

Integrating the Challenge Based Learning Approach in a Freshman Engineering Foundations Course: Project Team Perspective

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INTRODUCTION

While there is consensus surrounding the importance of STEM education in higher education, there is less agreement surrounding best practices on implementation in the classroom. Critical thinking is defined as the learning of complex, abstract concepts. Research demonstrates that critical thinking is not fostered in the typical college classroom. Numerous studies of college classrooms reveal that, rather than actively involving students in learning, they are lectured to, even though lectures are not nearly as effective as other means for developing cognitive skills¹. Students enter college without the skill and leave college without it as well.

The primary cause of this issue is the lack of training for doctoral students who want to continue as a faculty in academia. Research universities are the primary sources for granting doctorate degrees, with 55% of doctorate degrees being earned in these institutions and more than 60% of faculty and professional staff being employed in STEM fields². Faculty members are expected to conduct research and educate undergraduate students. However, graduate students are not trained to teach or educate students as part of their degree programs. Researchers have noted that there is a lack of training on faculty responsibilities and expectations for doctoral students³⁻⁶. This lack of training has a threefold effect: low teaching self-efficacy for graduate students, poor teaching preparedness for graduate students seeking careers in academia, and poor learning environments for the students they will teach.

To address the above issue, 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. This integrated engineering research-entrepreneurship experience was provided to students enrolled in four sections of ENED 1020 in BCEE through a special project executed by three doctoral engineering Fellows, aspiring to be future university faculty, as part of a Preparing Future Faculty program. This project was provided as part of a NSF S-STEM grant, entitled, “*Scholarships in Science, Technology, Engineering, and Mathematics (S-STEM): Bridging Our Students to Their Future*,” which focuses on engaging and preparing students for research or entrepreneurship careers through four degree tracks offered to BCEE undergraduate students from sophomore to senior year. The four

tracks to be piloted during 2014-2015 to 2017-2018 academic years (4 years) for a select group of BCEE students included:

1. A dual BS + MS Track in Engineering;
2. A dual BS in Engineering + MBA Track with a Certificate in Entrepreneurship;
3. A BS in Engineering with Graduate School Preparation Track; and
4. A Professional Preparation BS in Engineering Track with a Minor in Entrepreneurship.

The above S-STEM Tracks include Biomedical (**BME**), Chemical (**ChemE**), and Environmental (**EnvE**) Engineering in CEAS at UC, all housed in the Department of BCEE. The goals of the experience provided in ENED 1020 were: (1) to provide an experiential learning opportunity in the “engineering research” and “entrepreneurship” processes by conducting a Grand Challenge Project (**GCP**), launched at the beginning of the semester and executed during the last four weeks of the semester along with other requirements of the course. The GCP was structured around one of the fourteen *Grand Challenges for Engineering* identified by the National Academy of Engineers (**NAE**)⁷. (2) To create awareness of the S-STEM program, the four research/entrepreneurship degree tracks it offers, and the stipend (or scholarship) opportunities available for completion of the special S-STEM courses for the tracks besides their undergraduate BS degree program requirement. The outcome expected was to create an informed community of learners who will subsequently apply in the 2015 Spring Semester for the 32 open S-STEM positions. The expectation was about 50 students will be interested in applying for the S-STEM program at the end of the ENED 1020 course in the 2014 Fall Semester.

This paper provides: (1) a brief overview of the ENED 1020; (2) teaching methodologies and execution of the GCP in ENED 1020; (3) training provided to the doctoral engineering Fellows who executed the GCP; (4) the evaluations conducted and results; and (5) concluding remarks summarizing the key results and lessons learned.

ENED 1020: ENGINEERING FUNDAMENTALS

The *ENED 1020: Engineering Foundations* course serves as an introduction to all fields of engineering to incoming freshman. It is a common course taken by all incoming freshman in the first semester, in sections with 50 to 60 students in each. The course includes lectures as well as “hands-on” experimental modules that enable students to explore mechanical, chemical, and electrical systems, and conduct four required laboratory investigation projects in teams of 3-5 students each, including bridges, fuel cells, thermodynamics and electronic communications and signal processing applications. Special laboratory equipment and kits are provided to the students to conduct these experiments. Students are guided to perform these experiments by teaching assistants (**TAs**: trained senior undergraduates), with one TA support for every two teams. Each student team completes a report for each lab using a prescribed format. In addition, students complete a fifth project, called the “Choice Project,” in which the students are asked to design their own experimental investigation, different from the ones completed, using the knowledge and equipment from the four required projects. Usually, teams extend one of the required projects for the Choice Project, for example, doubling the energy production from a fuel cell. As for the required projects, each team submits a written report for the Choice Project as well. Students also receive training in engineering ethics and in professional skills such as

communication, teamwork, problem-solving, and synthesis. Representatives from degree-programs in CEAS and from industrial organizations are invited to provide additional information concerning career opportunities in engineering to students.

In addition to the five required projects described in the previous paragraph, students in those sections in which GCP were not implemented conducted a project addressing one of the fourteen NAE Grand Challenges for Engineering and presented a team oral PowerPoint presentation, which is evaluated using a prescribed rubric by peer students, TAs, and instructor. Students in the four targeted ENED 1020 BCEE sections conducted the GCP instead of the Choice Project. The GCPs were designed and executed by the engineering doctoral Fellows under the supervision of the course instructor, an assigned S-STEM advisor, the S-STEM Project Coordinator, and the S-STEM Project Evaluator. The four ENED 1020 BCEE sections, included one BME, one EnvE and two ChemE sections, each section taught by a different instructor. Though each discipline designated section predominantly consisted of students from that discipline, but it also included students from other engineering majors who could not enroll in their discipline specific section due to schedule conflicts. An engineering doctoral Fellow from Mechanical, Environmental and Materials Engineering coordinated the one BME section, one EnvE section and two ChemE sections of ENED 1020, respectively.

The student learning objectives (**SLOs**) for ENED 1020 are given below: At the completion of this course, students will be able to:

1. Describe their program's curriculum and co-op requirements and its experiential learning and career opportunities.
2. Describe the other CEAS disciplines and the career opportunities those disciplines provide.
3. Demonstrate the ability to design and conduct experiments, as well as to analyze and interpret data.
4. Demonstrate the ability to identify, formulate, and solve engineering problems.
5. Demonstrate the ability to communicate effectively and work in teams.
6. Demonstrate an understanding of professional and ethical responsibility.

The GCP executed by the Fellows was targeted to address SLO #s 3, 4 and 5. Additionally, at the completion of the GCP, students will be able to:

7. Explore, analyze, and discuss the concept of the "engineering research process."
8. Explore, analyze, and discuss the concept of entrepreneurship.

TEACHING METHODOLOGIES AND EXECUTION

Challenged Based Learning (CBL): Challenged Based Learning is an active learning environment that engages students to plan their own learning. It is a structured model for course content delivery with a foundation in earlier strategies, such as collaborative problem-based learning. CBL is different from project-based learning in that instead of presenting students with a problem to solve, it offers general concepts from which the students determine the challenges they will address. The faculty member's primary role shifts from dispensing information to guiding the construction of knowledge by his or her students around an initially ill-defined problem. Developed by Apple, Inc.⁸, CBL encourages student groups, under a faculty member's

guidance, to solve real world issues using technology and a hands-on approach. Grounded in student learning outcomes, students are introduced to a relevant “big idea.” This big idea is an item of global, regional or local significance – something a student can readily relate to his or her life. Once the big idea is introduced, the first step is to collaboratively develop - with the students - an overview of the big idea and the related “essential questions” and choose one that sets the broader context and foundation for the work that will follow. The class then identifies a suitable “challenge” or is guided to select the challenge. This establishes the context for the “engineering research challenge” selected for the GCP. The students then begin the process of identifying the “guiding questions” that will guide their analysis of the engineering research challenge topic. These questions outline what the students think they need to know to formulate a viable solution. Students need significant guidance from the faculty (Fellow in the case of ENED 1020) depending on the particular engineering research challenge selected for the GCP and student preparation. This is where content knowledge requirements can be established. Student teams seek to find answers to the guiding questions by participating in a variety of learning activities, conducting research, learning new material (independently, in groups or as part of a teacher (Fellow)-led lesson), experimentation, interviewing, and exploring various avenues to assist in crafting the best solution for the challenge. The CBL model used for executing the GCP by the Fellow is illustrated in **Figure 1**.

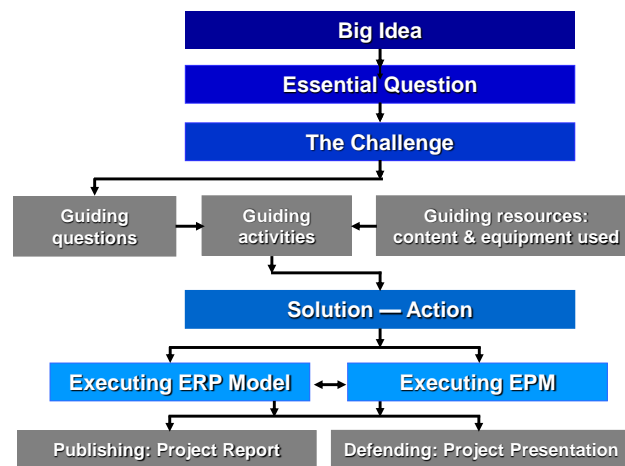


Figure 1: Challenge-Based Learning (CBL) Model

For the GCP, the CBL methodology is used to frame the engineering research challenge and its guiding questions for the big idea selected. The engineering research process (ERP) model, described below, is used to solve this challenge. Second, this solution for the challenge is tested for market-fit to investigate the parameters which will ensure its adoptability in the real world. This is investigated using the entrepreneurship process model (EPM), which is also described below.

Engineering Research Process (ERP): The ERP guides and informs the solution of the challenge. The goal of the educator is to generate interest in a topic chosen from the NAE Grand Challenges using the guiding questions (see **Figure 1**) and ERP, as shown in **Figure 2**. The objective is to guide the learner to a series of “observations” about potential problems associated with a Grand Challenge and to formalize a “hypothesis” that can be researched and answered.

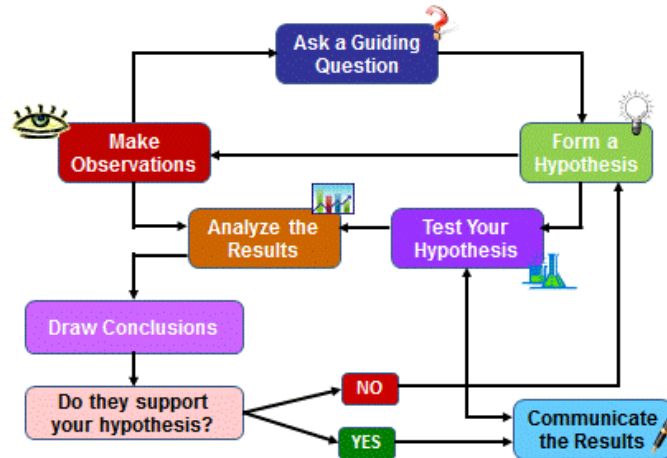


Figure 2: Engineering Research Process (ERP) Model (The Scientific Method)

Subsequent guiding questions will guide the students to an appropriate research method to “test” their “hypothesis.” From here on the students will take off on their own to generate the experimental data and “analyze” the “results.” Subsequently the student team will formalize their “conclusions” with regards to whether their data supports their initial “hypothesis.” A positive answer will move the student team to the final step, where they prepare to “communicate” and defend their “results.” A negative answer gives the student team a chance to formulate a new “hypothesis” and repeat the cyclic process.

Entrepreneurship Process Model (EPM): The Entrepreneurship Process Model (EPM), as shown in **Figure 3**, explores the viability of the product resulting from ERP, as a solution to the challenge, to take it to the real world (market-fit). The EPM is a comprehensive overview of the multiple interactions that occur in the ideation, conceptualization, formulation, and implementation of new venture creation process. The EPM includes following five key components: The value proposition, the focus, the entrepreneur, the environment, and engagement. These are explained below:

1. **Value Proposition:** Keep in mind that the entire entrepreneurship process model is underscored by the creation of value for the customer. That is, the value proposition must be sufficiently compelling to induce a *value exchange* between the good and/or service provided and the customer’s need, want, desire, pain, problem, etc.
2. **Focus:** Entrepreneurship includes three core elements of focus - the product and/or service offered; the customer; and the competition. All three interact to inform the fulfillment of the value proposition.
3. It is the **Entrepreneur** who alone and/or with others provides the leadership, creativity, and communication that propels the process forward.
4. Of course, this process unfolds in an uncertain, ambiguous, and often unfriendly **Environment**.
5. **Engagement.** It is within this environment that the entrepreneur must continuously assess the unserved and/or underserved market opportunity, needed resources, and team needs. The EPM is highly dynamic and interactive. For example, changing market conditions

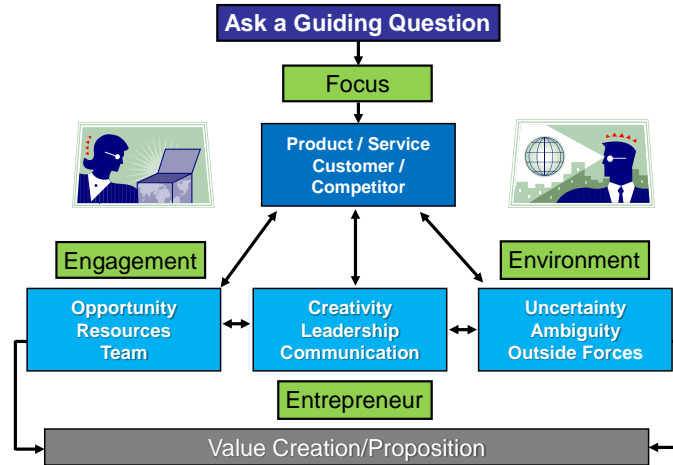


Figure 3: Entrepreneurship Process Model (EPM)

can influence the real or perceived need for a given solution to a problem. Moreover, direct and indirect competition can influence the dynamic between the value offered by one solution over another. Finally, changing technology may or may not yet be sufficient to enhance the development and deployment of solutions offered by the entrepreneur or sought by the marketplace. Often it is the entrepreneur who persists against the odds to succeed in the long run.

Tracking Progress and Planning Interventions: All engineering research projects are initiated with a defined scope, which is often controlled by constraints such as time, cost and availability of resource. The scope often evolves as the research proceeds. To simulate this situation in the GCP, each team is mandated to limit its search for the challenge solution using the kits, materials and test equipment available in the four required lab projects. After completion of each required lab project, each team was asked to reflect and document how the knowledge and testing skills learned is planned to be in the quest to find the “best” solution and its marketability for their GCP challenge, using the ERP model and EPM, respectively. The feedback was formally solicited through team and individual surveys required to be submitted after each required lab project. These surveys were used to track team progress and dynamics, and plan interventions, if needed. Completion of these surveys forced each team to spend time, after each required lab project, to work on their GCP and seek timely help to resolve difficulties. Completion of each team tracking and individual survey was treated as an assigned homework with assigned points, counted towards the GCP grade score.

Execution of the Grand Challenge Project (GCP): The full details of the execution of the GCP in ENED 1020 by the engineering graduate Fellows are presented in a separate paper, “*Integrating the Challenge Based Learning Approach in a Freshman Engineering Foundations Course: Teaching by Intern Engineering Doctoral Students Perspective,*” at this conference. In this sub-section the main process used by a Fellow, under the close guidance of the course instructor and the S-STEM Advisor and tracked by the S-STEM Project Coordinator, is presented, which included following steps:

1. Preparation of Documents Prior to Teaching:

- a. Selection of the big idea as one of the NAE Grand Challenges and articulation of its S-STEM connection, particularly integration of the engineering research and entrepreneurial experiences, which are new for the students.
 - b. Articulation of the student learning outcomes (SLOs) to be addressed in the GCP, and the assessment procedures to be used to measure them.
 - c. Formulation of the pre- and post-tests to assess impact on student learning.
 - d. Creation of a *Flipped Lesson* to introduce the GCP to the students and make it available on Blackboard before the start of the 2014 Fall Semester, with following learning objectives:
 - i. Students must demonstrate an understanding of the CBL process and be able to define big idea, essential questions, challenge and guiding questions, as well as their sequencing.
 - ii. Using the Flipped Lesson notes the students should be able to be knowledgeable about the big idea selected for their GCP, and be able to articulate at least three essential questions to their project team members in the class when their GCP is first introduced.
 - iii. Students must demonstrate a clear understanding of the different elements of the engineering research process (**ERP**) model and the entrepreneurship process model (**EPM**), their cyclic or iterative nature, and their integration into the CBL process to find the “best” solution for the challenge which is marketable.
 - e. Creating homework for the Flipped Lesson, completion of which prior to the class, demonstrates proficiency in acquiring the above learning outcomes. The Flipped Lesson homework has assigned points, which counted towards the GCP grade score.
2. Launching of the GCP:
- a. A 30 minutes visit by the Fellow to the first class for self-introduction and informing students about the availability of the Flipped Lesson and homework (besides earlier email notice), alerting of the online submission of the assigned homework for grade prior to the next lab period at which the GCP will be initiated, and asking the students to complete a *pre-test* to measure their initial understanding of the chosen *Big Idea* for the GCP.
 - b. Launching the GCP in a 2-hour lab session class in the first week, to accomplish the following:
 - i. Review the CBL Model.
 - ii. Introduce the big idea and engage student teams to move from the big idea → essential questions → challenge.
 - iii. Engage the student teams to move from the challenge → guiding questions.
 - iv. Get the students to complete the Student Big Idea Survey.
 - v. Review the ERP Model and EPM.
 - vi. Engage the students to outline initial ideas to use the ERP Model to solve the challenge and use of EPM to investigate its feasibility and potential market value.
 - vii. Explain the Progress Tracking Surveys to be completed after each required class project documenting team’s progress towards solving the challenge and its potential commercialization, identifying resources planned to be used from the recently completed required class project, and asking questions, if they had any.

3. Monitoring Progress of Student Teams and Individuals:
 - a. After completing each required lab project (four total), each team was required to submit the *CBL Progress Tracking Survey* and each individual team member was asked to complete a separate survey responding to questions on perceptions of team dynamics. The team *CBL Progress Tracking Survey* asked:
 - i. What is your challenge?
 - ii. How does it relate to your major?
 - iii. How does it address ACS (real world “application,” “career” opportunities related to this project, and current “societal” issues the project addresses)?
 - iv. What tasks do you plan to undertake: to solve the (1) challenge using ERP Model; and (2) to investigate its commercial viability using the EPM?
 - v. What content resources do you plan to use from the required lab project just completed to solve the challenge and its commercialization?
 - vi. What equipment/materials, do you plan to use from the required lab project just completed and why?
 - vii. How do you plan to present and defend your challenge solution and its business plan?
 - viii. Any questions or difficulty you have?
 - b. Using a rubric, the Fellow scores each CBL Progress Tracking Survey, and submits a report (using a standard template) to each team, and additionally, if needed, meets face-to-face, at the following lab class, the teams demonstrating inadequate progress and/or having team-dynamics issues.
 - c. The Fellow provides composite results of each CBL Progress Tracking Survey and summary of actions taken to the course instructor, S-STEM advisor and S-STEM Project Coordinator for their information.
4. Each student team executed their GCP in the last two weeks of the class during which:
 - a. Students hypothesized, experimented, tested, revised and documented their solutions in two lab sessions (2-hour each).
 - b. Guidance, directions and instructions were given by Fellows to students in two lecture sessions (60 minutes each). These sessions were also used to address special issues that required specific attention.
5. Final Deliverables and Evaluations:
 - a. Each team is required to submit (1) a typed project report (following a specified format), and (2) give a 10 minute PowerPoint presentation defending their challenge solution and its commercial potential.
 - b. Each team report is evaluated by the teaching assistant (TA) using a rubric.
 - c. Each team presentation is evaluated using a rubric by all other students, TA, Fellow and the course instructor.

TRAINING OF THE FELLOWS

Background: The engineering doctoral Fellows, who executed the S-STEM Grand Challenge Project (GCP) in ENED 1020, were trained as part of the [Cincinnati Engineering Enhanced Math and Science \(CEEMS\) Program](#), which works to connect the students’

motivation to what they are learning using the **CBL**. The CEEMS Program, funded by a NSF Math and Science Partnership (**MSP**) grant (#1102990), is led by the UC as the higher education core partner in partnership with 14 core K-12 partner school districts from Greater Cincinnati area. CEEMS works to meet the growing need for engineering educated teachers who are equipped to provide learners with opportunities to achieve recently revised Ohio State Science Standards and Common Core Math Standards juxtaposed with Universal Skills (21st Century Learning Skills). These standards are centered in “real world application: connections to engineering.” Math and science secondary school teachers from the partner school districts participate for two summers, complete seven weeks of six engineering content courses (three courses per year), and participate in a professional development program which trains them to use two pedagogical approaches, CBL and engineering design process (**EDP**), to take back the course-work experience to teach math and science courses to their students. During the training, teachers have the opportunity to not only develop CBL with EDP curricular units that will be implemented during the school year, but also work with the CEEMS project Resource Team. In CEEMS, an experienced Resource Team consists of three retired engineers and seven education specialists. While the whole ten members of the Resource Team are collectively available to all the teachers, each teacher is assigned to two Resource Team coaches. Generally, one is an engineer and another is a seasoned educator. In addition, teachers in their first year of the program are assigned a third member of the team—a Fellow, an engineering doctoral student who has expressed an interest in pursuing an academic career upon graduation.

Training of Fellows in CEEMS: As part of the CEEMS program, the training of the Fellows includes four components:

1. Educational seminars and CBL-EDP workshops as part of a three credit hour course, *Instructional Planning*, taken during the summer. The seminars are used as training tools for the Fellows to learn about the K-12 educational system, pedagogy, student learning, and assessment with a focus on teaching K-12 math and science instruction. Topics include instructional approaches and best teaching practices in teaching middle and high school students, creating course content, defining learning outcomes, conducting effective assessments, polishing presentation skills, encouraging active learning, managing student projects and teams, understanding the standards used in school systems, and conducting research in engineering education. The Fellows also participate, along with the CEEMS teachers, in following three skill building workshops:
 - a. *Modeling CBL & Evaluation Instruments Workshop:* In this workshop the teachers and Fellows take on the role of students as the presenters’ model the CBL process, including how to guide students to settle on the essential question, pinpoint the challenge for the unit, and identify guiding questions needing to be answered to solve the challenge. The student and teacher surveys, which they complete after the students formulate the guiding questions, are also introduced.
 - b. *Modeling EDP & Evaluation Instruments Workshop:* The presenters discuss EDP and provide participants with opportunities to brainstorm, in teams, ways to incorporate the design process in the curricular materials they will develop to bring back to their classroom. Both modeling of small design activities to show the application of an isolated content and a capstone EDP activity that ties the entire curricular unit’s content to ACS (application, careers and societal impact) are

discussed. The student and teacher surveys, completed at the end of the curricular unit, related to the EDP process are introduced as well.

- c. *Support for Unit Template Creation:* This is a two session workshop. In the first session, teachers and Fellows are introduced to the Unit and Activity Templates they will use to develop their curricular materials. In the second session, more details are provided regarding use of the templates. In addition, returning teachers showcase previously created units as examples.
2. **Apprenticeship:** Each fellow is paired with a team of experts that includes members of the CEEMS Resource Team and secondary school teachers. Fellows shadow teachers and Resource Team members by spending an average of 10 hours a week in secondary teachers' classrooms. The intention behind graduate students observing a secondary school classroom is to observe the theories learned in educational seminars used in a real classroom environment, gain a better understanding of the state of education and the environments their future students will come from, and enhance their teaching.
3. **Teaching experience:** Each Fellow teaches in an undergraduate classroom using the CBL pedagogy to gain the hands-on experience to supplement the seminars about teaching and education. The 2014 CEEMS Fellows taught the GCP in ENED 1020 as part of this requirement

Additional Training of Fellows for the S-STEM Project: In CEEMS, the Fellows learnt **CBL** as the primary teaching pedagogy and **EDP** as the secondary pedagogy used to solve the challenge. However, in the GCP, the Fellows are expected to use **ERP** to solve the challenge and the **EPM** to investigate the market-fit aspects to implement the engineering solution in the real world. Additionally, to standardize the tracking and analyzing of feedback to be provided to the student teams, as the teams incrementally conveyed their progress on the GCP after each required lab project, the Fellows used evaluation rubrics. Similarly, the final deliverables of the GCP (report and presentation) were also assessed using evaluation rubrics. Since creating evaluation rubrics was new for the Fellows, they were required to be educated on designing the evaluation rubrics for the S-STEM project. In view of these issues, the Fellows participated in following three additional seminars prior to the 2014 Fall Semester:

1. *Seminar on Implementation of the Engineering Research Process (ERP):* The seminar on the ERP discussed six specific topics relevant to the scientific method: (1) define what constitutes science; (2) the art of making a scientific observation; (3) proposed explanation types – hypothesis formulation, causation, and correlation; (4) test of explanation – hypothesis; (5) experimentation of causality, controlled experiments; and (6) fallacies in the name of science.
2. *Seminar on Implementation of the Entrepreneurship Process Model (EPM):* The agenda for the EPM seminar included an overview of six key concepts: What is Entrepreneurship? The entrepreneurship conundrum; the overall EPM; case illustrations, and questions and answers. In general, the essence of entrepreneurship is value creation. While entrepreneurship can be described as a complex social and economic phenomenon, the central aspect is venture and value creation. The entrepreneurship conundrum, however, is that we see entrepreneurship in its success, but need to understand it in its nascency. That is, we need to explore the value and venture creation process at the

beginning. The overall fundamental elements of the EPM directly address this value creation process and include Focus, Engagement, Environment, and the Entrepreneur. These four elements are underscored by the creation and implementation of the value creation/proposition delivered to the customer: (1) *Focus* to make an idea viable by anchoring it on products or services that create or add value to customers, and remains competitive or attractive, durable, and timely. (2) *Engagement* to put together a team to gather the required resources to identify a sound underserved and/or unserved market opportunity that fundable and executable. (3) *Environment* sensitivity for managing and dealing with ambiguity, uncertainty, and other outside forces (e.g., economic, legal, social, environmental, etc.) across multiple situations. (4) *Entrepreneur* driven by applying creativity, and providing leadership to manage the available resources in the most effective manner by communicating/interacting with multiple constituencies (e.g., customers, employees, suppliers, buyers, government, community, etc.) in a constantly changing environment. Because the four elements - Focus, Engagement, Environment, and Entrepreneur - are inter-related the process to implement EPM is iterative. If one element features are varied, it can impact features of one or all of the other elements and ultimately the value proposition.

3. *Seminar on Evaluation Instruments for the Grand Challenge Project (GCP):* To support the Fellows development of the project's assessment and evaluation instruments associated with the GCP, the Fellows attended two evaluation sessions in July and August. As pre-work for the first session, they had three websites to review: (i) Basics of teaching and assessment - <http://www.purdue.edu/cie/teachingtips/index.html>; (ii) Student Outcomes and Performance Indicators - http://www.abet.org/uploadedFiles/Program_Evaluators/Training_Process/program-outcomes-and-performance-indicators.pdf; and (iii) Tool for creating rubrics - <http://rubistar.4teachers.org/index.php>. During the first session, the Fellows received an overview of the similarities of assessment and evaluation, and summative and formative evaluation techniques that can be used to measure student progress and achievement. As part of these discussions, the Fellows learned about Bloom's Taxonomy, matching learning objectives with the GCPs' planned activities, and the basics of instrument development. Two weeks later, the Fellows and Evaluator met again to discuss and modify the assessment instruments created by the Fellows so that they are more pertinent for the GCP. These instruments included: student pre-post assessments, student tracking surveys, rubrics to assess the project presentations and written reports and the Student Feedback Surveys that would be used to evaluate the course. The Fellows, Evaluator and Project Team collaborated to modify and finalize all instruments, as needed, during the semester.

PROGRAM EVALUATION AND RESULTS

To evaluate the ENED 1020 Course development and implementation, we used a mixed methodology that provided data for formative continuous improvement of the project and summative evaluation of the effectiveness of the GCP from the Fellows', faculty's and undergraduate students' perspective. Qualitative interview data was collected from the Fellows, via focus groups, and or, phone interviews. Quantitative data included: Pre-Post Surveys to

assess Fellows' teaching engineering efficacy (Pre-Survey conducted in May 2014 and Post-Survey conducted in December 2014), Fellow's Post-Unit Reflective Surveys, and Undergraduate Student Surveys administered in the ENED 1020 sections after the flipped classroom and at the end of the course. Additionally, similar end of course data were collected from students in two comparison ENED 1020 sections. Due to the major differences in the implementation of the Fellow's GCP and that of the comparison section's Final Student Choice Project, the results from these two student groups are not directly comparable.

As discussed in the Fellow's focus groups later in this section, prior to the 2014 Fall Semester, fellows felt prepared to develop and implement their GCPs. They felt less prepared to discuss and implement the EPM aspects of the project. Specifically, they discussed how all Fellows supported each other in the classrooms and identified the flipped classroom training, and the support they received to develop assessment instruments as the most useful sessions during the summer. At the beginning of the summer, the Fellows reported being very comfortable with their engineering and ERP knowledge and ability to teach these aspects of the projects. They were understandably nervous about how they would be interacting with their section's faculty member and teaching assistants and how effective the CBL, ERP and EPM aspects of their projects would be integrated throughout the entire semester, particularly in a virtual manner between the first week in September, when the CBL process for the GCP project was initiated in a 2-hour lab period and each team identified their "challenge" and "guiding questions," to the third week in November, when each team actually worked on implementing their challenge solution in a 2-hour lab period and make revisions to improve performance, and finally left to prepare their team report and presentation. In between the first week in September and the third week in November, the student teams received input from the Fellows as a response report to their tracking survey after each required class project. Based on the tracking survey results, Fellows met student teams who were not making adequate progress. Other than such interactions, the Fellows did not have any physical evidence of actual progress towards the challenge solution made by a team. These reported perceptions were supported by the results of the Fellows Teaching Engineering Survey to be discussed later in this section.

During the focus group meeting at the end of the semester, the Fellows had mixed reactions to the course and GCP implementation. While they all felt that the CBL, ERP and EPM aspects of the GCP were designed to enhance student learning, the gap between the CBL flipped classroom that set up the GCP project in the first week of September (beginning of fall semester) and the implementation of the GCP in the third week of November (prior to Thanksgiving break) were problematic. In general, the Fellows felt that the students did not connect these two activities, and feel that the tracking surveys were inadequate by themselves to provide the needed continuity. As discussed previously in this paper, the tracking surveys were intended to provide a mechanism for the students to plan the activities they would need to complete the GCP after each required class project and for the Fellows to gauge student team progress and provide feedback to the teams. In practice, the tracking surveys were not consistently completed by students and the majority of the students did not understand why they were doing these surveys, in spite of the fact that completion of the survey was counted for homework grade. It was thought that assigning a homework grade will persuade students to honestly give the information requested and seek help if needed, but apparently the penalty was not significant enough for this

to happen. The fellows also commented on the issues they had communicating with students in the Fellows Reflective Survey:

Introducing the CBL at the beginning of the course then using online tracking surveys after finishing each experiment made it difficult to follow up with the student readiness and making sure that they fully understand the whole project, this was mainly because we were not the instructors of the course and there was very short time to communicate with the students about the GCP since each class was split into three different rooms.

For future implementation of tracking surveys, follow-up with all student groups needs to be built into the instructional timeline. The Fellows recommended that “the fellow or the one in charge of implementing the CBL as a methodology be the instructor of the course or be able to attend all the sessions of the lab and work with students while they conduct their experiments.”

As the Fellows conversation progressed during the focus group, we were able to identify that the Fellow’s relationship with the section’s faculty member contributed greatly to the success of the course. If the Fellow and faculty member worked effectively together, by meeting regularly and supporting each other in the classroom, the GCP was implemented more smoothly. During the focus group, one fellow commented on positive interactions, “I met each week with my faculty instructor, who was also my advisor, and this helped us support the integration of the Grand Challenge Project into the classroom conversations.” On the other hand, another fellow discussed how they did not get the needed support from their faculty, “my faculty did not remind the students about the connections between the Grand Challenge Project with other projects and I did not have time to talk with all students during the laboratory sessions.” When the Fellows and faculty feedback were triangulated, this conclusion was supported. Additionally, Fellow’s organizational and pedagogical skills also contributed greatly to the success of the course. Specifically, if the Fellow was highly organized and demonstrated effective pedagogical skills, the class “went well.” If the instructor was supportive of the Fellow, via class planning and reiterating the importance of completing surveys and planning for the GCP, the Fellow reported an even better experience which was supported by quantitative results of the student feedback surveys, which are discussed in the next paragraph.

The focus group data, related to training effectiveness, was supported by the results of the Fellows’ surveys. Specifically, the Teaching Engineering Efficacy Survey results supported Fellows’ high comfort level with the engineering research process model, “explaining the different elements” and “constructing an activity that mimics all its elements.” Fellows were more comfortable “discussing how criteria affect outcomes of the project.” A fourth item indicated that the Fellows had a higher comfort level “using a variety of assessment strategies.” The most significant pre-post results are shown in **Table 1**. Items that were rated high in Pre- and Post-Surveys indicated that the Fellows were very comfortable (all rated these items 6 out of 6 with a standard deviation of 0) in their knowledge of engineering (“I can stay current in my knowledge of engineering”) and their ability to explain the societal impacts of engineering to these students (“I can explain to non-engineers, K-12 students and beginning undergraduate engineering students how engineers impact the society”). They were also comfortable (mean of 5.67 out of 6 with a standard deviation of 0.577) in their ability to positively promote engineering learning with their students (“I can promote a positive attitude toward engineering learning in my students”). Fifty-one items had higher post means compared to pre means on this teaching engineering efficacy survey. Items that had high gains (gains greater than 1 out of 6

Table 1: Significant Results from Fellow’s Teaching Engineering Efficacy Surveys

Comfortable Rating Items	Pre			Post		
	N	Mean	Std. Dev.	N	Mean	Std. Dev.
Items with Significant Increases Post Mean versus Pre Mean (Paired-sample T-Test at 90% confidence level)						
14. I can explain the different elements of the engineering research process model.	3	3.33	1.528	3	6.00	.000
16. I can construct an engineering research activity which mimics all the elements of the engineering research process model.	3	3.67	1.528	3	5.67	.577
17. I can discuss how given criteria affect the outcome of an engineering research project.	3	4.00	1.000	3	5.33	.577
67. I can use a variety of assessment strategies for teaching engineering using challenge-based learning.	3	3.67	1.155	3	5.00	1.000

Paired Samples Test Results

	Paired Differences					t	df	Sig. (2- tailed)
	Mean	Std. Dev.	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair 14	-2.667	1.528	.882	-6.461	1.128	3.024	2	.094
Pair 16	-2.000	1.000	.577	-4.484	.484	3.464	2	.074
Pair 17	-1.333	.577	.333	-2.768	.101	4.000	2	.057
Pair 67	-1.333	.577	.333	-2.768	.101	4.000	2	.057

points possible, a 16.7% minimum gain) were related to the engineering research process and the entrepreneurial process model. The largest gain was for Fellow’s comfort level explaining the “engineering research model elements and concepts well enough to be able to use it effectively for a classroom project.” The lowest post mean was a gain higher than 1 out of 6 was 4.33, and it was for the question related to time management associated with “the time needed to execute an entrepreneurship process model activity for my class.” There were nineteen survey items that decreased from pre to post. The majority of the items with a mean decrease of 1 or 0.67 out of 6 (or approximately 10-17% of the scale), are related to the Fellows perceived ability to positively encourage or motivate students (see items 75, 76, 54, 74, 56, 52, 53, 59 in **Table 2**). In this same range, three items were related to management of negative student behaviors (see items 79, 80, 81 in **Table 2**). The final item (see item 40 in **Table 2**) with a mean of 0.67 out of 6 (or approximately 10% of the scale), indicated that the Fellows did not feel comfortable “in my knowledge of the entrepreneurship process model.”

At the end of the 2014 Fall Semester, the Fellows completed a reflective survey that elaborated on possible reasons for these quantitative results. Representative voluntary comments when asked about support provided and which workshops or seminars were most useful to their implementation of the GCP, following comments were received from the Fellows regarding the S-STEM Project Team’s supports:

My initial idea for the GCP ... constructing a simple portable ... machine ... the instructor for the section, and given his experience with freshmen students, suggested that we look at [another machine], as the students (mostly in [discipline]) could relate better to it. He helped me a lot with formulating the components and breaking down the project appropriately for the freshmen students.

Table 2: Non-Significant Negatively Trending Results from Fellow’s Teaching Engineering Efficacy Surveys

Comfortable Rating Items	Pre			Post		
	N	Mean	Std. Dev.	N	Mean	Std. Dev.
Items with Lower Post Means versus Pre Means						
75. I can encourage my students to think critically when practicing engineering.	3	5.67	.577	3	4.67	1.155
76. I can encourage my students to interact with each other when participating in engineering activities.	3	5.67	.577	3	4.67	1.155
54. I can motivate students who show low interest in entrepreneurship opportunities.	3	5.00	1.000	3	4.00	1.732
74. I can encourage my students to think creatively during engineering activities and curricular units.	3	5.67	.577	3	5.00	1.000
56. I can increase students' interest in learning how engineering research is conducted, documented and disseminated.	3	5.33	.577	3	4.67	1.155
52. I can motivate students who show low interest in learning engineering.	3	5.00	1.000	3	4.33	1.528
53. I can motivate students who show low interest in engineering research.	3	5.00	1.000	3	4.33	1.528
59. I can adequately assign my students to work at group activities.	3	5.00	1.000	3	4.33	1.528
40. I can stay current in my knowledge of the entrepreneurship process model.	3	4.67	1.528	3	4.00	1.000
79. I can redirect defiant students during engineering lessons.	3	4.33	1.528	3	3.67	2.082
80. I can calm a student who is disruptive or noisy during engineering activities.	3	4.33	1.528	3	3.67	2.082
81. I can get through to students with behavior problems while teaching engineering.	3	3.67	1.155	3	3.00	2.000

The S-STEM Project Team had regular meeting with us during the course of the semester. We discussed each component of our work ... (1) materials to conduct the flipped class effectively (2) feedback from each student tracking survey (3) technique for implementing ERP and EPM correctly. These discussions helped modify the lessons and the unit itself suitably. [Project team members] conducted seminars in the July 2014 to understand EPM and ERP respectively. Both these were very informative session. Towards the end of August, while designing and finalizing the unit plan, we fellows realized that we were not too sure of EPM and were not able to link it completely with our GCPs. [Project team member] was very kind to come again and talk to us individually later to clarify the implementation of EPM and clean it up. He provided some lovely inputs that greatly helped our improve EPM implementation.

Evaluation methods was an area where I have very little experience. [Evaluator] inputs and her sessions with us during summer 2014 were very informative. She was always available to help us out with all our queries while preparing the rubrics and the required surveys for the course.

They helped me improve my flipped class lesson material. They reviewed and helped in preparing the surveys, rubric. They provided me with ideas of how effectively implement the CBL [ERP and EPM models].

They provided me with the appropriate guidance to develop thorough and effective course materials. They gave timely feedback on our progress so that we could make the necessary changes to the implementation.

Regarding the seminars and workshops that were considered both useful, Fellows made following comments:

The teacher who did this workshop [Hand-Warmer CBL implementation] during summer 2014 SIT, conducted the entire CBL (inclusive of all the steps involved) for the SIT teachers. This was a very informative session and helped understand each component of CBL very clearly.

These [evaluation] sessions helped me during creation of rubrics and evaluation methods for the unit. The tracking survey too was created with help. She helped us correctly segregate and plan the tracking surveys too.

ERP and EPM training seminar: helped me understand the models and how to integrate them in CBL Evaluation Session training seminar: I learned the evaluation methods and how to prepare rubric and tracking surveys. Challenge-Based Learning/ Workshop: I learned the methodology and how to implement it in the classroom.

The workshop where we went through the CBL process doing the hand warmer activity was the most useful, as this experience helped us know the right questions to ask to get students through the CBL process, especially if they are unfamiliar with it.

Fellows suggested making following modifications for future training:

I feel that the entire process of creating the CBL units for the freshmen could have been started earlier. May be during May 2014 instead of July-end. This would have given us more time to design the CBL unit. If a small EPM project could be done by the fellows themselves, we could have understood EPM better. We required two rigorous sessions with [project team member] to help us through design of the EPM component. I understand that we were short on time for such activities. But I feel this would have greatly helped ease the process.

The seminars for the fellows where we learned the ERP and EPM were also very helpful. It would have been helpful to have received more lecture on the EPM, as in general the fellows were most confused about it.

Another measure of course effectiveness was the results from the Undergraduate Student Feedback Survey completed at the end of the course. When all sections were combined, students' feedback was low, most questions' mean response were less than 3 on a 4 point scale. But when individual section results are reviewed, the section with a very prepared and organized Fellow who had an excellent working relationship with the section's Faculty had higher student results. The student survey had questions related to several project constructs. The construct with the highest rated construct is "ERP Implementation" (mean of 3.32 out of 4 with a standard deviation of 0.446) which is also the aspect of the project with which the Fellows were most

Table 3: Results for Student Feedback Survey Constructs

Survey Construct	Highest Rated ENED 1020 S-STEM Section (n=58)
	Mean* (Std. Dev.)
CBL Implementation	3.21 (0.416)
EPM Implementation	3.18 (0.560)
ERP Implementation	3.32 (0.446)
Guidance from Faculty	3.19 (0.712)
Guidance from Fellows	2.48 (0.718)
Learning	2.60 (0.747)

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

comfortable. The lowest rating was for the guidance provided by the Fellows (mean of 2.48 out of 4 with a standard deviation of 0.718). As discussed previously, this was also an efficacy area that the Fellows reported a decrease in comfort from the Pre- to Post-Surveys. The highest rated Fellows section Student Feedback results are presented in **Table 3**. As part of the Undergraduate Student Feedback Survey completed at the end of the course, students provided comments describing how completing the Grand Challenge Project helped them learn. Comments included the following:

ERP- It gave me a base line for how to solve a problem, making the presentation allowed me to practice communicating results to others, EPM- taught me a bit on how to market a product.

If you don't get the result the first time try again, iterate. Understand the problem and solve it. Read if there is other technology that solves the problem.

It helped me learn how to develop problem solving skills. It also helped me to work in a group which is helpful in society.

My team worked well. We were able to find a valid solution. I learned more about my major.

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.

Importantly, when students were asked if they knew about the S-STEM Program and if they were interested in applying for an S-STEM scholarship, 34% of the students in the S-STEM sections knew about the program and 89 (45%) were interested in applying for the scholarship. These numbers were much higher than the students in the comparison sections (9% knew about program and 12 (26%) were interested in for the S-STEM scholarship.

CONCLUSIONS AND RECOMMENDATIONS

As discussed in the Evaluation Results section, the Fellow's integration into the ENED 1020 course helped promote the S-STEM Scholarship Program among freshmen, which was the primary goal of the NSF S-STEM project.

The integration of ERP and EPM into the student project was an academically important addition to the course, but the undergraduate students did not fully appreciate the additional work needed to incorporate them into a project presentation and report in their first semester as a college student. It is worth pointing out that the procedures to conduct each of the four required projects and produce the required lab report for each, which they were evaluated upon, was fully prescribed. It is the perception of the S-STEM Project Team that this format gave the feeling to the students that the GCP, which was an open ended project and thus involved much more work, required the students to work by their own time. However, some students recognized that they learnt about ERP and EPM from the GCP experience, which they recognized after making the presentation on the last day and defending their solution to the challenge, as can be seen from student comments presented previously in the Evaluation Results section.

Though there is a heavy investment of **TAs** in executing ENED 1020 (one TA for 2 teams, with 3-5 students per team), their role in conducting the GCP, however, was simply limited to helping students during the execution of GCP and grading of the final GCP team report and presentation using a prescribed rubric. Originally, it was envisioned that the TAs will be an integral component of the implementation of GCP, and will interact with the student teams in a separate class period devoted after each required experimental laboratory project. Special training for the TAs in the CBL, ERP and EPM pedagogies and their integration in GCP was planned. But just before the start of the 2014 Fall Semester, the NSF S-STEM Project Team, who were coordinating the implementation of the GCP, were informed that this was not possible since the TAs for all sections of ENED 1020 were paid hourly for their services and if we required them to devote mentoring time for the GCP then the S-STEM Project will have to pay for this extra time. Since this budget did not exist in the S-STEM Project for this service, their mentoring could not be integrated in the execution of GCP. The only service the TAs provided, was grading the final GCP report along with the fellows, and scoring the final GCP presentation along with the students and fellows. Because of this reason, the S-STEM Project Team had to institute the implementation of the four Tracking Surveys given and analyzed by the fellows after each required experimental laboratory project, with a follow up meeting with student teams that needed some additional guidance on the progress made towards the GCP. It is the perception of the S-STEM Project Team that if the TAs continuous help was available to monitor the progress towards the conduct of the GCP project after each required project, there would have been continuous structured student involvement in the GCP project throughout the semester, as was envisioned.

Fellow, faculty and student evaluation data are consistent and indicate that there were positive and negative aspects of the ENED 1020 GCP implementation. All fellows felt that they were prepared to teach; but after they taught, the Fellows identified that they needed more pedagogical support to motivate and maintain engagement of the undergraduate students. The Fellows and faculty need to closely coordinate with each other in the planning and implementation stages of the GCP. The faculty needs to support the Fellows and work with

them to maintain student engagement and promote steady planning progress so that the GCP is more fully integrated into the ENED 1020 course from the students' perspective.

The S-STEM team believed that the tracking surveys were the most significant part of the implementation process that were put in place to help students identify the resources they need for the GCP from the required labs completed, to seek individual feedback on student team dynamics, to help students plan how to execute the GCP, make students gradually prepare the required documents to present and defend their solution to the GCP, and assess whether students' progress are on target to complete the GCP as planned. The Fellows were instructed to make an effort to meet delinquent teams during following lab time, change the contents of the tracking survey based on the results of the previous one and report to the S-STEM team and course Instructor. By mid-October, one month after the launching of GCP, the Fellows informed the S-STEM team that the majority of the students did not understand the purpose of the Tracking Surveys. The students considered the surveys just like any other assignment given for the course. The S-STEM recommended for the fellows to send an email to the students describing in detail the purpose of the surveys. Fellows tried to meet student groups who were delinquent and reported that students were on track to execute the project as planned. Other than such interactions, the Fellows did not have any physical evidence of actual progress towards the challenge solution made by a team. Apparently, students' progress follow up using the tracking surveys were not pursued by the Fellows as expected. The fact that Fellows found it very difficult to follow up student readiness by using tracking surveys was not brought to the S-STEM Team's attention until the Focus group meeting at the end of the course. For the tracking surveys to be effective, it is recommended that following each required project, the Fellow needs to go to the classroom for 10-20 minutes during the recitation hours and describe the results of prior surveys, ask students how the project they completed relates to their GCP, and what resources are they planning to use. This will enable the students to ask questions and stay on track.

For this type of teaching approach to be successful, the following items were found to be very essential: (a) Fellows preparedness and commitment; (b) smooth and supportive interaction between the Fellow and the Faculty teaching the course; (c) tracking of student progresses in their GCP; and (d) effective utilization of the TAs. The S-STEM team believes that if these conditions are well planned and integrated, the CBL approach can be used as an effective teaching method in the ENED1020 course with the existing resources.

From the survey results and focus group meetings conducted with the Fellows, our approach is found to prepare them for academic career as opposed to the traditional TAs role. The Fellows participated in different trainings to develop their classroom teaching and evaluation skills. They developed unit and activity templates before teaching in the class. This enabled them to prepare in advance and take ownership of the class during the execution of the project. They were observed while teaching and critique was provided to them. Such support and training mechanisms are not available for the traditional TA training, where the TA's role is primarily limited to grading of exams and assisting in the laboratories.

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