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Project-Based Learning in a Multidisciplinary Two-Semester First-Year Experience

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ABSTRACT

Problem-based learning not only provides a platform for students to learn by performing hands-on projects, but also, with proper planning, it helps with development of their collaboration, communication, safety considerations, and critical thinking skills. On the contrary, it involves its own set of drawbacks, including the considerable time, energy, and resources instructors must invest in developing and implementing the course. In this work, we argue that, with proper planning over the span of several semesters, instructors can successfully transform a lecture-based first year course sequence for Chemical and Petroleum engineers' offering. This transformation aims to provide students with the active learning experience in a project-based team environment while significantly reducing the reliance on traditional lectures. At Mississippi State University, the Introduction to Chemical and Petroleum Engineering course (fall semester) and the Analysis course (spring semester) are examples of such an achievement. Beginning in 2006, transformation of the lecture-based Analysis course began with a modest transition to allow students learn STEM concepts through hands-on scientific team experimentation. Year-by-year advancements have transformed the course to a predominantly project-based learning approach with minimal traditional lectures. Through such transformations, this course meets all ABET student outcomes criteria 1 through 7, as well as, the 6 key characteristics of a successful problem-based learning experience provided by HQPBL organization. With the re-establishment of the Petroleum engineering bachelor's degree program in 2015, Petroleum engineering freshmen joined the Analysis course. In fall 2023, Chemical and Petroleum engineering freshmen were combined for an Introduction to Chemical and Petroleum Engineering course, as well. The aim was to offer a comprehensive first-year experience blending project-based learning with additional content delivered through lectures. This study highlights the successful transformation of a traditional engineering course into an experiential immersive learning experience. It demonstrates the positive impact on student engagement, skill development, and understanding of course materials. The study also emphasizes the importance of continuous assessment and improvement to ensure the effectiveness of project-based learning approaches.

1. INTRODUCTION

Project-Based Learning (PBL), defined as the exploration and gain of new knowledge through hands-on projects under the guidance of an instructor(s), originated in medical sciences at McMaster university in Ontario, Canada, in 1965 [1, 2]. PBL and Experiential Immersive Learning (EIL) are often used interchangeably. These pedagogical approaches are rooted in constructivism, an educational theory emphasizing the use of learners' experiences and interactions with the outside world to learn a subject [3, 4].

In higher education, active learning methods (e.g. PBL and EIL) may be utilized in lieu of or accompanying more passive, traditional education methods such as traditional lectures directing knowledge flow from the instructor to the learner [5, 6]. While the traditional lecture approach has evolved to be the predominant mode of instruction, it is well known that this approach lacks essential components for optimal learning in today's education and professional environments [6]. Hence, teaching methods such as PBL have gained positive attention among researchers and educators [1-2, 6-25].

There are varieties of PBL practices depending on cultural and educational backgrounds of a teaching entity [1, 2, 26]. Servant-Miklos [26] reports on the reinvention of PBL by Masstricht University in Netherlands. For the field of medical education, they argued that "Even though PBL was first conceived at McMaster, the innovations in PBL developed at Maastricht are sufficiently radical and sufficiently influential to consider the development of PBL at Maastricht as an educational revolution in its own right". Graaf and Kolmos [2] compared McMaster-Maastricht PBL model to the Aalborg University (in Denmark) model while elaborating on the Dutch and Danish approaches to PBL. All these approaches are varieties of the original McMaster University's approach to PBL.

It is worth noting that although PBL has proven to be an effective and authentic instruction strategy, it is not a straightforward or easy method to implement. Some of the difficulties associated with PBL include a considerable investment in time for planning and developing appropriate teaching material accompanied by an equally demanding investment in energy and financial investment to deliver a PBL experience of sufficient rigor to meet the criteria of the educational approach [11, 20, 27].

Project-based learning must meet a definitive set of criteria [28, 29, 30, 31]. Considerable debate in the literature has grappled with the criteria which truly constitutes a PBL experience. Thomas [28] proposed five criteria for a PBL experience: "Centrality", "Driving Question", "Constructive Investigations", "Autonomy", and "Realism". Based on these criteria, projects need to be the essential part of the curriculum and students need to achieve the course learning objectives by doing the projects. In addition, projects need to relate to the learning objectives by engaging students with the principles of a discipline. They should also be realistic, "giving students a feeling of authenticity", while engaging them in a "constructive investigation" with some level of difficulty [28]. Other efforts have been made to define the main criteria for a PBL experience, as well. The High-Quality Project Based Learning (HQPBL) project, supported by the Project Management Institute Educational Foundation [32] and the William and Flora Hewlett Foundation [33] is another such effort. According to the guidelines presented by HQPBL [29], a high-quality project-based learning experience must contain at least these 6 key characteristics: "Intellectual Challenges and Accomplishments", "Authenticity", "Public Product", "Collaboration", "Project Management", and "Reflection". Some of the criteria proposed by HQPBL are similar to the ones proposed by Thomas [28] and others [30, 31]. Based on HQPBL, a PBL experience requires multiple-answer, complex problems that engage students in critical thinking. The problems need to be authentic, meaning they could have a real-life impact on people and communities outside the school setting. Students need to share the results of their projects with their peers and present them to the public. Public may include experts and people outside the classroom. Teamwork skills are a necessity in a professional workplace; therefore, projects should be collaborative. Collaboration is not only limited to students' team members in class. They may also collaborate with individuals outside school, such as experts in the field or students in other schools, etc. In addition, PBL should be designed such that students may learn project management skills, such as time, task, and resources management. Finally, they need to receive feedback and learn how to utilize feedback for the improvement of their work. Students should also acquire skills to self-access the quality of their work. This helps students in retaining the acquired knowledge and produce better outcomes [29].

To implement PBL more efficiently, SrinivasaPai et al [34] proposed guidelines based on feedback from faculty and students: 1) PBL cannot be implemented for all courses, 2) Since PBL requires more work and problems could be more challenging, students may reject the adoption of PBL; hence the need for making them understand the benefits of this approach, 3) regular feedback from students is a requirement to access the success of a PBL approach, 4) the design of problems could be challenging, 5) Instructors must be available to students for help, 6) a group of 5 students is ideal and each should have an active role, 7) the progress of student teams need to be monitored constantly, etc.

PBL has been an essential agent of more efficient education in Engineering, as well. Among the research on this subject, some are more focused on a single course, while some have a broader impact on the curriculum [12-15, 17-25, 27, 35]. There are also research and reports on instructor training and teaching enhancement [16] showing the special attention to PBL given by the Engineering education community. Woods [12] presented results of a longitudinal study in Chemical Engineering classes over 13 years pointing to the effectiveness of switching to a new curriculum containing PBL components with fewer courses. The mismatch between the required skills by the industry and students’ skills has been one of the main driving forces for such a transition to a PBL-based curriculum. South Dakota School of Mines and Engineering initiated the implementation of PBL concepts across courses in general engineering, mathematics, science and English [17]. They presented a model for a PBL-focused first-year curriculum, while pointing at the fact that most universities (at that time) were not suitably structured to implement PBL practices straightforwardly; and noted that it will take some effort to add PBL practices to their course material and curriculum activities. They also pointed out that students can handle about 2 projects per semester efficiently and after that they might lose the ability to connect project objectives with course material [17]. Courses such as capstone design for senior Engineering students should inherently follow a PBL format; however, some instructors are not trained on implementing and merging PBL criteria with the design course material. Mclntyre [22] points at the necessity of such trainings for design course instructors. Havener and Dull [23] and Striegel and Rover [18] emphasize on the importance of designing a website for a PBL course delivery. We argue that a website may be replaced with Canvas or Blackboard learning management platforms which are currently widely utilized in Universities across the nation.

Most studies on BPL show, not only the superiority of this approach in comparison to more traditional lecture-based teaching philosophies, but also show that students support and prefer PBL. For example, Nasr and Ramadan [27] developed teaching modules for topics in thermodynamics at Kettering University and concluded that students prefer the PBL approach over lecture-based classes. They also point at some possible challenges, among which included the need for instructors to have some practical experience to design effective problems, noting that PBL consumes much more time from the instructor than traditional approaches, recognizing that the creation of good problems is challenging, and that proper assessment brings its own set of challenges. Regarding time, Bower et al. [15] explored the possibility of applying PBL effectively by a single instructor and showed that PBL can effectively be applied to a Civil Engineering course by a single instructor.

PBL has proven to be a very effective teaching strategy in multidisciplinary and interdisciplinary fields too [13, 20]. Wood [13] reports on creation of an interdisciplinary PBL engineering technology course for freshman and part of sophomore years. Arena et al. [20] report on challenges associated with implementing PBL in a multidisciplinary field such as Biomedical Engineering. They mention that PBL requires a “broad range of expertise and significant time investment” and if the number of instructors is limited and there is a large number of students, implementing PBL is going to be even more challenging. They proposed rotating faculty facilitators (usually graduate students under a teaching assistantship) to address this problem.

The current two-course, freshman year sequence for Chemical and Petroleum Engineering students at Mississippi State University has evolved over 19 years of iterative trials with extensive student feedback to produce a multi-faceted pedagogical approach using some traditional lecture to deliver introductory or background content efficiently coupled with collaborative learning and PBL as the primary "engine" for achieving the course learning objectives.

2. BACKGROUND

Originally structured as an introductory chemical engineering course sequence, the course content was delivered solely by lecture and focused on the overview of the chemical engineering field and traditional problem-solving through instruction, assigned homework, and paper testing. Course modification began in year 2006 with changes in the spring-semester to the three credit hour CHE 2213 Analysis course. To this end, projects rooted in use of the LEGO NXT robotics platform were introduced to demonstrate simple engineering processes, such as tank level control (Figure 1) [35]. Unlike Analysis course, the fall term introductory course (CHE 1101—a one semester credit hour lecture) retained the traditional approach at that time.

Figure 1. Tank level control using LEGO NXT robotics components [35].

Students' response was positive (assessed via surveys which report on the increased students' level of comfort, confidence, and efficacy for each ABET criteria) and additional projects were developed. These projects were tied to the classification of historical industrial practice of chemical engineers along the line of Unit Operations. An impetus for this approach was tied to the historical strength of our chemical engineering program in co-operative education and internships with regional industries (e.g. chemical process industries, pulp & paper, and oil and gas). While our undergraduate chemical engineering program does not require a work experience through co-op or internships, 60% of our graduates have such work experience (data spanning 20+ years).

In 2015, the Petroleum Engineering (PTE) Bachelor's degree program was reintroduce to our College of Engineering and was housed within the School of Chemical Engineering. CHE 2213 Analysis was incorporated into the PTE curriculum from the outset. By the 2023-24 academic year, both chemical and petroleum engineering freshmen have been combined into a common freshman year, which includes PBL elements. In addition, the first year course (CHE-PTE 1101) has been modified to also introduce students to PBL. This change provided a means for building student awareness of the PBL approach, team building activities, and an improved student preparation for the PBL-emphasis of the spring term.

Described as *Team Challenges*, projects introduced to this two-course sequence have included such topics as:

- Rates of heat transfer through various metals
- Convective heat transfer in solar ovens
- Tank level control
- Double-pipe heat exchanger performance
- Calibration of a flow sensor
- Centrifugal pump study
- Centrifugal pump impeller design, 3D printing & testing
- Energy conversion through use of a Wind Turbine
- pH control for a water treatment plant
- Flow through porous media
- Enhanced oil recovery (under development)

The portfolio of *Team Challenges* and regular improvements in each project provides an inventory of projects to select from each academic year. This keeps student's experiences fresh and interesting, allaying any concerns that material from year to year is transmitted between students at different classifications

A laboratory fee associated with the CHE 2213 Analysis course has provided support for project materials. The success of the PBL approach has resulted in the evolution of the CHE 2213 Analysis course for delivery as a dual enrollment course offered at multiple high schools in Jackson and Vicksburg Mississippi, as well.

As these courses evolved, so have the learning objectives. Table 1 outlines the current learning objectives for both courses in the first year sequence.

Table 1. Learning Objectives for CHE/PTE 1101 and CHE 2213

1. Apply basic knowledge of chemical and petroleum engineering fundamentals to setup and/or design projects, conduct experiments, as well as analyze and interpret data.
2. Function in teams, in various roles, with team members of diverse personal backgrounds to accomplish assignments.
3. Identify environmental, health, and safety issues related to industry practice associated with chemicals processing and production, pulp and paper, oil and gas, and many other industries open to chemical and petroleum engineers.
4. Recognize the contributions of others in group problem solving sessions, technical reports, oral presentations, and other formats.
5. Recognize the need for competent performance throughout all phases of work.
6. Recognize the need for an ability to engage in lifelong learning in engineering safety and engineering design/experimentation.
7. Be aware of contemporary issues in an industry environment (e.g. global awareness and social impact).
8. Use appropriate technology to record, organize, manipulate, analyze, and present experimental data and results in tabular and graphical formats and to write and orally present technical reports to a variety of audiences.

For each *Team Challenge* report, student teams provide an outcomes assessment tied to the learning objectives (Table 2).

Table 2. Team Outcomes Assessment

Describe the degree to which this *Team Challenge* enabled your team to…

1. Apply the principles of engineering to solve problems.
2. Apply the engineering design cycle [This is a systematic model presented to the student teams with each *Team Challenge*] to produce solutions while considering outside factors including:
    - Environmental
    - Economic
    - Safety
    - Public Health
    - Social
3. Communicate with a larger audience.
4. Address ethical and professional responsibilities
5. Grow as a Team

3. PROBLEM-BASED LEARNING IMPLEMENTATION

In retrospect, the evolution of the first year experience for our students has developed along the precepts outlined in the *Framework for High Quality Project Based Learning* [29]. As such the remaining discussion will track six criteria presented by the HQPBL Organization.

3.1. Intellectual Challenge and Accomplishment

The first criterion for PBL established in the HQPBL framework is *Intellectual Challenge & Accomplishment.* Recognizing the significant transition freshmen are making from their high school environment to the university campus life, our introductory course focuses on several foundational values. We believe these values encompass elements of the intellectual challenge and accomplishment inherent to undertaking a successful study in engineering:

- Establishment of a supportive student network for the engineering education endeavor
- Filtering the "noise" associated with the inaugural entrance to university campus life (e.g. the almost overwhelming opportunities to join numerous organizations and establish a new and vibrant social network and gauging competing interests with the demands of a rigorous engineering curriculum)
- Developing a "professional" approach to personal development for interactions with a new, and somewhat daunting, audience (i.e. faculty members, academic advisor, alumni and industry representatives providing mentoring and co-op/internship opportunities)

Each of these values must be adopted and adapted by the freshman engineering student to acquire the skills necessary for success in a highly competitive environment. To that end, the authors have structured the first semester course to introduce and begin establishing these values among students. This is done within the context of a systematic approach to inculcate the practices necessary for student success within a PBL approach. The CHE/PTE 1101 course opens with a brief overview of the broad range of professional practices in chemical and petroleum engineering fields followed by series of simple STEM based problems designed to quickly foster student interactions in an informal, collaborative working environment. This approach, established within the first few weeks of the fall semester, has proven to facilitate students quickly build working relationships with one another—a primary objective and a key to future persistence in engineering. Anecdotally, upper level students have reported over the years the initial hesitancy they felt with this approach but the surge of confidence gained by "jumping off the high dive" at the outset. While coaching by the instructors emphasizes that students have the necessary experience from high school in approaching these problems (i.e. using basic mathematics, chemistry, etc.), the open-ended nature of the approach (i.e. assigning a wide range of problems for in-class work while not covering specific topics in a lecture format beforehand) introduces an initial "fear factor". Instructors work to coach and reassure the students that they can do the work and that, as future engineers, each day brings unforeseen and new intellectual and technical challenges.

Student comments have ranged from, "I was initially scared, but I gained confidence as I started working with others in the class" to "I see what you are doing 'doc' and I realize this really isn't what I want to study". In the authors' opinions, both responses indicate success—on one hand, a student has seen the process of engineering problem solving and realized that they CAN do it (i.e. a qualitative boost in self-efficacy) and, on the other hand, a student has been saved significant time and resources by getting a crystallized view of engineering problem solving and choosing an alternative educational track early. For the second student, we have often seen them move to either a different engineering major or another STEM field with great success (one author having taught in engineering for 34+ years).

Team building exercises in the first course are followed by formally establishing teams. Typically teams of 4 members are established, though 3-5 members have proven successful where natural friendships were formed during the initial collaborative learning activities. Generally, teams are established through a process of self-selection. Time has repeatedly demonstrated that this process succeeds both in the establishment of teams among members who have built good working relationships, while also achieving solid diversification among the class members. Strong coaching by the Instructors has facilitated team formation and success across the range of student “credentials and preparation” from a variety of high school backgrounds.

Teams are then assigned *Team Challenges*, which include two projects for the fall term. For example, for fall 2023, the first *Challenge* tasked student teams with analysis of a simple experiment to examine flow through porous media (a phenomenon important to both chemical and petroleum engineering practices). Student teams performed the study and were challenged to evaluate the key variables associated with the phenomenon and the possible relationships among the variables. Akin to the concept of “dimensional analysis”, this project aims to build students’ knowledge of fundamental engineering dimensions and begin to formulate an idea of the importance of understanding the relationship between engineering variables, physical measurements, and evaluation of engineering data to assess a process. In the second *Challenge*, student teams were tasked with studying the rate of heat transfer through different metals. Figure 2 illustrates the setup for this *Team Challenge.*

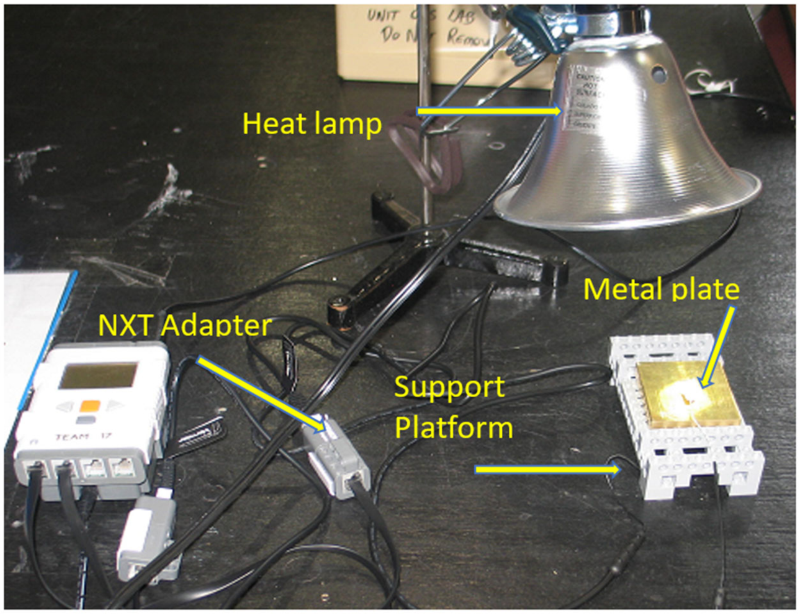

Figure 2. Rates of heat transfer through metal plates

Each *Team Challenge* is structured to engage students in activities directed at achieving learning objectives through each phase of the project. Table 3 illustrates the general format of each *Team Challenge.*

Table 3. General format for a *Team Challenge*

1. Safety First—this section introduces student teams to any potential safety hazards with specific instructions for performing the project safely. A *Job Safety Analysis (JSA)* form is required for all projects which engages students in a survey of the work environment for identifying safety equipment (e.g. safety showers, first aid cabinet, chemical spill kit, etc.) and any potential safety issues. A JSA is submitted with each *Team Challenge* report.
2. Background—a simplified theoretical background is presented to highlight the key concepts being studied and relevance to the broader practice of chemical and petroleum engineering
3. Outcomes Assessment & Learning Objectives—key outcomes and learning objectives are addressed by a series of statements and questions for guiding students in self-assessment at the conclusion of the project.
4. *Team Member Roles and Final Report format*—each team member has a specific role (some are shared) for conducting the project, for evaluating the results, and for specific report sections. Team roles are rotated among each member over the course of successive *Team Challenges* throughout the freshman year. Experience has shown that most teams are highly functional and readily share each role to accomplish the projects. Where teams have evidenced dysfunction, strong involvement and coaching by the instructors has proven to circumvent failure and the resulting discouragement of individual students.
5. Equipment Description and Procedures—each *Team Challenge* handout is richly detailed and visually engaging to guide students through the entire project.
6. Data management—the first year experience builds students' skill in using Microsoft Excel for data management and analysis. A few basic tools are illustrated over the course of the freshman year and students use these tools for data analysis (e.g. graphical representations and statistical tools such as ANOVA).

3.2. Authenticity

The HQPBL framework highlights *authenticity* as a second key criterion. Defined as "engaging students in projects that are meaningful and relevant to their culture, their lives, and their future", the PBL approach of our first year is directed specifically at the process of exploring the fundamental knowledge and skills associated with the study of engineering (with applications from chemical and petroleum engineering). Figure 3 illustrates a range of topics covered by *Team Challenges.* Emphasis is placed on engaging student teams in work that connects to the broader world of engineering practice and its relevance to building and maintaining a technologically-advanced society in an ever-changing world with inherent expectations that engineering will be conducted within the needs for sustainability.

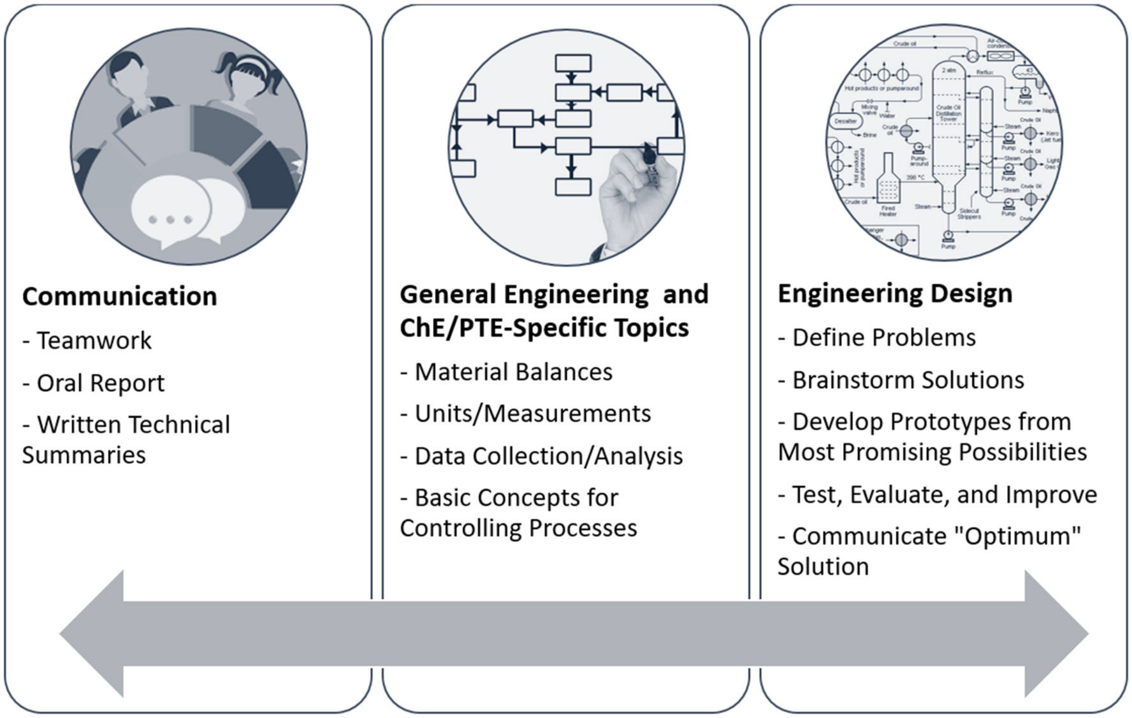

Figure 3. Range of topics covered by team challenges

3.3. Public Product

HQPBL describes the criterion *Public Product* as an approach whereby “students’ work is publicly displayed, discussed and critiqued”.

Each year, representatives from our industrial advisory board engage with our freshman class for the purpose of assessing students’ perceptions of their first year experience by examining their projects and providing them with feedback. Many of the advisory board members are alumni with long-standing activities in recruiting and hiring. This interaction is typically conducted through a project poster symposium, where advisory board members rotate among all teams who describe their projects in summary. This is then followed by general questioning and feedback from the board members. This has proven to be a highlight for both the freshmen and our advisory board—providing a valuable contribution to all stakeholders while also providing invaluable feedback for program assessment.

In addition to poster sessions, feedback from company representatives conducting interviews for cooperative education and internship positions consistently highlights students referring to first-year *Team Challenge* experiences, often during their sophomore year. This underscores the tangible value of the PBL approach in preparing students for real-world applications even in the first year of their studies.

3.4. Collaboration

The fourth criterion presented by HQPBL as necessary for successful project based learning is *Collaboration*. As illustrated in the aforementioned descriptions of our *Team Challenges*, the very nature of these projects relies upon a strong sense of collaboration among student team members and the coaching role of the instructors. Figure 4 shows a commonly used engineering design cycle employed within the *Team Challenge* structure. Students are coached to iteratively improve their project work through multiple trials via assessment and evaluation.

Through years of successive trials with various *Team Challenge* projects, the authors have observed that the relative success of student teams in tracking with the full cycle of the engineering design process (Figure 4) is strongly dependent upon the complexity of the project itself. For instance, consider the Team Challenge titled "Measurement of Porosity." In this activity, students are tasked with employing their creativity and judgment to build a porous medium and determine its porosity. Equipped with graduated beakers, glass beads, a caliper, and a specified volume of water, teams start the challenge. Their objective is to fill one of the beakers with glass beads and measure its porosity. To achieve this, they must envision how this setup mirrors the characteristics of a rock, including its pore and total volumes. Careful planning is required to decide when to fill the beaker with water and when to measure specific volumes. Given the known approximate porosity of a random packing of spheres, teams can compare their results and assess their work for potential improvements.

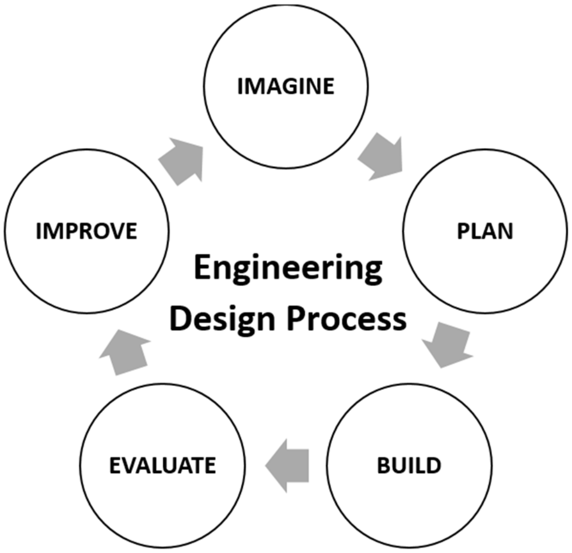

Figure 4. The Engineering Design Cycle

The strength of collaboration becomes evident over the course of the freshman year with the completion of each successive *Team Challenge*. Pre- and post-project surveys have shown improvements in student self-efficacy and their sense of collaboration in teams (Figure 5). Surveys are designed to include some of the ABET criteria 1-7 [36]. For example, Figure 5 shows the results of pre- and post-challenge administered in a recent CHE/PTE 1101 offering, which includes 5 ABET criteria. Each student reports their level of comfort, confidence, and efficacy for each criteria by providing a number between 1 and 5 (1: not confident at all and 5: completely confident). The average scores are then calculated as the final result for each criteria. The results show improvement in all 5 ABET metrics of the surveys. Included metrics are [36]:

A) "Ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science and mathematics."

B) “Ability to communicate effectively with a range of audiences (in this case your fellow team members and your instructors)”
C) “Ability to function effectively on a team whose members together provide leadership, create a collaborative & inclusive environment, establish goals, plan tasks and meet objectives.”
D) “Ability to develop & conduct appropriate experimentation, analyze and interpret data and use engineering judgment to draw conclusions”
E) “Ability to acquire & apply new knowledge as needed using appropriate learning strategies.”

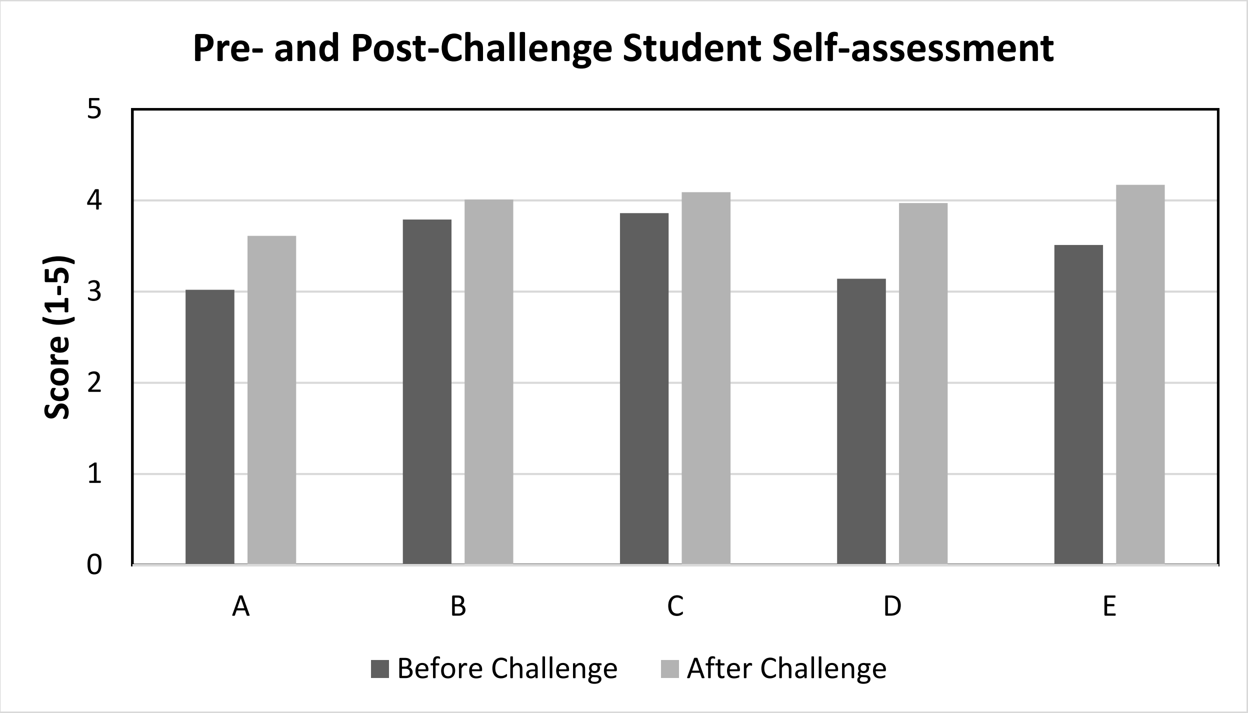

Figure 5. Results of pre- and post- challenge student self-assessment for a recent offering of CHE/PTE 1101 (A, B, C, D, and E refer to ABET criteria presented in this section)

In Criterion “A”, students inherently engage in identifying, formulating, and solving engineering problems that they perceive as “complex” during their initial encounter. Here, the 0.6 point increase in cumulative self-assessment by the students is deemed significant. On the other hand, survey results for criterion “B” show a modest increase of 0.22 points. Since student teams comprise a mix of mostly chemical engineering and significantly fewer petroleum engineering majors, their perceptions of communication with a range of audiences is limited. The initial rating of 3.8 is the second highest of cumulative pre-challenge self-assessment of any of the five criteria surveyed. This indicates that students entered the *Team Challenge* with a strong personal sense of their ability to communicate with a range of audiences. During the first year, individual students are navigating the challenges of forming working groups across a broad spectrum of social and academic encounters, both inside and outside of the classroom/laboratory.

The broad range of experiences for individual students is observed in our freshman teams—teams demonstrate rapid acclimation to the required skills for success (e.g. strong communication, regular meetings outside of class to work on data management and reporting, clear division of tasks, etc.). This is reflected in high ratings both pre- and post- *Team Challenge* for Criterion “C”. The most significant change between pre- and post- self-assessment was observed for Criterion “D” (pre- and post-challenge averages of 3.1 and 4, respectively). Anecdotal observations and student feedback suggest that this learning approach is novel to the majority of students, and they feel most capable of addressing these challenges once they have been exposed to them and actively engaged in the process.

Finally, before introducing the *Team Challenges* to students, significant time is devoted to introducing engineering problem-solving, which involves applying STEM concepts to practical applications. However, post-Challenge survey results of criterion “E” indicate improvement, suggesting that these challenges assist students in acquiring deeper knowledge by revisiting introductory concepts and implementing them into their projects.

The results of surveys has been anecdotally observed to often continue throughout the students’ entire undergraduate study (as observed by one author who also directs both junior and senior undergraduate Unit Operations laboratories in chemical engineering). Often, teams formed by students in the freshman year will remain intact in later courses where self-selection of teams is practiced.

3.5. Project Management

The fifth criterion highlighted by HQPBL as necessary for successful project-based learning is *Project Management*, wherein students “use a project management process that enables them to proceed effectively from project initiation to completion”. As mentioned in reference to Collaboration, the emphasis on the Engineering Design Process and guidelines for team roles and responsibilities presented with each *Team Challenge* has proven to offer students a framework for individual teams setting and achieving project milestones. Following the COVID pandemic and its impacts on education, one benefit that emerged in student collaboration and management was a significant increase in student proficiency with using online meeting tools and shared document authoring. For most of our projects, the actual laboratory work to set up the equipment, design the experiments, and acquire the experimental data is significantly less time consuming than the subsequent data management, analysis, and reporting. While students regularly report difficulty in finding times for everyone to meet face-to-face, the ability of students to meet and share work online has resulted in improved project management with accompanying improvements in *Team Challenge* products (i.e. Team written reports and Excel spreadsheet reports).

3.6. Reflection

The sixth and final criterion advocated by HQPBL as an indicator for successful project based learning is *Reflection*—the process of students reflecting on their work and their learning throughout the project.

The reporting mechanisms for our *Team Challenge* projects, particularly the required Outcomes Assessment for each report (Table 2) has served to guide students through the reflection process for multiple facets of their PBL experience. Coupled with multiple surveys and informal discussions over the course of each semester, students have shown great freedom in expressing their growth in facing the opportunities and challenges of pursuing rigorous career preparation through engineering study.

4. SUMMARY AND CONCLUSIONS

With 19 years of course evolution leading to the current multi-disciplinary first year experience for chemical and petroleum engineering freshmen, the authors believe that the project-based-learning approach has provided our students with an experience that accomplishes multiple goals:

- Provides an atmosphere for building strong working relationships with fellow students often carrying well beyond the freshman year
- Affirms (or guides) students in their efforts to define their pursuit of a major and personal career goals
- Enables students to acquire skills that are readily communicable to prospective employers for co-operative education or internship opportunities
- Builds professional skills for interacting with a variety of audiences in highly technical fields
- Engages students in a survey of advanced engineering topics from a practical standpoint enabling them to anchor generalized engineering concepts to highly visual applications.

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