Project Based Learning and Authenticity: An Instructor's View

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Abstract - **It has long been recognized that learning is at its best in a student-driven, project based, environment where real-world problems are presented in their naturally incomplete and messy nature. Students then need to wrestle their way to understanding, under the facilitation of an experienced and knowledgeable instructor who provides guidance at milestones along the journey. This philosophy has been refined over the years in both K-12 and postsecondary education, and it is being adopted in engineering education as Project Based Learning (PBL).**

Critical to the process of PBL is that the project provides an opportunity for authentic student inquiry while working with an authentic experience. The creation, and assessment, of an authentic project is a challenge in the implementation of PBL for first-year engineering students at a large university because of the need for low student to instructor ratios and laboratory space. This paper presents the experience of one instructor as Virginia Tech transitions their first-year engineering classes to a project based learning environment.

This work first details the administrative and pedagogical structure of the PBL instruction at Virginia Tech. Courses. Their objectives are detailed, as is the administrative framework under which the courses are taught. Both project content and implementation are summarized and discussed. Additionally, both quantitative and qualitative data from a smaller number of students is discussed.

Index Terms – Project Based Learning (PBL), Authenticity, Outcomes, Fundamentals.

FIRST-YEAR ENGINEERING AT VIRGINIA TECH

All engineering students at Virginia Tech are required to take two introduction to engineering courses: EngE 1215 and EngE 1216, Foundations of Engineering. Both classes are two credit hours and are taken sequentially, typically in the fall and spring semesters. In the fall of 2014 there were 48 sections of 30 students each, taught by eight faculty and fifteen graduate teaching assistants. In the spring of 2015 there were 45 sections of 30 students each taught by nine faculty and eleven graduate teaching assistants. Each section meets twice a week for 75 minutes each meeting. These courses represent a major redesign of the first-year engineering courses and instructors were requested to adhere closely to common content and testing.

The course goals established for 1215 are:

- Compare and contrast the contributions of different types of engineers in the development of a product, process, or system
- Develop a plan of study for your undergraduate career
- Articulate holistic issues that impact engineering solutions
- Solve problems using systematic engineering approaches and tools
- Model an engineering system
- Synthesize information from several sources
- Communicate information effectively
- Contribute effectively to an engineering team

The course goals for 1216 are:

- Demonstrate the ability to use various engineering skills and tools in solving design problems
- Demonstrate proficiency with implementing an engineering design process
- Collect, analyze, represent, and interpret data
- Use systematic methods to develop solutions for problems
- Identify all relevant stakeholders, constraints, and needs
- Communicate engineering decisions to technical managers
- Contribute effectively to an engineering team
- Evaluate ethical implications of engineering solutions

As is evident from the two sets of course objectives, the first semester objectives are much broader than those of the second semester course.

In the fall 2014 semester, there was a single project team project for EngE 1215 that focused on analyzing the feasibility of two sources of renewable energy. The majority of the student groups would select photovoltaics, geothermal, human power, or hydropower for their renewable energy sources.

In the second semester there were two projects. The purpose of the first was to create a prototype prosthetic hand or arm. Most students took advantage of the department's Ware Lab and its 3-D printers to create a prototype prosthetic initial created in Inventor CAD software. The second project was to create a computer decision support system to analyze water quality and quantity from Virginia Tech's on-campus stream gauging site, the LEWAS Lab. The core of this project was the creation of a series of MATLAB programs that would input and analyze data from the LEWAS Lab.

ENGE 1215 OVERVIEW

The assignment statement for the project was:

Your assignment is to select an application for sustainable energy and evaluate the use of two forms of sustainable energy for this application. You will make a recommendation for the sustainable energy form most suitable for the application, justifying your recommendation with engineering analysis [emphasis in the original] of economic, energy, environmental, and social/ global impacts.

The goal of the project was to facilitate student learning in a project based learning (PBL) environment.

The class met for fifteen week with two 75 minutes meetings per week. The project was divided into three parts, with the first few weeks focused on engineering careers, library resources, and product archeology. Product archaeology was selected by the course coordinators as a framework for the engineering method. The middle six weeks were largely dedicated to supporting the renewable energy project. During these weeks, group homework assignments were related to the project: the creation of a bibliography; the creation of a team charter; four concept maps; three memos; and one presentation. Little time was available for the development of problem solving, either individually or as a group.

The remaining weeks were largely related to an introduction to programming in MATLAB.

PROJECT BASED LEARNING AND FOUNDATIONAL KNOWLEDGE

As noted in the project statement, and in agreement with the concept of creating a meaningful product, analysis was identified as a critical goal. Using Bloom's taxonomy as a framework, analysis requires pre-requisite knowledge in the lower cognitive domains of Remembering, Understanding, and Applying. Required knowledge for the lower domains include facts, terms, and basic concepts [1]. In engineering these fundamental facts, terms, and basic concepts include units, precision, and accuracy.

As defined by Thomas [2], PBL is based around a project that requires complex tasks to answer challenging questions. The intent is for student groups to work autonomously to create a realistic and meaningful answer or solution to the complex and difficult question. The role of the instructor is to act as a resource guiding, but not directing, students to their final product. Integral to the concept of a PBL learning environment is that the problem, solution, and assessment be authentic.

Using PBL in the engineering classroom is compelling in light of widely held definitions of the characteristics of good engineering education. For instance, in *The Engineer of 2020* [3], states:

We aspire to engineers in 2020 who will remain well grounded in the basics of mathematics and science, and who will expand their vision of design through a solid grounding in the humanities, social sciences, and economics. Emphasis on the creative process will allow more effective leadership in the development and application of next-generation technologies to problems of the future.

In order to achieve these aspirations the Olin College of Engineering sees four characteristics that they seek to instill in their students [4].

- a superb command of engineering fundamentals
- a broad perspective on the role of engineering in society
- the creativity to envision new solutions to problems
- the entrepreneurial skills to bring these visions to reality

Authenticity requires that the instructor be knowledgeable and experienced enough to provide meaningful guidance, and that the student be both motivated to engage in autonomy, and possesses sufficient knowledge, background, and experience in order to work towards a meaningful solution [5]. A meaningful engineering solution and a command of engineering fundamentals requires that the technical analysis of a project be firmly based scientific theory and engineering analysis.

ENGE 1216 SURVEY RESULTS

In May 2015, at the end of the spring semester, a survey was completed by 75 students to assess their knowledge of facts and basic technical concepts required for a meaningful analysis of their energy projects, specifically the knowledge of units . These students completed the EngE 1215 (fall 2014) course and participated in the sustainable energy project. Students were advised that their answers to the survey would not be graded for correctness, only participation. There were also advised that the purpose of the survey was to assess their knowledge as a group and that no individual results would be examined. The questions were presented sequentially: a student could not view a later question before answering all prior questions. The following figures summarize the results.

Question as asked: “Using only the units of M (mass), L (length), and T (time). What are the units of Force? Please format your answer using this as an example: (T^2)/(L*M^3)”

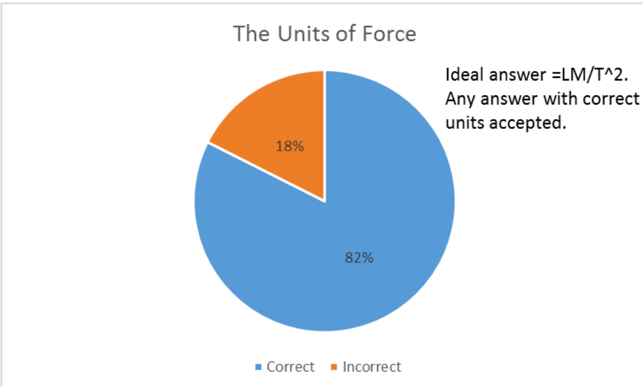

FIGURE 1
UNITS OF FORCE

Question as asked: “The numeric value of the acceleration due to gravity in the Imperial system =____ Please use 3 digits.

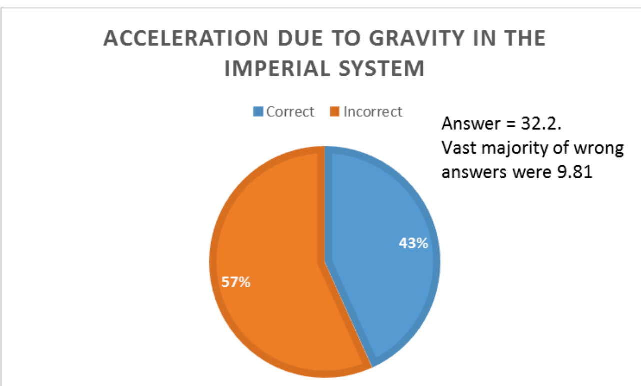

FIGURE 2
VALUE OF GRAVITY

Question as asked: “Weight = mass * acceleration due to gravity. 32.2 feet per second squared is the value of acceleration in the English system of units. To calculate weight, the units of mass would be ________”

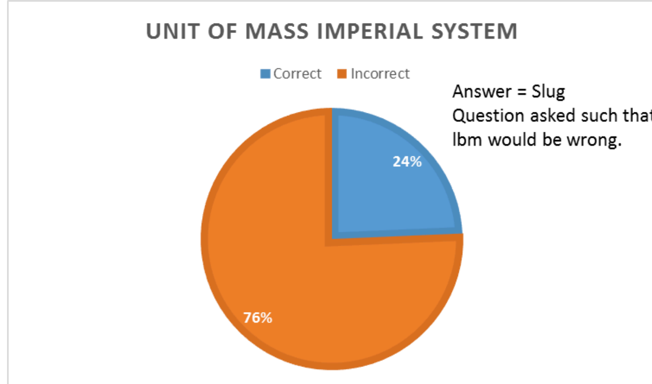

FIGURE 3
VALUE OF GRAVITY

Question as asked: “Using only the units of M (mass), L (length), and T (time). What are the units of power? Please format your answer using this as an example: (T^2/(L*M^3)”

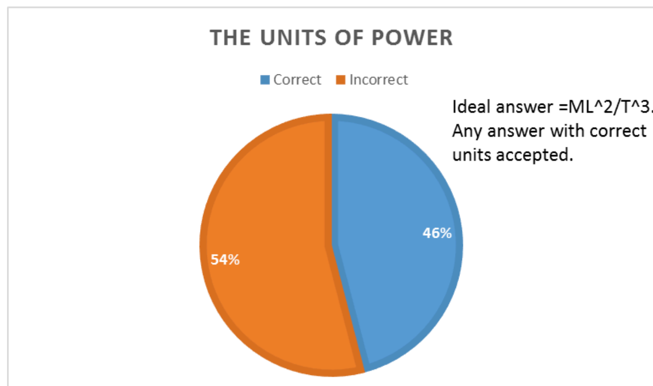

FIGURE 4
UNITS OF ENERGY

Question as asked: “Select the energy unit(s). Please do not guess.

A. Joule
B. Watt
C. Horsepower
D. BTU
E. Kilowatt-hour
F. None of the above

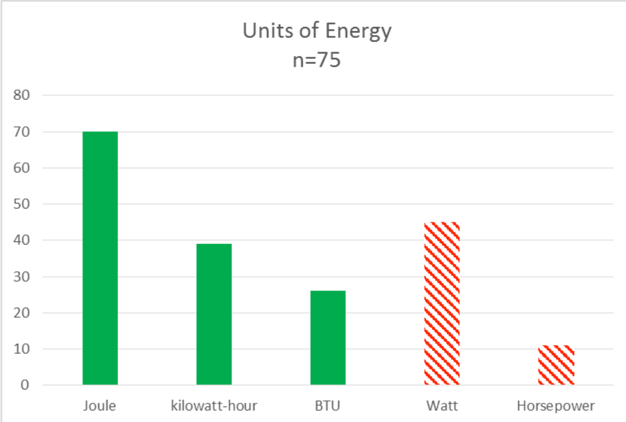

FIGURE 5
UNITS OF ENERGY
NOTE: A PERFECT RESULT WOULD HAVE ALL SOLID BARS EQUAL 75, AND ALL STRIPED BARS EQUAL 0.

DISCUSSION OF RESULTS

This results look only at the knowledge of students in a technical sense, other skills such as communications are not discussed. After examining the results and discussing the survey with a handful of students it is most probable that all of the students could recite the formula F=ma, but the 13 students who got it wrong appeared to not know the meaning of the formula. A typical incorrect answer was F=M/(L*T^2) where acceleration is placed in the denominator. Grading for this and the other questions was liberal. For example, an answer of (kg*m)/(s^2), for instance, was labelled correct despite not using the M, L, T format.

As evidenced by the $125 million Mars Orbiter disaster [6], there is a need for engineers to be conversant in, and comfortable working with, both Imperial and SI units. Figure 2 shows the results of a question that asked students to calculate force in Imperial units. Over half were incorrect, with their answers off by a factor of three. The large majority of incorrect responses answered with a value of 9.81 which is the value of acceleration in the SI.

Figure 3 shows the response to a knowledge question of the units used in calculating pounds-force. Unfortunately, while 56 of the responses should arguably have selected the provided "I do not know" option, only three students replied in this manner. Popular incorrect responses included pounds or pounds mass (17) and kg or g (12).

The question in Figure 4 was asked with the prior semester's project in mind, so as to assess the students' fundamental knowledge of power. Over half of the students responded incorrectly.

The results shown in Figure 5 are also related to the fall semester project. The large majority of teams should have discussed power and energy throughout their reports. While a large majority correctly identified a Joule as a unit of energy, only a third selected the BTU.

CONCLUSIONS

As noted, during the last academic year the Department of Engineering Education at Virginia Tech implemented a change of curriculum in its first-year engineering program. The goal of which is to provide its students with a firm foundation in the knowledge and skills required for the successful practice of engineering. These goals are both technical and non-technical. This course failed to meet the technical goal of providing a firm foundation of analytical skills.

Like any engineering design, this rethinking of the courses required a balance of competing objectives. One of those objectives could be defined as developing what are often seen as non-technical engineering topics such as teaming, communication, and stakeholder needs. On the other side of the balance would be technical, fundamental, engineering topics such as problem format, units, precision, and mathematical modeling. There is consensus in the engineering education community that both skill-sets are necessary for the education of engineer who will practice in a complex world. All of it is good stuff. But the question is not whether a topic is good. The more difficult and important question is what is *best* given the constraints of time and resources.

In the case of Virginia Tech's course redesign, the mark was missed. The weeks of class time and numerous homework dedicated to memos, presentations and teamwork left only a portion of one class in the first semester for units and precision. Unfortunately, the allocation of class and instructor time is a zero-sum game.

This is not a criticism of PBL; rather, it is a recognition that PBL is difficult to implement. The goals of PBL are the goals of the engineering education community. The question for a first year program in a large university is what goals we can accomplish without sacrificing essential, technical knowledge. Bloom is explicit that fundamental knowledge is essential to higher cognition. The Olin College of Engineering states that such knowledge is essential, with the first characteristic being "a superb command of engineering fundamentals". In his 1995 address to the National Academy of Engineering Past MIT president Charles Vest stated that rigor and the scientific basis that underlies engineering education and practice is a "sine qua non" (indispensable and essential ingredient) [7]. In its fall of 2014 introduction to engineering class, Virginia Tech failed to provide that indispensable and essential ingredient.

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