Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
Paper ID #48019

WIP: Evaluating the Impact of Multi-Disciplinary Projects on Students' Engineering Discipline Choices

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Outside of his academic responsibilities, Daniel Raja is passionate about community service and often participates in initiatives that promote STEM education among young students. His dedication to both his profession and his community makes him a respected and valued member of Greenville University.

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The Need

The dynamic and multifaceted nature of today's engineering profession necessitates a holistic and integrative approach to education, particularly at the first-year level. First-year engineering students often encounter the daunting task of selecting a specific branch of engineering without a comprehensive understanding of the diverse fields and the unique skill sets they require. This lack of exposure can lead to uninformed decisions, potentially affecting students' academic and professional trajectories. To address this critical issue, we offer a unified introductory course designed to provide a broad overview of the various engineering disciplines. This course aims to equip students with essential hard skills specific to electrical, mechanical, and computer engineering fields, while simultaneously fostering the development of crucial soft skills like teamwork, oral and written communication, and the engineering design process that are common to all fields of engineering.

The Proposal

A course that offers first-year engineering students a panoramic view of the engineering landscape by introducing students to the fundamental principles and practices of multiple engineering branches. Additionally, the course encourages and facilitates students to gauge the job prospects of their intended/desired field of engineering study using market trends and databases, thus enabling students to make more informed decisions about their academic and professional paths. This exposure is invaluable and crucial to students in helping them identify their interests and strengths early in their academic journey.

In addition to the technical (hard) skills, the course strongly emphases the development of soft skills that are universally applicable across all engineering disciplines. Teamwork, for example, is a critical component of engineering practice, as most projects require collaboration among professionals from various fields. Through group projects and collaborative assignments, students will learn to work effectively in teams, leveraging diverse perspectives to solve complex-to-them problems. Similarly, the course will focus on enhancing students' communication skills, both oral and written. By engaging in presentations, report writing, and peer reviews, students will develop the ability to convey technical information in a clear and concise manner to technical as well as non-technical audiences.

Furthermore, the course introduces students to the engineering design process, a systematic approach to problem-solving by eliminating uncertainties/unknowns, is fundamental and crucial to all engineering disciplines. Students are provided multiple opportunities to brainstorm solutions, create prototypes, and test their designs, iterating as necessary to achieve results.

Self-efficacy, motivation, and agency are essential components for effective student learning and academic success. Self-efficacy, described as an individual's belief in their ability to succeed in specific tasks, can significantly influence motivation and perseverance. Motivation, which drives individuals to engage in activities such as learning, is crucial for achieving success in engineering education. According to Self-Determination Theory, motivation can be derived from external rewards (extrinsic) or internal satisfaction and interest (intrinsic). This theory emphasizes the importance of autonomy, competence, and relatedness in fostering intrinsic motivation. Student agency, the capacity to take control of one's own learning, is closely linked to both self-efficacy and motivation. [1, 2]. Research shows that students with high levels of self-efficacy are more likely to be motivated internally and show strong agency. This has been shown to lead to better academic outcomes [3]. Therefore, effective instructional practices that can develop these characteristics can improve the outcomes for many students.

One such instructional practice is Project-Based Learning (PBL) which has long been utilized. This practice, based on Constructivist Learning Theory [4–6] and Experiential Learning Theory [7], emphasizes the role of active learning using hands-on projects to build the necessary skills engineering requires. Recently it has become quite popular in education because it helps to foster internal motivations for students by creating engaging, and relevant projects that can pique student interest. Motivation is further promoted by the collaborative learning process which enhances peer interaction and support structures for students. Previous research has shown that PBL can improve feelings of self-efficacy [8–12], student motivation [13, 14], and student agency [10, 13, 15]. Therefore, for educators aiming to enhance student engagement and achievement, PBL is an appropriate instructional practice.

The integrative approach of this course aligns with the evolving needs of the engineering profession, which increasingly values interdisciplinary knowledge and collaborative competencies. As engineering challenges become more complex and global in nature, the ability to work across disciplines and communicate effectively with diverse teams becomes ever more important.

In this paper, the implementation of a unified introductory course for first-year engineering students is discussed along with students perceived outcomes. It is to be noted here that this is an ongoing research.

Outline of the Course

A 3-credit course that meets three times a week for fifty minutes is best to deliver the content of this course. The schedule for this course is provided in Table 1. The first six weeks are a combination of chalk talk, peer discussions, in-class assignments, and homework assignments. The remaining nine weeks involve projects. The first project that the students work on is the tower building project. A total of three class periods is reserved for this project. The physical building of the tower is one class period. The remaining two class periods are utilized to compile the necessary reports and documentations. Students work on the bridge building project during weeks eight and nine. A total of six class periods are reserved for this project. Basic introduction to force calculation is provided along with safety demonstration and proper handling of power tools. Students get four class periods to build the bridge and one to compile the necessary documents. The remaining one class period is used to test and present their design, lessons learned, Gantt

Chart, Responsibility Assignment Matrix, among other documentation. During weeks twelve and thirteen, students work on the digital circuit projects. A total of six class periods are reserved for this project as well. During the first two class periods, an introduction to semiconductors, transistors, and digital logic is given, along with Boolean Algebra, truth-tables, and K-Map. Students work on building the circuits in the remaining four class periods. The robotics project is relatively more complex and requires nine class periods. Students are introduced to computer programming via the Arduino IDE. Instructions pertaining to specific topics related to digital input/output, analog input, analog-to-digital conversion, servo-motors are provided along with accompanying circuits before the project is assigned. The instructions typically take about two class periods, students are given the six class periods to work on the project and the last class period is reserved for presentation and testing. During the last week of classes, students are encouraged to reflect on their calling to be an engineer and their thoughts are discussed in a group discussion setting. The feedback of the course is collected and recorded using various tools.

Table 1: Course Schedule of the Unified Introductory Course

Week 1	Making the Transition from High School to College
Week 2	Getting Involved with an Engineering Organization
Week 3	What is Engineering?
Week 4	Engineering Disciplines
Week 5	Engineering Design Process
Week 6	Engineering Code of Ethics
Week 7	Tower Building Project
Week 8	Bridge Building Project
Week 9	Bridge Building Project (contd.)
Week 10	Digital Circuits Project
Week 11	Digital Circuits Project (contd.)
Week 12	Robotics Project
Week 13	Robotics Project (contd.)
Week 14	Robotics Project (contd.)
Week 15	Thanksgiving Break (No Classes.)
Week 16	Self-Reflection and Final Thoughts

Details of the Projects

1. **Tower Building Project:** This project is designed to help students understand basic principles of structural engineering, teamwork, and creativity. The objective is to design and construct the tallest and most stable tower possible using only the materials provided. The main caveat is that students *cannot* share their ideas by talking or writing. They can only draw their design and thoughts and share it with the group on paper. Specific requirements and thresholds are set for the tower to meet for it to be considered a success. Deliverables include an individual reflection report documenting the design process, tasks assigned, design evolution, and the ease or difficulty of communicating without written and verbal communication. Students are instructed to adhere to a specific writing style like the

Chicago manual. The assessment criteria for this project include measuring the height of the tower, ensuring it stands independently for at least thirty seconds when subjected to wind from a blow dryer to test stability, and evaluating the documentation of the design process and division of labor. Additionally, teamwork is assessed using a team member evaluation form. Students are instructed to complete the form without discussion with their group-mates. This project gives students the opportunity to work with the Chicago style and introduces them to new concepts such as the Responsibility Assignment Matrix (RAM). Students are also provided the opportunity to contemplate the need for engineering graphics. This project prepares students for a future in civil and structural engineering.

2. **Truss Bridge Project:** This project involves designing and constructing a bridge to span a finite gap, capable of supporting a significant mass as it crosses the bridge using the materials provided. Students must deliver a safe and stable bridge, a detailed blueprint of the design, a cost estimate and actual cost, a list of tasks performed by each team member, and a timeline of the design and building process. Assessment criteria include the bridge's stability, safety, and usability, the accuracy and detail of the blueprint, the cost-effectiveness of the design, the clarity of the task list and timeline, and the quality of the final presentation. This project offers students the opportunity to work with handheld power tools, with instructions provided for safe use. Additionally, students gain experience with RAM and the Chicago style, and are introduced to Gantt charts, force analysis, and labor and material cost estimation and calculation. Teamwork is evaluated using a team member evaluation form, ensuring that each member's contribution is recognized and assessed. The project also emphasizes the importance of effective communication and collaboration within the team, as well as the application of theoretical knowledge to practical challenges. By engaging in this project, students develop critical thinking and problem-solving skills, gain hands-on experience in engineering design, and learn to navigate the complexities of project management. This comprehensive approach prepares students for future engineering endeavors in civil, mechanical, and structural engineering.

3. **Logic Gates Project:** This project introduces students to the fundamental concepts of digital logic design and Boolean algebra. The project begins with the construction and analysis of basic logic gates, including NOT, AND, and OR gates, using BJT-NPN transistors and NAND gates (IC-7400). Students create circuit diagrams, truth tables, and logic circuits for each gate type; ultimately, culminating in a project that involves the design of a circuit that demonstrates the outcome of a predetermined Boolean expression. This comprehensive project helps students understand the principles of logic gates, their symbols, Boolean expressions, and truth tables, which provide a exposure for more advanced studies in digital electronics. By working in pairs, students enhance their collaborative skills and gain hands-on experience with digital circuits. The project also requires students to submit a video recording of their working circuits, ensuring they can effectively demonstrate and communicate their understanding of the material. Through this project, students develop critical thinking, problem-solving, and technical skills essential for a future in electrical engineering and/or mechatronics careers.

4. **Building and Coding a Robot Project:** This project involves designing and programming a robot to detect and respond to varying light levels using photo-transistors and servo

motors. Students work in groups to build a robot that uses two photo-transistor-resistor circuits as inputs and two servo motors for movement. The robot's behavior is programmed based on the light intensity detected by the inputs. Specific tasks must be performed by the robot based on light intensities. The project includes creating circuit diagrams on software such as TinkerCAD or Multisim, programming the Arduino, building the photo-transistor-resistor circuits, coding the servo to move the robot in all four directions, along with writing a detailed report that covers the project's objective, circuit design, explanation of the logic of the code (pseudo-code), lessons learned, and challenges encountered. Additionally, students must also present their project in a 10-minute presentation using well designed and animated slide-shows. Through this project, students acquire various skills, including circuit design (carried over from the previous project), programming, and technical documentation. Students are provided with another opportunity to hone their teamwork and collaboration skills by working in groups and problem-solving and critical thinking abilities through the design and troubleshooting process. Additionally, students enhance their communication skills by preparing and delivering a presentation and authoring a comprehensive report. This hands-on experience with robotics provides a solid foundation for a future in robotics, mechatronics, and computer programming.

Details about Sample and Population

Students enrolled in unified introductory course created the basis of the sample population. Most of the students who participated were male (85%). The students were from various racial and ethnic backgrounds, with 15% identifying as Asian, 10% identifying as Black, 35% identifying as Hispanic or Latino, and 40% identifying as White or Caucasian. Additionally, the class comprised of international and domestic students. Demographics will neither be shared nor analyzed to maintain the anonymity of the participants due to the small sample size of twenty (20) students that took the survey.

Data Collection

The data collection process utilized an Appreciative Inquiry (AI) questionnaire. This involves the gathering of student provided qualitative data to explore the positive aspects of a course utilizing project-based learning (PBL). Students were asked to voluntarily share experiences in an anonymous Microsoft Form. The form consisted of various questions designed to have students reflect on the projects they had completed over the semester, and how those projects affected their self-efficacy, motivation, and agency. Both Likert type scale questions and open response questions were utilized.

Data Analysis

Students were asked to rate their perceived level of competency on a 4-point Likert-like scale (1 = Beginner, 2 = Intermediate, 3 = Advanced, and 4 = Expert) for the beginning and end of the semester regarding the following skills: Critical Reading, Effective Communication, Report Writing, and Plagiarism Avoidance. Students reported an increase in perceived skill level for every skill measured, with the majority of respondents shifting from the Intermediate level to an Advanced level. Students were also asked to indicate what part of the course facilitated improvement of each skill. For Critical Reading, 30% of respondents indicated the technical report requirement as beneficial, while 25% indicated the course instruction itself improved their skills. According to 70% of respondent's communication skills were improved by the projects, with one student indicating

> "I was introduced to topics I had no knowledge on, so I had the opportunity to really expand my English vocabulary."

Over 55% of the students indicated that the course improved their writing skills by introducing the Chicago Style Format, with one student saying

> "This class helped me improve in my writing skills since I had never had to write any kind of report, so I had to use a new writing format, The Chicago style, I learned how to avoid plagiarism and how to structure properly my work in the engineering field."

Students were asked to rate improvement in their teamwork skills through the small group work using a 5-point Likert-like scale (1 = not at all effective, slightly effective, 3 = partly effective, mostly effective, and 5 = extremely effective), with students indicating that the small group work was mostly to extremely effective with an average rating of 4.65. 75% of respondents indicated that the projects required effective communication, so improvement was necessary. An example response is

> "I think that, throughout all the projects we had, having good teamworking skills was the most important thing for us to succeed, without proper teamworking doing these projects would have been impossible."

Students were asked to rate the effectiveness of basic engineering skill acquisition through the small group work using a 5-point Likert-like scale (1 = not at all effective, slightly effective, 3 = partly effective, mostly effective, and 5 = extremely effective), with students indicating that the small group work was mostly to extremely effective with an average rating of 4.50. The projects were the driving force for most of the students with 50% indicating one or more of the projects as improving their skills. One student indicated that

> "Engineering for me was a whole new topic, I have never seen not even a little bit of what we studied here; so for me it was a great experience to learn how to code, crafting skills, designing skills, it was a really great class."

Overall, students indicated positive perceptions of the course, and the projects utilized, rating themselves as being very satisfied with their experience with all four projects. The highest rating of satisfaction came from the Tower building project and the Bridge building project, with both receiving a 65% very satisfied majority. The least satisfying experience was the robotics project with only 45% being very satisfied. However, students indicated that overall, the projects helped them understand the various disciplines of engineering better. Using a 5-point Likert-like scale (1 = not at all effective, slightly effective, 3 = partly effective, mostly effective, and 5 = extremely effective), students averaged a 4.60 rating indicating that the projects were quite effective.

The projects also helped students by reinforcing or discouraging their aspirations for a specific field of engineering. Most students felt that they needed to rethink their idea of which branch of engineering they wanted to pursue. An example of this is a student who indicated

> "The circuit project had me rethink my decision to be an electrical engineer because it was very difficult for me to understand how it worked."

Many students indicated that the experience of the projects introduced them to a field of engineering that they had not previously considered. One student indicated that the projects helped to give

> "A real perception of your strengths and weaknesses and helps you choose correctly what you want to pursue."

Conclusion

The results from the unified introductory course survey highlighted the significant impact the course had on students' development of soft skills, such as writing, and communication, and hard skills, such as coding and construction. Students emphasized the use of project-based learning and teamwork as catalysts for their improvement. The multidisciplinary projects were instrumental in facilitating the acquisition of basic engineering skills and in the understanding of the various engineering fields. While these projects certainly enhanced the technical competencies of the students, they also positively inspired their academic and career objectives. Self-efficacy, motivation, and agency can be seen in the responses of the students. The course helped them to take possession of their own learning and pursue their academic and professional goals. The feedback provided underlines the importance of the activity based, collaborative learning experiences provided by the course. Overall, the course has effectively provided students with a strong foundation on which to build their engineering studies and careers.

Future Work

The data analyzed clearly shows the perceived level of soft skills acquired by the students. The future scope of this project involves one or more of the below listed trajectories.

- **Longitudinal Studies:** Conducting long-term studies to track the progress and career outcomes of students who participated in the unified introductory course. This would provide insights into the lasting impact of the course on students' academic and professional trajectories.
- **Integration with Advanced Courses:** Exploring how the skills and knowledge gained in the introductory course can be integrated and built upon in more advanced engineering courses. This could help in creating a more cohesive and comprehensive engineering curriculum.
- **Technological Enhancements:** Incorporating new technologies and tools into the course, such as virtual reality for simulations or advanced software for project management. Evaluating the impact of these enhancements on student learning and engagement.

- **Industry Collaboration:** Partnering with industry professionals to provide real-world exposure for students. This could help in bridging the gap between academic learning and industry expectations.
- **Soft Skills Development:** Further research on the development of soft skills, such as teamwork, communication, and problem-solving, through project-based learning. Identifying best practices and effective strategies for fostering these skills.
- **Student Feedback and Iteration:** Continuously collecting and analyzing student feedback to refine and improve the course. This iterative approach can help in addressing any challenges and enhancing the overall effectiveness of the course.
- **Publication and Dissemination:**Publishing the findings in academic journals and presenting at conferences to share the insights and best practices with the broader educational community. This can help in promoting the adoption of similar courses at other institutions.

Acknowledgment

The authors would like to extend their gratitude and appreciation to Dr. Mark Pousson for their help reviewing the appreciative inquiry interview protocol developed for this research. The authors would also like to thank Prof. Laura Schaub and Prof. Danara Moore for their feedback and support with this paper and for suggesting potential future trajectories and expansion of this research.

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