beginning of the project period students had the opportunity to visit a power plant of one of the major energy providers in the area. Three professional engineers were engaged in a variety of the course activities and also provided feedback to all projects groups.

Task

The groups were introduced to the scenario that they are a global project manager of a fictitious company engaged in the design and construction of various kinds of electrical power generation systems around the world. They were told that their company is looking for potential new projects in three small countries—Jamaica, Namibia, and Rwanda. Although each of these countries faces unique challenges to economic development, all three are in need of increased electrical generation capacity. Each group selected one of the three countries to focus on and were responsible to write a proposal for a thermal energy system to meet the electrical generation needs of that country for the next ten years.

The proposal was written for review by the owners of their fictitious company as a first step toward preparing a bid for a job in the country of choice. The proposal needed to include an explanation of the need for additional electrical power generation capacity in the country of choice, the resources (or lack thereof) available to meet those needs, and the economic, political, and social situations in the country. In the proposal, students needed to describe the technology they were proposing to meet the needs in the chosen country as well as provide a justification of their choice of technology. The description of technology had to include specifications for the system including the power generation capacity, the maximum theoretical efficiency of the system, the working fluid of the cycle, and a schematic diagram illustrating the components and configuration of the system, all key aspects of a typical thermal system. In addition, students were asked to discuss the environmental, societal, and economic impacts of their proposals.

Each project report was evaluated using a rubric which can be found in Appendix I. This project made up 20% of the course grade for the semester and had two submission deadlines thus allowing students to iterate on their ideas and make improvements to their solution based on feedback from the first submission. While working on the project, students were able to consult with the course instructor, the two course teaching assistants, as well as the university's Center for Teaching for Excellence where a tutor was hired specifically for the thermodynamics class.

After the grading with the rubric was complete, all group proposals were sent to the three practicing engineers from the energy company who were engaged in the course. These engineers provided written feedback on each group's proposal. At the end of the semester, the five groups with the highest scores presented their proposals in front the class, the engineers from industry, and some faculty of the Aerospace and Mechanical department with a thermodynamics background. Special recognition was given to the group in the class with the highest combined evaluation from their presentation.

The project was designed to align with the following course objectives and ABET criteria.

Course Objectives:

1. Basic Competencies – Apply concepts of energy, heat, work, power, process, state and thermodynamics property data to the solution of thermodynamics problems.
2. First Law Analysis – Perform a First Law analysis on arbitrary steady flow systems and elected time-dependent open and closed systems
3. Second Law and Entropy Concepts – Apply Second Law and entropy concepts to thermodynamic systems, including gas and vapor power cycles
4. Property Data Tables – Solve thermodynamics problems using traditional property data tables
5. Contemporary Issues – Demonstrate an awareness of the impact of thermodynamics on contemporary issues such as air pollution and Power Generation

ABET criteria [12]:

3c An ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.

3f An understanding of professional and ethical responsibility.

3g An ability to communicate effectively.

3h The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.

The study presented in this paper evaluates the alignment of student learning with these course objectives and ABET criteria. At the end of the semester, students filled out a questionnaire with items based on the outcomes above (the questionnaire can be found in the Appendix II). Students rated each item on a scale of 1 to 5. The questionnaire also contained three open-ended questions that gave students an opportunity to discuss aspects of the project that they found engaging and challenging and also to discuss what they had learned from the project. Seventy-two of the 88 students in this course participated in this study by completing this questionnaire. Because this study involved the use of human subjects, Institutional Review Board approval was obtained before data collection began.

Results

Table 1. Responses to questionnaire items (see Appendix I for questionnaire).

Questionnaire items	Mean response	Std. dev.
3. Before starting the project, I knew little to nothing about the country for which my group developed a thermal system (Course objective 5 and ABET 3c)	4.11	0.81
4. After the project I feel more confident in my ability to design a thermal system to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability (ABET 3c)	4.01	0.77
5. The project encouraged me to think about the impact of engineering solutions in a global, economic, environmental, and societal context (ABET 3h)	4.43	0.97
6. After the project, I have a better understanding of professional and ethical responsibility(ABET 3f)	3.88	0.64
7. Working in a group increased my ability to communicate effectively (ABET 3g)	3.92	0.65
8. After the project, I feel more confident in my ability to apply course concepts to aspects of my real life	3.92	0.60
9. Having the project *evaluated* by practicing engineers on the appropriateness of the thermal system for the chosen country will increase my confidence in mastering the relevant course material	4.10	0.70
10. The project was interesting	4.29	0.90
11. The project was difficult	3.77	0.51
12. The project was enjoyable	3.83	0.55
13. The project helped me learn	4.25	0.89

The average project score for the class based on the rubric (see Appendix I) was 80.15%. Nearly all of the 72 respondents to the questionnaire expressed enjoyment of the project. Students strongly agreed that the project encouraged them to think about the impact of engineering solutions in a global, economic, environmental, and societal context (4.45/5, Table 1) and found the project interesting (4.29/5) and helpful in learning (4.25/5).

Reported via end of the semester course evaluations, 62% of the class indicated that the project greatly increased their knowledge of a specific course topic and 58% listed the project as a course activity that increased their interest in engineering. A majority of students agreed that having the project evaluated by practicing engineers increased their confidence in mastering the relevant course material (see item 9 in Table 1).

The questionnaire also included three open ended questions. The first question asked students what aspects of the project they found engaging (see Appendix II, question 1). Most students found the background research into current energy production in the target countries engaging and also enjoyed learning about possible sources of energy in the three target countries. Some students also felt that learning about green energy and its importance was engaging. Most students were engaged by aspects of designing an energy system including drawing schematics and going through all the different steps involved in creating electricity from thermodynamic cycle. Specifically, some students found performing cycle efficiency and production calculations engaging. Learning about different countries and different kinds of thermodynamic power cycles was often listed as engaging. For example, one student explained that they found engaging "*learning new facts about a country that I knew nothing about and the multiple ideas that were considered during the project*." Working in a group and interacting with other members of the group was also mentioned as engaging. One student explained that they found engaging, "*working on a real-life problem and the idea of designing something that could have real-life impacts; it made me excited about engineering*."

Aspects of the project that students found challenging (see Appendix II, question 12) included: choosing which energy sources were most suitable for the country they had chosen, justifying their choice of energy system, and performing energy production calculations. Working as a member of a team was also often listed as a challenge. Most of the students in this study were sophomores (N = 88) and this was their first experience working on a project as a member of a team. Student listed the following challenges that their teams encountered: "*Getting the group to work together; Scheduling group meetings; Trying to come up with one answer that everyone will agree on. Inputting everyone's opinion into one project.*"

When asked what they learned from the project (see Appendix II, question 14), the following themes emerged from students' responses. Supporting quotes are provided.

1. <u>Students learned how abstract concepts can be applied in a real-world context</u> (Course objectives 1, 2, 3, and 4 and ABET criterion 3c)

   "[I learned] more about thermal power plants in general."

   "[I] also learn how to apply the concepts we learned in this class."

   "[I learned] how the concepts can be applied to everyday life."

“[I learned] how a geothermal power plant works (building wells, power lines, “flash” chambers, etc.).”

“[I learned] a lot about cycles and energy.”

”I also learn why and how quality was so important. It was impossible to do the calculations without this understanding.”

“[I learned] how thermo can actually be applied to real-world scenarios.”

“[I learned] about the pros and cons of various types of power plants and how they operate.”

“I developed a more thorough understanding of the Brayton and Rankine cycles.”

“[I learned] a lot about Jamaica’s existing power supply as well as the functioning part of a combustion power plant.”

“[I learned] about the Rankine cycle and how it is involved in a nuclear plant.”

“Taking what you taught us in class and putting it in a real-life scenario.”

“I learned a lot about the Rankine cycle how supercritical steam generators work to produce power. How to calculate required power output and efficiency in the overall system.”

“[I learned] about the different types of nuclear reactors and how they work.”

“[I learned] the operation concepts of a nuclear plant and how the electricity generated is distributed to consumers.”

2. Students learned about the global, economic, and social impacts of engineering solutions (Course objective 5 and ABET criteria 3c and 3h)

“[I learned] How much engineering is needed for everything from social to economics.”

“[I learned] a lot about green energy and what people need to do more to change our energy usage.”

“[I learned] the importance of energy systems and their role in our modern society.”

“Engineering solutions can have a significant impact on countries around the world – especially the lesser countries with limited resources.”

“[I learned] how to use existing resources of a country and combine with thermodynamics concepts in order to create efficient ways of improving a country.”

"[I learned] how the implication of a thermal system can impact thousands of people's everyday life."

"[I learned] how to better access risks/rewards with an enterprise such as this."

"[I learned] more about the impact I will have in the future making me want to be my absolute best."

"The world is in great need of sustainable energy sources. What we currently use is effective but it is not realistic and the entire population of this planet needs to reevaluate their energy usage and production."

3. Students learned how to work as a member of a group (ABET criterion 3g)

"[I learned] what it takes to a group to cooperate successfully."

"[I learned] how to be a more productive team member."

"[I learned] that assigning tasks early on in group work will save you from last minute frustrations."

4. Students learned about a developing country (ABET criterion 3g)

"[I have learned] that Namibia is not only a very beautiful place to live but also very expensive."

"[I learned] many things about Rwanda and other geographical qualities."

"[I learned] about a new country that I never would have studied without this project."

Conclusions

When practicing within the profession, engineering students will be dealing with ill-structured and complex problems that need more than technical solutions alone. It becomes equally important for engineers to be technically skilled but also fully able to identify non-technical aspects of problems, to communicate professionally these solutions, to be socially responsible, and globally collaborative. To simulate real-life scenarios to integrate the aspects of the engineering practice into engineering education is challenging and requires unconventional pedagogical engagements in courses that are steeped in pedagogical traditions. While unconventional, and perhaps uncomfortable for some instructors, these approaches offer novel ways to engage students and guide them in making connections between real-life activities and the somewhat limited domain of their experience, thereby activating deeply influential and retained understanding.

Experiential learning has the educational potential, particularly through a project-based approach to enable engineering students earlier in the curriculum to sustain and learn general skills and to promote non-technical yet vitally important competencies. This study supports the idea that a project situated in a real-world context helps students to achieve the course and ABET outcomes that often receive little attention or are addressed in a cursory fashion. Providing these situated learning opportunities also benefit students in ways that may not be obviously considered. First, socio-economic challenges that students bring with them to a classroom can limit their exposure to both global and industrial contexts that are rich with subject matter content. Working on a project situated in a global/industrial setting provides a virtual opportunity. Second, having the opportunity for engineering professionals to share feedback with students, aids in both, correcting students' misconceptions of their technical development, while at the same time bolstering their confidence in facing challenging problems to solve. Finally, exposure to the "real-world" learning environments affords community building between students, faculty and industrial professionals. In the course project elaborated upon here, an unexpected but serendipitous outcomes emerged. A student from the top performing group was offered a summer internship from the power company they had visited, based solely on the company's exposure to the student work product, attitude, passion, and communication performance. This same student shared his thoughts regarding the course:

"*... not until we started talking about the open and closed systems, the different laws and rankine cycle did I realize just how fascinating it [thermodynamics] was. Touring the power plant and seeing what engineers duties are made me realize that out of all the different directions I could go as a mechanical engineer, the production of electricity caught my attention the most".*

A carefully scripted project such as the one described in this study provides students an opportunity to integrate technical learning with the development of professional skills and to learn about the broader impact of engineering solutions in a global context. Our discussion underlines the importance of applying a problem-oriented rather than a subject-oriented approach in order to create a balance between problem existence and original problem solving. We conclude that to educate the engineers of 2020 who are able to handle ill-structured and complex problems, their education must allow for alignment with, and be fully relevant to current engineering practice in an integrative way.

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Appendix I

Dimension/ Weight	Points			Score
	2	**1**	**0**	
Organization (sections, order) 10 %	All sections are present and in correct order. Sections include: Abstract, Background, Technical Details.	A section is missing or sections are not in correct order.	Sections are missing or are not clearly marked.	
Formatting (fonts, header, footer, cover page, margins, spacing) 10 %	Header, footer, and cover page are present and contain required info. Fonts are acceptable.	One of these required items is missing, fonts are not acceptable, and/or info in these sections is not correct.	No header, footer, and/or cover page.	
Figures, tables, and equations 10 %	Figures and tables contain clear captions, are centered and of equal size and proportions, have appropriate margins, and do not contain excess border lines. Equations are centered and are numbered.	Figures and tables do not contain compete information. Formatting could be improved. Equations are incorrect.	No figures, tables, or equations.	
Graphics (photos, figures, diagrams) 10 %	Graphics/photos are cropped correctly, the subjects are clear and they support the content in the report.	Photos, figures, and/or diagrams are present, but of poor quality and do not support the report.	No photos, figures, or diagrams.	
Mechanics (spelling, grammar, punctuation) 10 %	No spelling or grammar errors.	Two or three spelling or grammar errors.	Too many errors to count!	

Dimension/ Weight	**Points**			**Score**
	2	**1**	**0**	
Citations 10 %	All claims are supported by citations. Citations are correctly formatted.	Citations are not correctly formatted and some may be missing.	No citations.	
Calculations 10 %	All calculations are correct.	Small errors in calculations.	Calculations are absent or totally incorrect.	
Abstract 10 %	The problem is clearly presented. Solution is presented along with brief justification. One succinct paragraph.	The problem is obscure. The solution is missing adequate justification. The abstract is too long or two short.	The abstract is opaque and fails to encapsulate the entire proposal.	
Background section 10 %	Clearly explained are: the need for additional electrical power generation capacity, the resources that are available for meeting those needs, and the economic situation.	Background information is missing or poorly explained and supported.	No background section.	
Proposed system 10 %	Clearly explained are the technology you are proposing and justification for your choice. All of the items requested in the project write-up are included.	Some of the required items of the proposal are missing.	The proposed system is not adequately explained.	
Total 100%				

Appendix II

Your Name: ____

Project I

1. What aspects of the project were engaging?

2. What aspects of the project were challenging?

3. Before starting the project, I knew little to nothing about the country for which my group developed a thermal system.

1	2	3	4	5
Strongly disagree				**Strongly agree**

4. After the project, I feel more confident in my ability to design a thermal system to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.

1	2	3	4	5
Strongly disagree				**Strongly agree**

5. The project encouraged me to think about the impact of engineering solutions in a global, economic, environmental, and societal context.

1	2	3	4	5
Strongly disagree				**Strongly agree**

6. After the project, I have a better understanding of professional and ethical responsibility.

1	2	3	4	5
Strongly disagree				**Strongly agree**

7. Working in a group increased my ability to communicate effectively.

1	2	3	4	5
Strongly disagree				**Strongly agree**

8. After the project, I feel more confident in my ability to apply course concepts to aspects of my everyday life.

1	2	3	4	5
Strongly disagree				**Strongly agree**

9. Having the project *evaluated* by practicing engineers on the appropriateness of the thermal system we chose will increase my confidence in mastering relevant course material.

1	2	3	4	5
Strongly disagree				**Strongly agree**

10. The project was interesting.

1	2	3	4	5
Strongly disagree				**Strongly agree**

11. The project was difficult.

1	2	3	4	5
Strongly disagree				**Strongly agree**

12. I found the project enjoyable.

1	2	3	4	5
Strongly disagree				**Strongly agree**

13. The project helped me learn

1	2	3	4	5
Strongly disagree				**Strongly agree**

14. What did you learn from the project?