Integrating the Challenge Based Learning Approach in a Freshman Engineering Foundations Course: Teaching by Intern Engineering Doctoral Students Perspective

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1. Introduction

Accomplishment of future and current engineers depends on their ability to integrate innovation with their technical expertise. Engineers need to be adept at understanding and applying the fundamental principles of their field, and are also required to display ability to accommodate for future opportunities and innovations as the engineering world evolves. To give an insight into this essential caliber that engineers need to possess, the Department of Biomedical, Chemical and Environmental Engineering (**BCEE**) in the College of Engineering and Applied Science (**CEAS**) at the University of Cincinnati (**UC**) provided a unique and challenging engineering research and entrepreneurship experience as part of a required first-year Engineering Foundations (ENED1020) course in the 2014 Fall Semester at UC.

In order to broaden the impacts of this project beyond that of the participating students and faculty members, three doctoral students (referred here after as Fellows) from relevant engineering disciplines were recruited to participate as intern instructors, handling a majority of the course planning and in-class implementation related to the Grand Challenge Project (**GCP**), the specific segment of the ENED1020 course that was executed using Challenge-Based Learning (**CBL**) approach. The internship experience served as experiential training in preparation for the Fellows' future careers in teaching at the university level.

1.1 Engineering Foundations Course (ENED 1020)

This is a common course taken by all freshman engineering majors and its objective is to provide a generic overview of engineering. There were 22 sections with each section having an average of 50 to 60 students. The course involves lectures and recitation "labs" that provide hands-on experience to explore and conduct four required experimental laboratories. The four required recitation laboratories were: Electrical Circuits, Solar/Fuel-cells, Bridge Building and Thermodynamics. Teams consisting of 3 to 5 students were provided kits that contained the requisite laboratory equipment needed to perform these experiments. Lecture classes were used to instruct students on the concepts involved in these experiments and to guide student teams in their ability to work in groups towards completion of the experiments. Trained teaching assistants (TAs) were present during execution of these experiments to guide student teams. The last project (fifth) was designed as a student choice project, where students selected an experiment of their choice from a list and conducted an investigation on it. The student choice project was required to be different from the four required experiments provided as a part of the course. Students were allowed to use any of the four available kits for their choice project.

As part of this project, this fifth project was modified and conducted using a *Challenge Based Learning* project (**CBL**) for four of the targeted sections (amongst the total 22 sections for all CEAS freshman engineering students). This was called the *Grand Challenge Project* (**GCP**), and was required to address one of the fourteen National Academy of Engineering (**NAE**) Grand Challenges for Engineering[1]. These sections primarily included students from Biomedical, Environmental and Chemical engineering majors. The three doctoral fellows, chosen as a part of Cincinnati Engineering Enhanced Math and Science (**CEEMS**) program, were trained to conduct this last project in these four sections. The training that these fellows received as a part of the CEEMS program is outlined below and has been elaborated in detail in the companion paper "Integrating the Challenge Based Learning Approach in a Freshman Engineering Foundations Course: Project Team Perspective"[2].

1.2 Challenge-Based Learning Process (CBL)

CBL is an innovative pedagogical method that encourages active learning by students through a structured approach to solving real-world problems. Detailed information on CBL can be found in the companion paper "Integrating the Challenge Based Learning Approach in a Freshman Engineering Foundations Course: Project Team Perspective"[2].

1.3 Integrating the Engineering Research Process (ERP) and Entrepreneurship Process Model (EPM)

The **ERP** and **EPM** are two decision-making models that were used significantly during the GCP to guide the students and give them grounding in the systematic and multi-stage processes that are used when engineers and entrepreneurs jointly develop solutions. Detailed information on the ERP and EPM can be found in the companion paper "Integrating the Challenge Based Learning Approach in a Freshman Engineering Foundations Course: Project Team Perspective"[2].

Ongoing innovation is required to address current problems and to maintain global competitiveness. Engineering often forms the foundation for such innovations. To present these creations and designs, engineers are frequently needed to collaborate effectively in teams and exhibit leadership and awareness in moving ideas to market. Therefore, in addition to sound technical and analytical expertise developed through engineering education, engineers must also have the ability to recognize and plan for the process in which a technologically viable solution is positioned in the market for direct application to a real-world problem. In order to provide an introduction to this essential integration, the GCP was designed to feature two distinct models: ERP and EPM. The integration of the two models was executed beginning with activities planned specifically so that students develop an understanding of the two models and their importance to engineers and entrepreneurs. Once a basic familiarity had been established, both models were used in the GCP where the students developed their own solutions to problems and were required to describe and document their integration of the ERP and EPM.

1.4 Role of the Fellows

Research universities are the primary sources for granting doctoral degrees, with 55% of doctoral degrees being earned in these institutions and more than 60% of faculty and professional staff being employed in STEM fields[3]. The faculty members in these institutes teach engineering to undergraduate and graduate students and conduct research with them. Studies have observed that doctoral students are seldom trained for faculty responsibilities and expectations[4-7]. As these untrained doctoral students embark on their academic career, they struggle to provide a good learning experience for their students. To help address this specific issue of training doctoral students to prepare them as future university faculty members, three engineering doctoral fellows, belonging to three different engineering backgrounds (Mechanical, Environmental and Materials Engineering) were chosen as a part of Cincinnati Engineering Enhanced Math and Science (CEEMS) program. These fellows were required to conduct the GCP for the chosen four sections of the ENED 1020 course. To help and prepare the fellows in conducting the GCP, the following training was provided.

- Seminar on Implementation of the Engineering Research Process (ERP)
- Seminar on Implementation of the Entrepreneurship Process Model (EPM)
- Seminar on Evaluation Instruments
- Additional Training as Provided in Connection with the CEEMS Program.

Detailed information on the training of the fellows can be found in the companion paper "Integrating the Challenge Based Learning Approach in a Freshman Engineering Foundations Course: Project Team Perspective"[2].

1.5 The Grand Challenge Project (GCP)

The four targeted ENED 1020 sections (designated here after as Sections A, B, C and D) involved one biomedical, one environmental and two chemical engineering sections. Though each section involved primarily students from that disciple, each section also included students from other majors as well. One engineering doctoral fellow was assigned to each section, with one fellow responsible for two sections.

The GCP was executed as the last project of the ENED 1020 course, replacing the final project in the other sections. It aimed at providing students a perspective on real world problem solving. The five student learning objectives (SLOs) outlined for this unit were:

SLO1 Demonstrating the ability to design and conduct experiments, as well as to analyzing and interpreting data.
SLO2 Demonstrating the ability to identify, formulate and solve engineering problems.
SLO3 Demonstrating the ability to communicate effectively and work in teams.
SLO4 Exploring, analyzing and discussing concepts of "engineering research process."
SLO5 Exploring, analyzing and discussing concepts of entrepreneurship.

2. Methodology for Implementation of GCP

The GCP was a new concept introduced into the *Engineering Foundations* class – a basic course conducted for freshmen engineering students from a variety of engineering disciplines. CBL was the primary pedagogy used for introducing the project to the students. A general overview of the project structure and the implementation timeline is described below. Additionally, a visual representation of the timeline is presented in **Table 1**.

Table 1: ENED 1020 Classroom Activity and Assessment Timeline

Week #	Classroom Activity		Assessments	
1	Introduction to GCP	Distribution of S-STEM Information to Select Sections	Pre-Test	
2	Flipped Classroom	Launching the GCP with CBL	Flipped Class Quiz	Post -CBL Student Survey
3	Non-GCP Experiment 1			
4			Student Tracking Survey 1	
5	Non-GCP Experiment 2	Feedback to Student Groups if Needed		
6			Student Tracking Survey 2	
7	Non-GCP Experiment 3	Feedback to Student Groups if Needed		
8			Student Tracking Survey 3	
9	Non-GCP Experiment 4	Feedback to Student Groups if Needed		
10			Student Tracking Survey 4	
11	Work on GCP Solution	Feedback to Student Groups if Needed	Presentation and Report Rubrics Distributed to Students	
12	Complete work on GCP Solution	Section-Specific Activities	Section-Specific Activity Assessments	
13	Present GCP Results as Final Presentation and Report		Presentation and Report Evaluation	Student Presentation Peer Evaluation
			Post-GCP Student Survey	Post-Test

2.1 Introduction: Week 1 – 30 Minutes

During the first week of the *Engineering Foundations* course, the fellows introduced themselves and the concepts that were integrated into the GCP. Following this, a short *pre-test* was completed by the students. The purpose of the pre-test was to gauge students' understanding of the chosen big idea for the GCP and to estimate their familiarity with the chosen pedagogy. Notification and materials for the forthcoming *flipped* classroom were provided. Flyers describing the details of the NSF's Scholarships in Science, Technology, Engineering, and Mathematics (**S-STEM**) Program Opportunities to be available in the Department of BCEE starting from the 2015-2016 academic year were also distributed to the students in the four targeted sections of the course.

2.2 Launching the GCP: Week 2 – 120 Minutes

Students were provided a week to work on the *flipped class notes* packet that provided information on the pedagogy used and terms involved in the process. An introduction to the big idea along with related current world scenario was also included in the packet supplied. A week after the packet was provided, student understanding was tested by a quiz. Prior to engaging students in discussions to launch the GCP, a *hook* was used to intrigue student interest in the chosen big idea.

To introduce and develop the GCP, the class was broken down into two main segments. The first segment consisted of utilizing the components of CBL to help student teams develop their challenge. Student teams discussed *essential questions* that they derived from their understanding of the big idea. The fellows then led the discussion to get all teams in the class to analyze their common ideas and narrow down to one essential question. A similar process was used to formulate the *grand challenge* for each section. In order to keep with the CBL process, the fellows ensured that the challenge statement or the essence of it was not disclosed during its development.

The second segment of the class involved each team going from the broad student-selected challenge to two specific activities: one utilizing the *Engineering Research Process* (ERP) and another utilizing the *Entrepreneurship Process Model* (EPM), which upon completion would lead to a comprehensive solution to the challenge. In addition, a post-CBL survey was given by the S-STEM evaluation team on the efficacy of the CBL teaching model at the end of this class period.

2.3 Student Tracking Surveys: Weeks 3 to 10 – 40 minutes

The *Engineering Foundations* course consisted of four well-defined pre-determined experiments that student groups performed through the semester. As mentioned earlier, these were: Basic Electricity, Bridge Building, Thermodynamics and Solar/Fuel Cells. The culmination of the course was designed to be the GCP, as it required students to use basic skills and knowledge that they learned through these four preliminary experiments. Four tracking surveys were designed to assess their level of preparation for the GCP. They included 3 to 4 simple questions that act as guidance to help prepare teams towards planning for the GCP and to allow the fellows to track individual team's progress towards planning for the GCP. The fellows reviewed these individual survey responses and identified students that needed some additional guidance. Recitation labs were used to provide this feedback and to meet and guide some specific student teams that were found to be lagging behind.

2.4 Executing the GCP: Weeks 11 and 12 – 360 Minutes

Student teams were provided time and material to work together to create a viable solution to the GCP that they had chosen. Since the challenge was sectioned into the engineering (ERP) and the entrepreneurial (EPM) components, teams had to work on integrating the two sub-sections into their final solution. Two laboratory classes (120 minutes each), were utilized by the student teams to hypothesize, experiment and test, revise and document their solutions. Two lecture classes (60 minutes each), were used to provide instruction and guidance on areas that required specific attention. One of the two lectures was dedicated to providing directions on how to integrate EPM into their solutions. During this time, some activities and assignments were designed to guide the student teams through the process, since EPM was completely new for the students.

2.5 Final Presentation and Report: Week 13 -120 Minutes

Each team was required to present a PowerPoint Presentation and submit a typed project report. The required report and presentation rubrics and a format template for organizing each as a guide were provided to students in advance. Reports were graded by the TAs according to the previously developed rubric. One recitation class (laboratory time) was dedicated to the team presentations. Each team had 10 minutes to present their findings to their peers and 2 minutes was allotted for any audience questions. Peers were then required to complete a peer evaluation form (rubric) for each presentation. TAs and the fellows also filled out an evaluation rubric for each presenting team. After completion of all the presentations, students completed a post-GCP survey provided by the S-STEM evaluation team. Following this, a post-test (similar to the pre-test completed during Introduction Week) was also completed by the students.

2.6 Project Evaluation

Pre- and Post-Test: These were used to evaluate growth in student understanding and knowledge. The pre-test was given on the introduction day and the post-test was given after completion of the GCP presentations. Both tests included the processes of CBL, ERP and EPM and some generic information on the big idea. There were 6 questions in total and were either multiple choice or fill-in-the-blank type questions. Students were given class credit for completing the pre-post tests and the tests were graded for correctness to measure student growth in content knowledge related to the GCP.

Tracking Surveys: The primary objective of these surveys was to understand the level of preparation of the students of their GCP and to track the progress made by the student teams in planning their GCP solution as they completed each required lab experiment. Based on the input from the students, feedback was provided to help students stay on track and help them prepare better for the GCP. This input from students and the analysis by the fellow were discussed with the S-STEM project team.

Quiz Pertaining to the Flipped Class Notes: The main purpose of this quiz was to test the effectiveness of the flipped class notes in providing the content knowledge to the students prior to coming to the class, and the secondary purpose was to understand if using the flipped lesson format enabled the execution of the CBL process in one two-hour lab session possible. This session started with the introduction of the big idea. Then, student teams were guided to: define the essential questions that clarify the big idea; choose one and define the grand challenge for it; and outline guiding questions what the students think they need to know to formulate a viable solution to the grand challenge. The quiz was evaluated by the fellow who used a predetermined rubric.

Final Report and Presentation: The final report and presentation were the two significant final deliverables produced by each student team. These were evaluated as part of the execution of the GCP and included as part of the students' grade for the GCP. The report and presentation represented the cumulative effort that each team put from the beginning of the GCP to its end. Both were used to evaluate attainment of the five unit learning objectives outlined for the GCP. Grading was done by two separate rubrics developed for the report and the presentation that assessed communication ability, defense of the solution selected for the GCP, and demonstration of the understanding of the use of the elements of ERP and EPM in the solution process.

2.7 Implementation of the Flipped Class and Introduction of GCP

How Did It Help: The process of introducing the GCP required students to have some basic knowledge of the big idea and some familiarity with key terms used in the CBL approach that was followed in the class. Additionally, ERP and EPM were two concepts that required some prior understanding to plan the solution of the challenge. Students were presented with a conceptual flow chart for ERP and EPM that explain the basic elements (or steps) involved along with some examples that illustrate the execution of each element (or step). This helped students understand how to integrate the ERP and EPM into the *Grand Challenge* they chose.

Variations Used During Teaching: There were primarily three variations in the teaching methods used during the introduction of the GCP by the three fellows.

- While revisiting the ERP and the EPM processes after the students had read the flipped lesson for it, a quick review was made for Section B students by introducing the term *flow chart* and explaining how the two processes involve the execution of the model elements (or steps) in a prescribed sequence, which also included repeating some steps to revise and improve the solution along the way. The whole process is pictorially represented in a flow chart with arrows showing the sequencing of the elements (or steps) of the process, which was new for most students. For the other three sections (A, C and D), the flipped class notes were revised to explain in more detail the ERP and EPM flow charts, with examples, as was done in Section B and the students were informed to review the flipped class notes again. It was noticed that elaborating the term *flow chart* helped students understand the processes better, and in the following week, this explanation was revised for Sections A, C and D.
- The *flipped class quiz* was to be completed after students went over their *flipped class notes*. There was some variation in the way the quiz was conducted, as explained below:
  - Section A did a timed quiz before commencement of the class.
  - Section B and C did a timed quiz during the first 15 minutes of the class.
  - Section D was given a paper quiz to do before the start of the class.
- The other major variation was in the way the *hook* was provided to the students when introducing the big idea either as part of the flipped notes or at the beginning of the lab session during which the GCP was started. This included:
  - Section A had two senior students talk about their internship experience in a company that worked in the area of Atrial Fibrillation.
  - Section B had a video and a webpage that was presented to the students in the flipped class notes.

- Section C and D had a video that was presented to the students in the flipped class notes.

How Students Received It: As a result of the flipped class notes, students were able to comprehend technical terms that were used in the class when introducing CBL, ERP and EPM. They, however, felt that too many concepts were introduced in the two-hour time period during the launching of the GCP. Also, many students failed to see the immediate connection between the *Introduction to GCP* class and *Execution of the GCP.*

2.8 The Three GCP Units

Three separate GCP units were conducted by the three fellows. These three units were tailored based on the disciplinary demographics (biomedical, chemical and environmental) of the students enrolled in the targeted class sections. The three units are described briefly in this section.

2.8.1 GCP Conducted in Section A

The class consisted primarily of freshmen studying biomedical engineering and a mix of chemical and environmental engineering students and few other freshmen studying other engineering majors.

Big Idea: Atrial Fibrillation, a potentially life threatening condition of the heart that affects more than 2.5 million adults in the United States alone.[8]

Essential Question: How does AFib manifest itself in the heart and how can treatments be made more effective?

Grand Challenge: Effective modeling of treatment methods and development of documentation template for the process. Student groups wanted to model the working of both surgical methods and medications. Therefore, they had one lab that required them to utilize their basic electrical circuits knowledge to model possible surgical treatments, and another that required them to use their basic MATLAB skills to test a drug implementation on an affected heart. Students then developed a means to document and market their idea.

Guiding Questions for ERP:

- Can the heart be modeled by an electrical circuit?
- How does AFib alter the electrical pathway?
- How do drugs help control a heart that is affected by AFib?

Guiding Questions for EPM:

- Why do entrepreneurs protect their ideas?
- How can 'stolen' ideas benefit other competitors specifically in the area considered?
- What are some key components in the documentation that you need to look out for?

2.8.2 GCP Conducted in Section B

The class consisted of primarily of freshmen studying chemical and environmental engineering and a mix of students studying biomedical engineering and other engineering disciplines.

Big idea: Providing access to clean water, a worldwide crisis that affects 750 million people, or approximately 1 in 9 people worldwide.[9]

Essential Question: How do social and geographic issues impact access to clean drinking water?

Grand Challenge: Develop a technology or process that can sustainably produce clean drinking water. The students were free to pursue any type of water treatment method to treat water contaminated with either clay (particulate contamination) or a food coloring dye (organic contamination). Students were permitted to use materials from the preceding non-GCP experiments, and were also allowed to bring simple materials from home. Development of a test method for determining the degree of treatment efficiency was also required.

Guiding Questions for ERP:

- What contaminants are found in water?
- How clean must the water be and how can that be tested?
- What is the simplest design that can be used to produce clean water?

Guiding Questions for EPM:

- Who are the potential customers?
- How can we maintain a competitive edge?
- How will the water treatment device be maintained?
- How can we work directly with the local population to implement a solution?

2.8.3 GCP Conducted in Sections C and D

The class consisted primarily of students studying in chemical engineering.

Big Idea: The United States alone consumes 20%-30% of the world's energy. Also, because of increased consumption of crude oil, its oil reserves are vanishing at rate of 4 Billion tons per year[10]. The big idea was to look at viable clean energy technologies.

Essential Question: What options are there for storage and converting of energy?

Grand Challenge: Design, test and refine a method/model that can increase the efficiency of a fuel cell. Students wanted to increase the efficiency of a hydrogen fuel cell, first by developing an understanding of how a fuel cell operates, and, second developing a method or building a setup that improves the output power.

Guiding Questions for ERP:

- What are ways to get the solar cell to store more energy in less time?
- What factors affect the energy input of our fuel cell?
  - How can we improve the speed at which water can be converted to hydrogen gas?

Guiding Questions for EPM:

- What are the technologies used for generating energy in urban areas?
- What are the benefits and significance of your design relating to market?
  - How do entrepreneurs make plans to reduce risk

3. Results and Discussion

3.1 Closed-Ended Student Feedback Results

A number of surveys were provided to the students throughout the course of the GCP, as described previously and listed in **Table 1**, with the Post-GCP Student Survey serving the main purpose of quantifying the students' reactions to and opinions of the new concepts and pedagogies they were being exposed to. This survey consisted of both closed-ended and open-ended questions. A factor analysis was used to identify seven constructs to evaluate the results of the closed-ended questions of the Post-GCP Student Survey, which included the following: "CBL," "EPM," and "ERP" constructs that assessed the students' understanding of the important concepts that were introduced to the students in the GCP; the "Project Comparison" construct which assessed the students' opinions on the GCP as compared to the four non-GCP experiments; the "Guidance from Faculty" and "Guidance from Fellows" constructs which assessed how satisfied the students were with the support they received throughout the course; and the "Learning" constructs which assessed the students' perceived importance of what they were learning in from the GCP. The specific Post-GCP Student Survey questions considered for each construct are presented in **Table 2**. The scale used for each survey question is: 4=strongly agree, 3=agree, 2=disagree, and 1=strongly disagree. Using this scale, the mean, standard deviation and Cronbach's Alpha coefficient value for the constructs obtained using the feedback received from the students for the closed-ended questions listed in **Table 2** are presented in **Table 3**.

When interpreting Cronbach's Alpha coefficient, the closer the coefficient is to 1.0, the greater the internal consistency of the survey questions used for the construct. In other words, a question is more likely to be measuring one construct, which is dependent on one or more factors (questions) but they are internally consistent[11]. George and Mallory[12] provide the following rules of thumb: "$\alpha > 0.9$ – Excellent, $\alpha > 0.8$ – Good, $\alpha > 0.7$ – Acceptable, $\alpha > 0.6$ – Questionable, $\alpha > 0.5$ – Poor, and $\alpha < 0.5$ – Unacceptable" (p.231). As can be seen from the results presented in **Table 3**, students' responses varied between Disagree and Agree for all constructs, with the highest results (closest to Agree) seen for the CBL, EPM, and ERP constructs (vary between 2.92/4.00 to 3.00/4.00). This likely indicates that the delivery of the primary content related to the GCP project to the students was most successful, but still receiving a mean rating about equal to Agree or 3.00/4.00. In addition, the lower ratings for the guidance from instructor and fellow constructs likely stem from lack of familiarity with the process and inadequate time during weeks 3-10 for the fellows to interact with and guide the students as they prepared for the GCP. This lack of continuous interaction of the fellows with the students as they worked on their GCP may have been perceived by the students as lower guidance for the GCP. It should be pointed out that the fellows were the primary instructors for the GCP, the faculty member's role was just to support the fellow. As far as the execution of the GCP is concerned, the student contact with the fellows occurred at discrete points: the first week when the CBL process was launched, after the 4 tracking surveys were completed to provide feedback, and during the last two weeks when the students worked on the GCP project during lab periods and presented their projects. Additional data that is presented in the following section along with the fellows' personal reflections support these results.

3.2 Open-Ended Student Feedback Results

While the results of the students' feedback to the close-ended questions show a neutral impact, the responses to the open-ended questions are interesting and very informative of the students' feelings about their participation in the GCP. Students were free to comment on various

Table 2: Detailed Description of the Post-GCP Student Survey Questions Included in Each of the Closed-Ended Survey Constructs

Construct Name	Questions Included in Construct
CBL	1. I felt fully prepared to identify the questions that guided the Grand Challenge Project at the beginning of September. 2. I felt fully prepared to start the Grand Challenge Project in November. 3. I understand the real-world relevance of the Grand Challenge Project. 4. Solving this challenge can help others, our community, and society. 5. I contributed to the development of the group's solution to the challenge. 6. There are many solutions to this challenge. 7. Listening to other student team member's ideas was an important part of the Grand Challenge Project. 8. After finishing work on this Student Choice Project, my team and I successfully presented and defended our solution to the class.
Project Comparison	1. I preferred completing the Grand Challenge Project compared to the Thermodynamics project. 2. I preferred completing the Grand Challenge Project compared to the Bridge Building project. 3. I preferred completing the Grand Challenge Project compared to the Fuel Cell project.
EPM	1. I understand how the Entrepreneurship Process Model (EPM) activity allowed us to use the guiding question(s) to solve the challenge. 2. After finishing work on this Student Choice Project, my team and I successfully presented and defended our solution to the class.
ERP	1. I like problems best when they really make me think. 2. We were able to test our initial solution. 3. After our initial test, we were able to think about changes to improve the solution to the challenge. 4. After our initial test, we were able to implement changes to improve the solution to the challenge. 5. After finishing work on this Student Choice Project, my team and I successfully presented and defended our solution to the class.
Guidance from Faculty	1. I received guidance from my faculty instructor when I asked for it.
Guidance from Fellows	1. I received feedback from the CEEMS Fellow after the FIRST Tracking Survey that helped me plan or refine the Grand Challenge Project. 2. I received feedback from the CEEMS Fellow after the SECOND Tracking Survey that helped me further plan or refine the Grand Challenge Project. 3. I received feedback from the CEEMS Fellow after the THIRD Tracking Survey that helped me further plan or refine the Grand Challenge Project.
Learning	1. I learned a lot while completing the Grand Challenge Project. 2. I better understand the Engineering principles as a result of completing the Grand Challenge Project. 3. This Grand Challenge Project made me feel more confident about math and/or science. 4. This Grand Challenge Project made me feel more confident about engineering. 5. Working on the Student Choice Project enhanced my oral and written communication skills.

Table 3: Composite Closed-Ended Student Feedback Results

Construct	n	All Sections Combined	
		Mean* (Std. Dev.)	Cronbach's Alpha
CBL	214	2.96 (0.550)	0.808 (Good)
Project Comparison	214	2.09 (0.792)	0.844 (Good)
EPM	214	2.92 (0.670)	N/A**
ERP	214	3.00 (0.605)	0.770 (Acceptable)
Guidance from Faculty	212	2.81 (0.846)	N/A**
Guidance from Fellows	214	2.30 (0.909)	0.960 (Excellent)
Learning	214	2.46 (0.766)	0.913 (Excellent)

* Scale: 4=Strongly Agree, 3=Agree, 2=Disagree, 1=Strongly Disagree
** Not enough survey questions in the construct to make a scale for Cronbach's Alpha

aspects of the implementation of the GCP. Supporting the previous claims that students' content knowledge was enhanced through the GCP, a common theme across sections was comments from students indicating a strong comprehension of the ERP and EPM models, including how they are interrelated when solving problem, as is evident from following student comments:

> *"The two processes support each other in real-world applications, because a product created as a solution for the ERP must be supported by the EPM in selling and supporting the project."* - Section A

> *"The models both were composed of multiple steps. The models required students to consider several different factors that come into play and affect the success of the solution"* - Section B

> *"They* [ERP/EPM] *work alongside one-another to create a realistic view of how to solve a problem in the real world"* - Section C

> *"You have to create a solution that is both viable for the company/consumers* [EPM] *as well as is a fix/need for the problem* [ERP]*"* - Section D

When solicited for responses on what worked well during the GCP, students praised the benefits of working in teams, as well as the depth and creative freedom associated with the GCP and reinforced through the inclusion of CBL. Some student comments indicating a positive learning experience from the GCP are as follows:

> *"Self-guided research, hands-on experimentation, conveying research to uninformed people"* - Section A

> *"Working as a team, seeing application to the real world, learned more about my major"* - Section A

> *"The idea of the challenge was fun and I liked that it had to do with real world problems, I enjoyed creating something and testing it, the EPM helped to create a business aspect and put out testing into the real world"* - Section B

Despite some students reporting significant benefits in terms of content knowledge and the benefits of the GCP structure, the implementation was not without its shortcomings, and a significant number of students articulated concerns with the pacing and organization of the course. Typical negative comments focus on confusion with the GCP and how it was integrated, and a dissatisfaction with the level of support provided by the instructors, fellows, and TAs. These problems, however, were anticipated and expected to a degree as many of the instructional methods and content (flipped classroom, CBL, ERP, EPM, and GCP) were never experienced by students in the past. Furthermore, the methods were new to the full instructional teams teaching each section. Selections of common negative responses from the students relating to the implementation of the GCP are presented below:

> *"I think something other than* [chosen big idea] *should be the next Grand Challenge, (2) Better explain concepts, (3) Make sure both* [fellow and instructor] *are on the same page"* - Section D
>
> *"Fewer surveys, less spread out, more focused in a smaller time, more emphasis on the research into the* [big idea]*"* - Section B
>
> *"I would make the goal of the challenge more clear from the start, establish a better line of communication between students and instructions, and set reasonable deadlines for assignments"* - Section C

To guide students in their planning for the GCP solution, students had to complete tracking surveys after each pre-determined experimental (non-GCP) lab was executed. Fellows reviewed each tracking survey and provided regular feedback to students. While some students felt that these surveys helped them in their progress towards determining a practical solution to their GCP, others felt it could have helped more if the process was more organized and more class time was allotted to the GCP. Additionally, as elaborated in the companion paper "Integrating the Challenge Based Learning Approach in a Freshman Engineering Foundations Course: Project Team Perspective"[2], the services of the TAs could not be availed in providing longitudinal mentoring support to the student teams for their GCP project during the semester. Some distinctive comments from students that found these surveys to provide good guidance are:

> *"*[Fellow] *helped us stay on track. Talking to* [fellow] *helped clear the mass amount of confusion"* -Section B
>
> *"Helped us with ideas, and how to implement them"* -Section D

During implementation of the GCP, the seeming lack of coordination between the course instructor and the fellow could have led to the decreased significance of the tracking surveys. If the instructor was supportive of the project during class planning and reiterated to the student teams the importance of completing these surveys for planning the GCP, the class on an average experienced better benefits from the tracking surveys. This was reflected in some comments from the students. Additionally, students felt that more time could have been dedicated to providing individual team feedbacks. Some reflective student comments are:

> *"Did not aid, allowed me to challenge my thoughts, though"* -Section A
>
> *"It helped but needs class time to back up general needs"*- Section C

3.3 Post-CBL Student Survey Results

Following the execution of the CBL process to develop the *Grand Challenge* with the students, as shown in the timeline in **Table 1**, a *post-CBL Survey* was provided to the students to assess the outcome of this implementation of CBL. The objective of this survey was to determine student understanding of the components of the CBL process, and their feelings about the upcoming GCP. As can be seen in **Table 4**, the results of this survey show high effectiveness of the implementation. It is clear from the results that students reported levels between "Agree" and "Strongly Agree" for all survey questions, indicating that they prepared well for the flipped/CBL class, were engaged during the class period, and possessed a high degree of excitement in anticipation for the upcoming GCP. This aligns well with expectations during an implementation of CBL. The results confirm that the combination of CBL and a flipped classroom were successful, and should be maintained in future iterations of the course. Proper training of the fellows and instructors are critical to this success, as CBL particularly requires significant involvement of the instructor/fellow in order to direct and develop the discussion and brainstorming portions. More information on training can be found in the companion paper, as mentioned previously [2].

Table 4: Detailed Post-CBL Student Survey Results Included in Each of the Closed-Ended Survey Questions

ENED 1020 Fall 2014	ALL Sections		
	n	Mean*	Std. Deviation
1. I was able to successfully complete my homework assignment before coming to this class session.	227	3.46	0.693
2. During this discussion, my ideas were considered.	225	3.35	0.623
3. I understood the "Essential Question" identified at the end of this class.	226	3.21	0.646
4. My group received guidance from the instructor when developing our guiding questions.	227	3.37	0.569
5. I understand how the "Guiding Questions" will help us find an approach to solve the Engineering Research Process (ERP) activity.	224	3.21	0.601
6. I understand how the "Guiding Questions" will help us find an approach to solve the Entrepreneurial Process Model (EPM) activity	225	3.16	0.603
7. I am excited about finding one possible solution to solve the Engineering Research Process (ERP) activity.	225	3.28	0.610
8. I am excited about finding one possible solution to solve the Entrepreneurial Process Model (EPM) activity.	227	3.15	0.664
9. Completing my homework prior to this class, prepared me to contribute during the class discussion.	225	3.08	0.806

* Scale: 4=Strongly Agree, 3=Agree, 2=Disagree, 1=Strongly Disagree

The open-ended questions in the survey were primarily directed to assess student comprehension of the CBL process and the resulting GCP project. A good number of students expressed their preparedness for the GCP project, as is indicated from the close-ended survey results (see **Table 4**). Here are some student comments which identify the benefit they reported getting from the flipped class and CBL pedagogy used for this class.

"It allowed the group to get right into the work without using time to learn concepts." - Section A

"It familiarized me with the terminology and essential knowledge necessary to understand what was being said." - Section B

"Reading the material gave me a rough understanding before class discussion of the topic." - Section C

"The homework made us do research on our own before the class discussion." - Section D

3.4 Assessment Results for Student Learning Objectives (SLOs) for the GCP

Direct assessment of the student learning objectives (SLOs) for the GCP was performed through the grading of the most important deliverables produced during the GCP: the final team report and presentation. Detailed rubrics were used for grading, and the results were used to determine the total class attainment of the five SLOs presented in **Section 1.5**.

The degrees of attainment of the SLOs for the four sections as a percent of the total number of points possible by the entire section are presented in the four parts of **Figure 1**. Across all four sections of the course, all SLOs reached over 80% attainment, exceeding the initial expectations during instructional planning. This is significant because the learning objectives that were selected for the GCP reflect some of the most important skills (the "21st Century Learning Skills": critical thinking, problem solving, creativity, innovation, communication, and collaboration) that need to be developed in young engineers. The learning objectives go beyond that of typical first-year engineering education by incorporating "entrepreneurship" through the EPM, an important but often overlooked concept for engineers. From the high attainment of the learning objectives, it can be concluded that the learning objectives were fully met in each section of the course.

A pre- and post-test was also used to investigate the effect of the GCP project on individual student learning. The test had a total of 6 questions that included key specifics from the processes involved (CBL, ERP and EPM) and some key concepts based on the chosen big idea. These questions were either multiple choice or fill-in the blank type questions. Students were awarded credit for completion of these tests. The scores of the test were used for comparing and gauging the increase in student knowledge as a result of the GCP. The pre-test was provided to the students on the introduction day (1st week of class). The post-test was provided on the last day after all student presentations were completed. The assessment results from the pre- and post-tests for all the four sections as shown in **Figure 2**. A paired sample t-test for significance was used to determine whether there is a significant difference between the pre- and post-test data. The paired sample t-test data is presented in **Table 5**. The table shows a significant improvement in post-test data. Since the p-value for all the sections are below 0.01, this indicates that there is a 99% confidence level that these results are significantly different from pre- to post-test, with the post-test scores being higher.

3.5 Fellow Reflections

Each fellow reflected on three issues after the GCP project's execution: what worked during its execution; what did not work or what were the challenges; and what are their suggestions for the future, if it were to be implemented again. Each fellow's personal reflections are presented in this section, as reported by them.

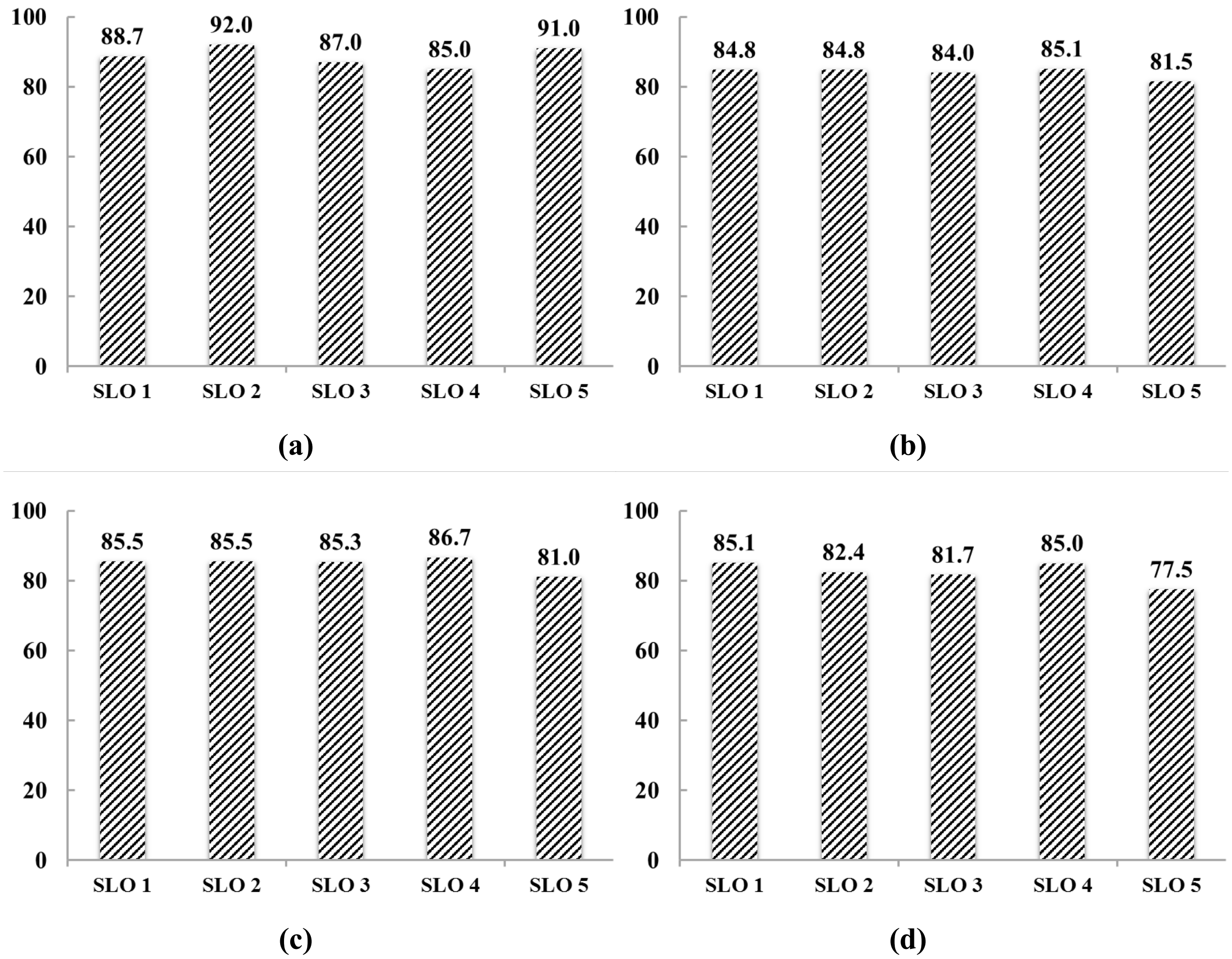

Figure 1: Attainment of Student Learning Objectives (SLOs) for (a) Section A, (b) Section B, (c) Section C and (d) Section D

Table 5: The t-Test Results for Pre- and Post-Test for All Sections

Section	Paired-Sample t-Test
A	t(42) = 18.585, p = 0.000
B	t(57) = 8.188, p = 0.008
C	t(46) = 16.366, p = 0.000
D	t(51) = 18.601, p = 0.000

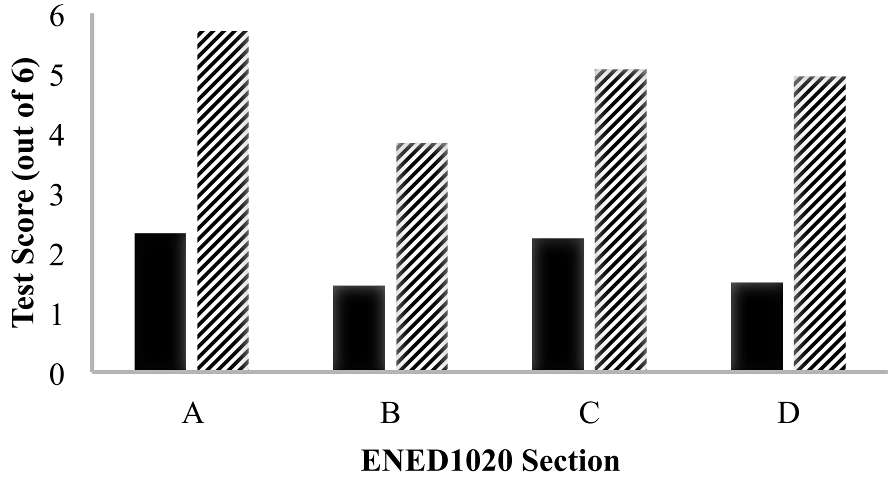

Figure 2: Pre-Test Results (Solid Colored Bars) and Post-Test Results (Hatched Bars)

3.5.1 Feedback from Fellow for Section A

What Worked: "The GCP as a whole, definitely helped students get a hands on experience in handling a real-world engineering problem. Student worked effectively in groups to integrate both engineering and entrepreneurial aspects in their project solutions. With a majority of students majoring in the field directly related to the big idea, this project helped them understand the amount of training, knowledge and research that goes into engineering problems in that discipline. Also, the hook that involved senior students talking about their co-op positions, helped the freshmen get a real-world perspective of the project they were working on."

What Did Not: "The GCP was intended to teach students multiple concepts such as ERP and EPM apart from the big idea. The method used to teach these concepts was a new pedagogy: CBL. The information for all these new concepts (that involve multiple new terminologies) was primarily provided in the flipped class notes and was further executed in short time frame, two hours. This may have caused a certain amount of anxiety amongst the students. Also, the students, actually experimented, tested, revised, and documented their solutions to the challenge during a period of only two weeks (4 hours of working time during the last two weeks). As the chosen challenge involved a new concept, many thought that if they were provided more time, they could have dedicated more time for research and thus produce better results. Also, the tracking surveys were to be filled by each individual student. For the first three surveys, it was seen that students were not discussing their ideas with their other team members and were still trying to understand the various concepts and terms introduced during the flipped class. This led to a bit of confusion when the teams got together. By advising and guiding the student teams individually after the third survey, the groups were in a better state to commence work on their GCP."

Suggestions for the Future: "Firstly, the time frame for introducing the content of the flipped class could be increased and more spread out. This would provide students time to familiarize themselves with the new terms and concepts they learned. Secondly, with respect to the tracking surveys, if each group were to submit one tracking survey during the last 15 minutes of their recitation bi-weekly, the problem of miscommunication between group members could be eliminated. The TAs could not be trained specifically for the GCP. Therefore, their input during the execution of the GCP was missing. In addition, they were responsible for grading the reports and presentations partly. TAs had to be given a quick sum-up of the concepts involved. This affected grading to some extent."

3.5.2 Feedback from Fellow for Section B

What Worked: "The implementation of the GCP was successful in a number of ways, most notably the exposure of the students to a number of important concepts that they will need as they advance as students and in their future careers. Throughout the GCP the students were exposed to CBL, an innovative pedagogy that they will likely see again in the future, the ERP, a fundamental process that all engineers must be acquainted with, and the EPM, a model for making business decisions that often is left out in engineering education. While developing their GCP solutions, the students also had the opportunity to work in long-term groups to solve real-world problems in a minimally constrained environment. This setting is very comparable with real engineering work, and the exposure will help students validate or refine their career path. Lastly, the GCP, with its focus on solving a real-world problem, helped to develop a sense of awareness in the students, many of whom were not majoring in the field specific to the big idea."

What Did Not: "With this implementation being the first implementation of its kind, there were a number of shortcomings that can be addressed in future implementations of the course. The main shortcomings stem from two areas, timing and content. The concern with timing is that there were at least eight weeks between the CBL portion of the course where the challenge was developed and the actual classroom time when the challenge solution would be attempted by the students. This led to confusion and required significant additional guidance from the fellow and instructor to keep the students on track and aware of the course schedule. The problem with content is that the students were overloaded with new content at the beginning portion of the GCP when CBL was introduced and implemented. During the two hour "flipped" classroom, the students were required to learn and be able to use three different models: CBL, the ERP, and the EPM. These three models are foreign to almost every student, and contain over 20 new terms. The timing and content issues led to a general environment of confusion that took away from the limited time available to implement CBL and lead the students to develop a solution."

Suggestions for the Future: "A majority of the suggestions relate to the scheduling of the course components and the management of the limited time for the GCP. First, it is recommended that CBL be integrated into the entire course, with a reframing of the four hands-on projects as training that is preparing the students to complete the GCP at the end of the semester. To solidify the connection to the GCP, at the completion of each hands-on project, the fellow/instructor should be given at least 30 minutes to lead a discussion with the students that focuses their learning from the project and ties it into the upcoming GCP. With respect to the instructional plan, the ERP and EPM should be taught in advance of the start of the CBL process. This way, when the CBL process is executed more focus can be given to the brainstorming and less to grappling with unfamiliar terms and models. During the execution of the GCP, at least 4 class hours to develop the ERP solution and at least 2 class hours to develop the EPM solution (a total of 6 hours) should be provided so that the students are able to properly explore and address the components of each model. Finally, in response to the underutilization of the TAs during the recent implementation, it would be advantageous to hire TAs who were students during the recent implementation and ensure that they are able to fully participate in the execution of the GCP, including grading and receiving all necessary training. In the case of implementations where there is no pool of experienced students, a special focus should be given to providing the TAs with the necessary classroom training in advance."

3.5.3 Feedback from Fellow for Sections C and D

What worked: "The GCP was beneficial to the students for three main reasons: the GCP was implemented as a student-driven project (unlike a Project Based Learning (PBL) project) throughout the CBL methodology used to implement it; it utilized ERP and EPM to solve an open ended project with constraints which represented a real-world application; and the implementation of the GCP was more enjoyable and more effective because students went deeper into the subject and tried to justify their result in a meaningful way which they could relate to. There were some strengths over the four previous required experimental laboratory projects the students performed in the course, which included: the implementation of the required experimental projects followed prescribed procedures and instructions to record, analyze, and report results, which left little room for creativity and innovation, whereas the use of the CBL method integrated with ERP and EPM motivated the students to seek their own optimum solution and they had the responsibility to present and defend their solution. Also, students learned: to collaborate in teams, to use internet (Google documents) to conduct literature search, and about careers and co-op opportunities connected with their GCP."

What did not: "The method was introduced to the students at the beginning of the course, and the implementation was at the end of the course, this big gap created some confusion and stress for the students. The level of preparation demonstrated by the students in understanding well the CBL, ERP and EPM methodologies was not adequate, although they were given flipped class notes. There were several reasons which may have contributed to this situation. The fellow feels that the students did not use the flipped class notes to extent as was expected. There was not sufficient time to rectify this weakness. The quiz to assess content knowledge preparation of the students from the flipped class notes was simple, and did not reveal this weakness thoroughly. The students felt that it took them significant time to prepare for the GCP in comparison to the time required for the other four experimental laboratory projects. Since they felt that preparing for GCP took more time, and that it took time away from studying for other required subjects (which were for more credit), they did not give it a high priority. Additionally, the students felt that the weightage for the GCP project grade, which represented only 20% of the course grade, was not commensurate with the effort needed to do a good job. The fellow was not the instructor of record for the course, and his communication with the students was limited to either online interaction through the tracking survey reports or short meetings after each required experiment lab, which was not enough. Students implemented the project based on teams chosen at the beginning of the course by the course instructor (faculty of record), and the fellow didn't contribute in forming the teams."

Suggestions for the Future: "Introducing the project as part of the course a week or two before the implementation would help in reducing the anxiety that the students experienced or construct all projects for the whole course using the CBL methodology, including the four required experimental labs and GCP. In order for a flipped classroom to be successful, a more rigorous quiz and homework be given to demonstrate proficiency achieved, and a more reasonable grade be assigned for this effort which is commensurate to the time expected to be devoted for it. The CBL integrates ERP and EPM, which are used as the tools to solve the challenge, so it is important that students fully understand these two models. It is recommended that a reasonable time should be given to educate the students about these two models. Getting purely online feedback to gauge understanding is not sufficient, face to face interaction, presentations or writing comprehensive reports should also be used. The GCP should be implemented by the person who is the instructor of the course, or if that's not possible, the fellow should be involved in the whole course instruction as an assistant instructor. It is also recommended forming teams using criteria that helps better teamwork and assign roles for each team member, such as team leader, activity coordinator and members."

3.6 Student GCP Solution Examples

In this section examples of the "best" and "low" evaluated grand challenge solutions are presented for each section's GCP to give an idea of the quality of deliverables produced by the students. Rubrics were used to assess the team deliverables, which included a final presentation and a project report.

3.6.1 Section A

High Scoring Solution: Core Solutions – This team concentrated on looking at basic mechanism of the working of a drug treatment process. Their solution not only identified the ion channel in the heart that needs treatment, but also researched and provided possible protein molecules that could act as cardiac glycoside in their drug. They also looked at possible side-effects and recommended economic benefits of their research. This group went beyond the requirement to find a possible solution and researched on a means of achieving their solution with possible fallouts. Their report contained good understanding of the concepts and the presentation of their experimental data and analysis was very thorough.

Low Scoring Solution: Gene Therapy: A Cure to Atrial Fibrillation – This team developed a target medication to alter all ion concentrations in the heart. Since, this was not an efficient method, the team decided to research on alternate therapy methods and recommended pathways to research the same. After their initial experiment, this group lost motivation to reiterate to find a better solution. They instead choose to alter their therapy methods which led to them recommending future research pathways only. Their integration of ERP and EPM was not easy to understand.

3.6.2 Section B

High Scoring Solution: The Aqua Floca Filter - The students developed a multi-media filter to remove clay particulates from influent water. The final results displayed an excellent understanding of the ERP and EPM. Additionally, the students went beyond and developed a method to measure the turbidity of the effluent water as a means to determine the efficiency of their filtration process.

Low Scoring Solution: Clean Water Grand Challenge - The student team developed a method to use light energy to heat the contaminated water and condense it, then, innovatively, used a computer program to analyze the color of the effluent water in an attempt to determine the efficient of the process. Despite the interesting ideas, they failed to properly integrate the ERP and EPM, and displayed a clear lack of leadership and organization through the submission of a low quality report and presentation.

3.6.3 Section C

High Scoring Solution: Pure Oxygen - The hypothesis for this project was based on observations of fuel cell mechanism that the students studied in one of the required experiment lab. They demonstrated full understanding of how the fuel cell works, and defined clearly the variables that affect the output power. When studying these variables, they considered following questions: "What change will this variable produce?"; "What variables can be kept the same and which one can be varied?"; and "Will the change produced be significant?". They followed all the steps of the ERP and were able to address most of the EPM principles. They made quantitative measurement which lead to good data to defend their best final solution. Also, they went beyond the flipped class material notes and studied from different journals and cited them as references.

Low Scoring Solution: Altering The Set Up of a Circuit for a Fuel Cell – Students hypothesized that by changing the arrangement of the setup using less connecting wires, switching the position of the fan, tanks and the solar panel the efficiency can be increased. Students did not present much information about the science behind the setup or enough justification of their design. They showed lack of organization and did not fully follow the ERP model steps, including revision. Students did not study any external references and did not demonstrate they understood the process of producing electricity from the cell. Their discussion was poor and justification of the final results was unsatisfactory.

3.6.4 Section D

High Scoring Solution: Heating Water of Storage Tank – Students focused on the electrolysis reaction that generates the hydrogen fuel required for fuel cells. They hypothesized that using hot water would make the process of hydrogen production faster. Students provided all the necessary information required for ERP and EPM. They used clear and good visual aids, graph, reference citations, and suggestion for iteration for improvement, and future work planned. Students made and showed quantitative measurements which supported their results.

Low Scoring Solution: Fuel Cell Efficiency with Pressurized Gases – Students hypothesized that changing the flow rate of the gases will affect the output power. They suggested that pressurizing the oxygen and hydrogen in the tank would increase the efficiency. Students did not provide details of the process and their results were not explained well and were ambiguous. Students did not provide references. Students showed lack of understanding for the ERP and they were confused between the big idea and the challenge.

4. Conclusions

Implementing the GCP in the ENED1020 course primarily: helped promote the S-STEM Scholarship Program amongst freshman students; introduced students to the innovative pedagogies, CBL and flipped classrooms; promoted important skills such as delivering presentation and working in groups; and developed awareness in students of some of the world's most significant challenges in engineering. Using CBL to identify a grand challenge for the given big idea, the students used ERP to come with a desired engineered solution which meets the constraints for the challenge and the EPM to look at the best market-fit of this solution. Finally, they revised or iterated the ERP and EPM solutions to obtain the most optimum solution, and communicated and defended their solution. This required students to be conversant with a number of new terms that were introduced in the process. While many students felt that the format of the GCP helped them understand how to solve a real-world problem in its entirety (using ERP and EPM), a number of students felt overwhelmed with the workload and the uncertainty inherent in completing such an open-ended project.

As was expected with the implementation of the GCP, the student evaluation data indicated both positive and negative aspects of the project implementation. Overall, this project helped students identify two key aspects of the problem: engineering research and entrepreneurship. The primary observation from student evaluation data and fellow reflections suggest better coordination between the fellows and the course instructors to establish improved organization during execution. The tracking surveys that were used to monitor student progresses towards the GCP was shown to benefit a few student groups. Many student groups felt the need for the instructional team to spend more face-to-face time providing feedback based on these surveys.

The assessment results from all the sections depict positive outcomes of the project implementation. To understand the impact of the GCP on student learning, pre- and post-test results for the attainment of the student learning objectives were used. For all the sections, the learning objectives, covering student communication ability and understanding of important engineering research and entrepreneurship concepts, were met. Additionally, from the pre- and post-test results, an observable increase in student learning is noted.

At the conclusion of the GCP, many students not only benefited from the integration of ERP and EPM, but were also able to connect and relate their major to the identified problem. Overall, the implementation was a success, but concerns with pacing and the exposure of students to multiple new concepts need to be addressed to ensure full engagement of the students in the GCP. More seamless integration of the GCP concept for all the projects selected for the entire course (ENED 1020), would lead to a more streamlined and efficient implementation.

5. <u>Acknowledgments</u>

The authors would like to acknowledge the financial support provided by the U.S. National Science Foundation Awards, DUE-1356656 for S-STEM grant and DUE-1102990 for MSP grant. Any opinions, findings, conclusions, and/or recommendations are those of the investigators and do not necessarily reflect the views of the Foundation. The authors will like to thank Dr. Cathy Maltbie, Program Evaluator for assisting in conducting the analysis of the data collected from all the evaluation instruments, and for Dr. Anant Kukreti, Principal Investigator, and Dr. Temesgen Aure, Project Coordinator, to review and provide input of their draft paper and for their guidance throughout this study.

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