ASEE AMERICAN SOCIETY FOR ENGINEERING EDUCATION

Paper ID #47727

A Case Study on the Design of a College-Level Online Hands-On Engineering Course Offered to High School Students

Lelli Van Den Einde, University of California San Diego

Van Den Einde is a Teaching Professor in Structural Engineering at UC San Diego and the President of eGrove Education, Inc. She has decades of experience teaching hands-on, project-based curricula, spanning high school camps, K-12 outreach, and undergraduate design courses. Dedicated to fostering diversity, she creates supportive environments for students of all backgrounds. Her teaching approach emphasizes scaffolding multidisciplinary skills to boost student self-efficacy and foster meaningful learning outcomes. Dr. Van Den Einde's research focuses on student engagement in large classrooms, developing adaptable design-build-test projects, and creating software to enhance spatial visualization skills, a key factor in improving STEM retention and success.

Cindy Mui Perez, University of California San Diego

Cindy Mui Perez is a Senior Instructional Designer at the Teaching and Learning Commons at UC San Diego. She specializes in inclusive online learning and equitable access to higher education.

Karen Flammer, University of California San Diego

Dr. Flammer is the Director of Digital Learning in the Teaching and Learning Commons. Motivated to increase equitable access to high quality education using digital technologies, she oversees the development of robust online learning programs serving a wide audience; high school students, undergraduate and graduate students and professional learners.

Mimi Phung, University of California San Diego

Mimi Phung is an Instructional Designer at the Teaching and Learning Commons. She started her career in learning as a high school teacher where she taught English Language Arts. As a teacher, she focused on creating inclusive and student-centered learning environments and curricula.

A Case Study on the Design of a College-Level Online Hands-On Engineering Course Offered to High School Students

Abstract

This paper presents a case study of a pioneering online engineering course for high school students, highlighting its innovative approaches and challenges. The course's learning outcomes and rigor are equivalent to the in-person college course. In addition, the course is a part of the Discover UC San Diego program, which aims to offer opportunities for local high school students, particularly underrepresented and first-generation students, to take college-equivalent courses that are otherwise not available to them. The study will focus on five main themes that were integral to the course design: strategies used to create a cohesive and engaging learning community, methods employed to help students manage their learning in an online environment, building students' self-efficacy in their engineering abilities, approaches used to maintain student engagement, learning and motivation in a virtual setting, and the implementation of online hands-on laboratory sessions that students completed at home. By examining these themes, the paper aims to provide insights into the effectiveness of online STEM education and offer recommendations for future iterations of similar courses.

Background

The percentage of young adults with bachelor's degrees has doubled over the past fifty years, yet this achievement varies substantially by race, ethnicity, and family socioeconomic status [1]. Key predictors of college attainment are rooted in students' beliefs in their ability and the skills they develop to engage in college-level courses [2]. Structural differences in high school offerings and disparate access to advanced coursework lead to inequality in educational pathways. With a commitment to reduce these inequalities and provide access to high-quality educational opportunities, UC San Diego launched an initiative, Discover. The Discover program provides high school students the opportunity to take online undergraduate courses, free of charge, for academic credit, which is transferable to any university accepting UC San Diego credit. The program specifically targets low-income schools and districts where students do not have opportunities to take Advanced Placement courses and jump start their progress towards a college degree. The program also demonstrates to students, particularly students who would be the first in their family to attend college or those from backgrounds typically underrepresented at colleges and universities, that they do belong in the university environment and that they can be successful at college. By offering entry level college courses in a wide range of subjects, Discover UC San Diego not only gives students the opportunity to experience a college course, it also allows them to explore different disciplines and gain confidence in their ability to pursue further study.

While the courses offered through the Discover program are identical in learning outcomes and rigor as the equivalent college course, efforts are made to provide additional support to the high school students since, for many of them, this is their first online, college-level course. It is widely recognized that online learning environments require self-regulated learning, which can be challenging for young students [3]. Research shows that embedding interactive functions into the design of these environments that guide students to use self-regulatory strategies greatly benefits their learning process [4]. This research further suggests utilizing the skills of instructional designers to assist in developing well-structured, interactive courses that lead students through a scaffolded, regulated learning experience.

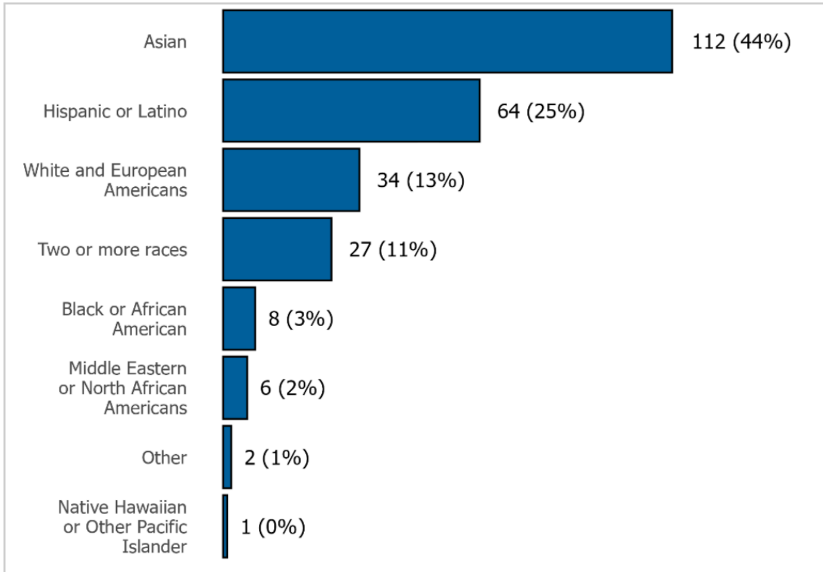
It is important to note that the course discussed in this paper is the first online engineering course offered through the Discover program and the first to require a hands-on, remote lab based on customized lab kits sent to each student. Considerable thought went into creating the individual student kits of materials and distributing them within a specified budget absorbed by the Discover program. Previous studies on the use of remote laboratories indicate the challenges of engaging students without the presence of teachers and peers to encourage, motivate, and support them [5]. While there is little research on effective pedagogies for engaging students in online labs, a recent study suggests that providing support for students before and during the hands-on projects, clear instructions about the experiment and set-up, and pre-structuring of lab activities, lead to successful student engagement with the activity [6]. Moreover, an important goal of Discover UC San Diego is to build confidence and self-efficacy, especially in first-generation high school students, for college success. As defined by [7], “self-efficacy refers to an individual’s subjective conviction in his or her capabilities to perform a specific task successfully to achieve a desired outcome”. Students with strong self-efficacy beliefs are typically more motivated to pursue higher academic achievement and persist longer at challenging tasks [8], [9]. In engineering in particular, educational experiences that result in creating an artifact or solution considered representative of an engineering profession are often linked to enhancing confidence and building self-efficacy for engineering [10]. The hands-on lab and design project incorporated into this engineering course are designed to increase high school students’ beliefs in their ability to succeed in future college-level engineering courses.

Course Overview

The online engineering course was part of the broader Discover program designed to provide high school students access to undergraduate-level education while addressing the growing demand for STEM education to inspire future engineers. The course "Introduction to Structural Engineering" ran for 10 weeks, providing high school students from all grades (9th -12th) with a comprehensive foundation in structural engineering principles while fostering critical thinking, problem-solving skills, and ethical awareness. Institutional data were collected on students participating in this program. Student racial and ethnic backgrounds are shown in Fig. 1. The engineering course was one of four courses offered in Summer 2024, accounting for approximately 21% of the total summer enrollments, or 53 students.

Figure 1

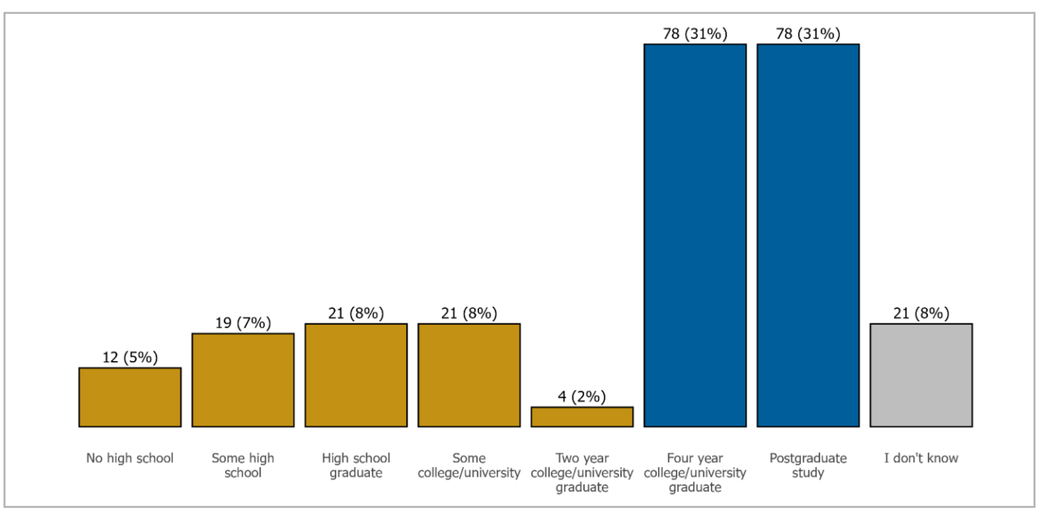
Student Racial And Ethnic Background (N=255) In The Discover Program



Students enrolled in the Discover program came from 25 high schools in the greater San Diego area. Out of 255 enrolled students across all courses, 77 students (30%) were potential first-generation college students. First-generation status was defined as students whose parents' highest educational attainment was a 2-year college degree or less (see Fig. 2). 86% of the students were entering 10th and 11th grades. 53% of students identified as male, 46% as female, and 1% as gender other than male or female. Of this larger student body, 53 students were enrolled in this engineering course.

Figure 2

Parental Education Of Enrolled Students In The Discover Program (N=255)



The online engineering course was developed and taught by an instructor with over 20 years of experience in teaching introduction to design to first-year college students. This expertise was complemented by extensive research in K-12 engineering education, including the development and deployment of curricula for high school students. While this was the instructor's first intentionally designed online course, they had previously implemented flipped classroom models in most of their courses prior to the COVID-19 pandemic. Additionally, the instructor received specialized training from institutional instructional designers to effectively design courses for online delivery. This rich background in engineering education, coupled with recent training in online pedagogy, uniquely positioned the instructor to create and implement this innovative online engineering course for high school students, bridging the gap between K-12 and college-level STEM education.

Course Structure

The course was a comprehensive 10-week online engineering program that ran during the summer and was designed for high school students. It blended asynchronous and synchronous learning components to provide a comprehensive engineering education experience that balanced theoretical knowledge with practical, hands-on learning, all within the constraints of an online environment. The program featured two synchronous sessions per week, each lasting one hour. One session was dedicated to lectures employing active learning, while the other focused on laboratory work. These synchronous live sessions emphasized the importance of active participation and were mandatory, with students allowed to miss up to 20% without impacting their grades.

As a 4-unit course, students were expected to dedicate approximately 12 hours per week to their studies. The time was divided as follows:

- 2 hours of synchronous sessions (1 hour Lecture, 1 hour Lab)
- 10 hours of asynchronous work, including:
    - Watching lecture videos
    - Completing pre-lecture reading quizzes
    - Preparing for Lab or Design Build Project (DBP) sessions with individual exploration assignments
    - Collaborating on Lab or DBP Discovery reports with partners
    - Finishing individual weekly homework (Engineering Exercises)

Hands-On Philosophy

Project-based learning (PBL), such as hands-on laboratories and design-build-test challenges, has emerged as a powerful pedagogical approach with numerous benefits such as the application of theory to practice, enhanced problem-solving and critical thinking skills, improved creativity and innovation, development of transferable skills (teamwork, communication, time management), increased student motivation and career preparation, and a more rewarding teaching experience for educators [11-14].

While PBL has gained global popularity, its implementation requires careful design to ensure quality learning experiences, efficient use of student time, and achievement of desired learning outcomes, particularly in online environments [15]. Designing effective online laboratories necessitates a holistic approach that considers technical aspects, pedagogical dimensions, and social elements of the learning experience, "it is imperative to situate online laboratories within the broader learning ecosystem, encompassing learning goals, student activity design, assessment methods, and the facilitation of social presence and interactions mediated through digital tools" [5]. While online hands-on environments present challenges, techniques exist to maintain PBL's benefits through strategies such as virtual and augmented reality technologies, simulation tools, remote access to physical equipment, and collaborative online projects [16], [17]. These approaches allow for the continuation of engaging, practical learning experiences in virtual settings, preparing engineering students for successful careers in the digital age. One of the primary goals of this course was to design online hands-on activities that maximize the benefits of PBL while addressing the unique challenges of remote and online education.

Curriculum

Throughout the 10 weeks, students explored a wide range of topics, from basic design processes to complex concepts like statics and bending behavior. The course materials were thoughtfully designed to create a cohesive learning experience across various modalities, including lecture videos, live sections, lab work, and weekly engineering exercises, providing students with multiple perspectives and opportunities to engage with the material. Online labs played a crucial role in reinforcing engineering concepts. These hands-on experiences, such as material testing and analysis, provided students with practical skills and a deeper understanding of structural behavior. The labs also incorporated technical writing and teamwork skills. This integrated approach ensured a deep understanding of each topic while strategically and gradually building proficiency in communication and collaboration.

The course culminated in a comprehensive team-based Design-Build Project, challenging students to iterate on their project design choices through testing, analysis, and evaluation of a simple structure, synthesizing all the knowledge acquired throughout the program. The well-rounded curriculum not only provided students with a solid foundation in structural engineering principles and practices but also equipped students with essential professional skills for their future careers in engineering.

Learning Objectives and Outcomes

By the end of the course, students were expected to demonstrate a solid understanding of structural engineering basics, including the ability to identify and describe different structural components and systems. They developed skills in applying mathematical and data analysis techniques to understand structural behavior under various loads. Additionally, the course emphasized the development of professional skills such as teamwork and communication, which are crucial in the engineering profession.

A significant focus was placed on understanding the ethical responsibilities of engineers and the paramount importance of safety in structural design. This holistic approach aimed to provide students with a well-rounded introduction to the field of structural engineering, preparing them for potential future studies or careers in this discipline.

Course Components and Design

The course was designed and developed with instructional designers from the university's Teaching and Learning Center. Most of the course development was informed by the Backward Design model, beginning with identifying desired skills and outcomes for students. Course content was hosted via the Canvas Learning Management System (LMS), and Zoom was used as the main video conferencing platform for hosting live sessions. Kaltura was used as the primary video hosting platform to deliver asynchronous lectures. All chosen tools and software were intentionally selected for maximum compatibility with students' district-issued Chromebook computers.

The course structure, with its weekly topics and consistent learning modalities, supported the development of self-regulation skills. Students were encouraged to manage their time effectively, set goals, and reflect on their progress throughout the program.

Learning and motivation were enhanced through various strategies, including peer instruction during live lecture sections and collaborative lab work. The course's emphasis on the iterative design process and failure analysis encouraged critical thinking and problem-solving skills, keeping students engaged and motivated to learn.

Flipped Classroom

At the heart of the learning experience was a flipped classroom approach, shifting the focus from traditional content delivery to active problem-solving and application of concepts during class time [18]. In this model, students watched pre-recorded lecture videos to learn theoretical content at their own pace before class to prepare for interactive live sessions that utilized Peer Instruction, a method developed by Mazur and colleagues [19],[20], focusing on addressing common misconceptions in structural engineering.

Students attended live sessions twice a week consisting of one lecture and one lab session. These live sessions were held in the late afternoon to avoid potential scheduling conflicts with summer school or other student obligations. Prior to the live sessions, students were randomly divided into groups of 4-6 participants, with 8-9 groups in total. These initial group assignments remained in place for 3 weeks. After this time, the groups were reshuffled. At the 6-week mark, students were randomly placed into their Design Build Project Teams, where they remained for the rest of the quarter. This is described further below. In these mandatory synchronous sessions, students answered concept questions individually and then discussed them in small breakout groups to reach a consensus. This approach has been shown to improve conceptual understanding and problem-solving skills in various STEM disciplines [21], [22] and [23]. Furthermore, research has demonstrated that the combined approach of flipped classrooms and peer instruction can lead to improved learning gains, increased student engagement, and better retention rates compared to traditional lecture-based courses [18]. By integrating these evidence-based instructional practices, the course aimed to provide a comprehensive engineering education experience that balanced theoretical knowledge with practical, hands-on learning, fostering critical thinking, problem-solving, and collaborative skills essential for success in engineering [24], all within the constraints of an online environment.

Online Engineering Labs

Perhaps the most novel feature of the course was its incorporation of weekly hands-on laboratory exercises in a fully online environment. Lab activities ranged from pre-recorded video experiments and scavenger hunts to identify structural elements in their environment to building and testing physical structures. Students also worked with 3D-printed manipulatives to explore weekly topics and used computer simulations to analyze structural behavior.

The Design-Build Project required students to work in teams to design and iterate on physical structures. The term project was structured in two phases to maximize collaborative learning and hands-on experience. In Phase 1, students worked in teams of four, subdivided into pairs. Each pair focused on designing, building, and testing one of two project components, allowing for independent iterations and home-based testing while facilitating the comparison of results within the pair. During an online lab session, the teams presented their best designs for both components to the class. In Phase 2, the class worked in small groups to evaluate all presented designs, ultimately selecting three prototypes for each project component, resulting in six different structures for further testing. The teaching team constructed these final iterations and subjected them to rigorous testing in the engineering lab.

Physical Lab Kits

Enrolled students received mailed kits with the components necessary to complete weekly lab activities at no cost. The kits included materials for the one-off lab activities and the end-of-course Design-Build term project. The materials students received depended on which project group they were randomly assigned to.

The course design strategically delayed the use of physical kit materials for the first three weeks, instead relying on common household items or low-cost alternatives. This approach served multiple purposes: it reduced overall costs associated with lab materials, allowed time for the shipment of specialized kits to students, and provided a buffer period for student enrollment to stabilize, minimizing the risk of sending materials to students who might drop the course. This strategy aligns with the Discover program's goal of providing equitable access to engineering education, and optimizing resource allocation while supporting the program's commitment to inclusivity in STEM education.

With a budget of $50 per kit, including shipping fees, materials were kept under $30 to ensure cost-effectiveness. To keep costs down, materials were purchased in bulk and processed by the course team into individual kits. Some lab activities necessitated custom materials, such as small-scale beams with different cross-sectional shapes and properties to demonstrate bending principles. These were developed by the instructional team and provided to students free of cost. Undergraduate tutors were hired to assist in manufacturing these custom 3D-printed materials and assembling the lab kits.

The design of the lab activities was additionally constrained by the 14″ x 12″ x 3 1/2″ USPS flat-rate boxes in which they were shipped to students, which dictated the size of the building materials. Lab activities were also designed to avoid potentially hazardous materials, such as lithium batteries or flammable materials, that could restrict the use of mailing services. Each kit included an inventory sheet for students to verify that they received all necessary items for each activity (See Fig. 3).

Figure 3

Sample Lab Kit Inventory Sheet

Kit Inventory

Blades Group 1

Qty	Description	Image	Qty	Description	Image	Qty	Description	Image
Lab 4								
3	6" 3/16" OD x 0.014" Wall Aluminum Tubing		3	6" x 1/4" x 1/4" balsa sticks		3	Pieces of Chalk	
Lab 6								
Qty	**Description**	**Image**	**Qty**	**Description**	**Image**	**Qty**	**Description**	**Image**
1	3D printed I-beam		1	3D Printed Circular beam		1	3D Printed Rectangular beam	
1	3" Wooden Dowel		1	3D Printed Triangular Base w/ Cap		1	3D Printed Triangular Base w/ hole	
Design Build Project (Blades Group 1)								
Qty	**Description**	**Image**	**Qty**	**Description**	**Image**	**Qty**	**Description**	**Image**
4	Poster Paper		1	Foam Board		24	Coffee Stirrers	
1	Fan		2	Command Strips		6-8	2" Dowels	
1	Blade Hub		12	Red Dot Stickers				

During the second week of the course, a Google Form was used to collect student shipping information prior to shipment. This form also emphasized to students that they would only receive one kit and asked them to confirm that they could receive any mailed materials. This was especially important during the summer when students were more likely to travel.

Campus mailing services were utilized to ship lab materials to individual students. Once kits were mailed, students were notified via a course announcement and advised to contact the instructional team if they did not receive them within a week.

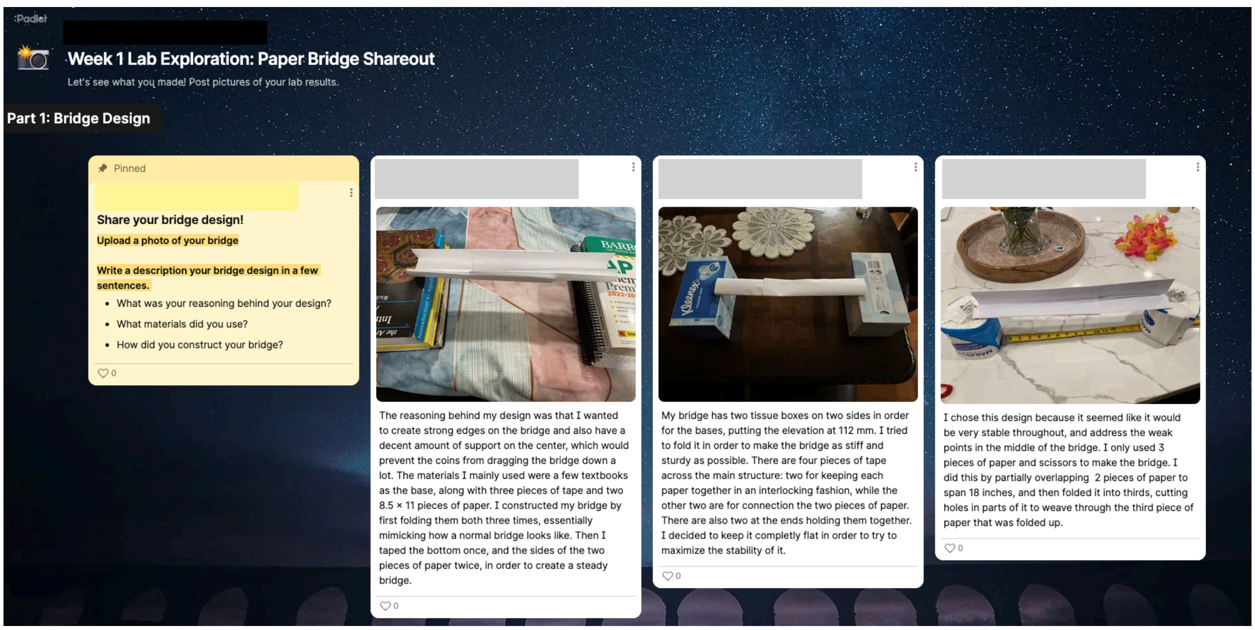
Overall, the shipment process was fairly smooth, and only 1-2 students in the course experienced shipment issues. The use of mail tracking would have been beneficial for the instructional team in investigating reported issues. Subsequent runs of the course will utilize package tracking.

Lab Format

Each lab involved a pre-lab Exploration activity that students completed individually before joining the live lab. These Lab Explorations consisted of watching an instructional overview video, completing a hands-on activity, and sharing their results in a classwide discussion forum using Padlet (Fig 4). During the Thursday synchronous lab session, findings from pre-lab work were discussed, instructors conducted live demonstrations, and students worked in small groups to complete and submit the Lab Discovery report by the end of the week.

Figure 4

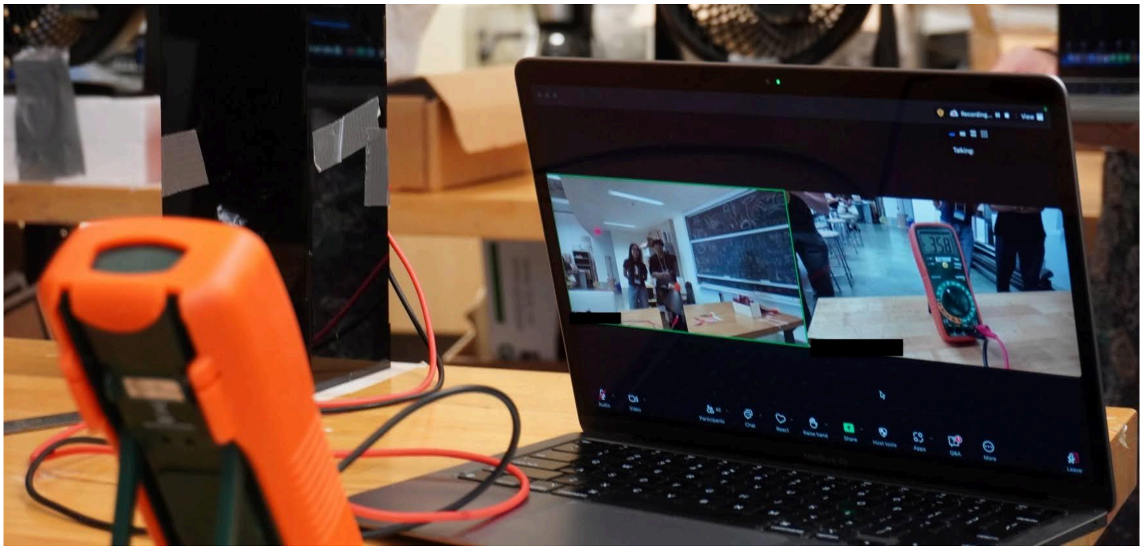
Pre-Lab Shareout Activity hosted via Padlet.com



The majority of live lab sessions were conducted without the instructor needing physical lab equipment. However, a few lab sessions required specialized equipment to demonstrate specific engineering principles or help quantify results. For these sessions, a teaching team member conducted live demonstrations using on-campus facilities with specialized recording equipment, which students observed via Zoom. Personal computing devices were sufficient to capture live demonstrations. As necessary, live demonstrations captured the necessary quantitative data using sensors or measurement devices. The supplemental data were provided after the lab to the students for data plotting and analysis (Fig. 5).

Figure 5

Capturing Data During Live Demonstrations And Experiments



Student Support Structures

Considerable efforts were made to identify opportunities for targeted support without impacting the rigor of the course material. From conversations with instructors involved in the Discover program and consultations with K12 educators, the design team identified common themes to address with the course design: (a) Many high school students are unaware of the differences between high school and college level courses, such as expectations for late assignments or workload; (b) students have limited attentional capacity and benefit from targeted content delivery; and (c) students need guidance to develop skills such as time management and other self-directed learning strategies. Despite challenges unique to young learners, high school students have the desire and the capacity to be successful with intentional guidance and support.

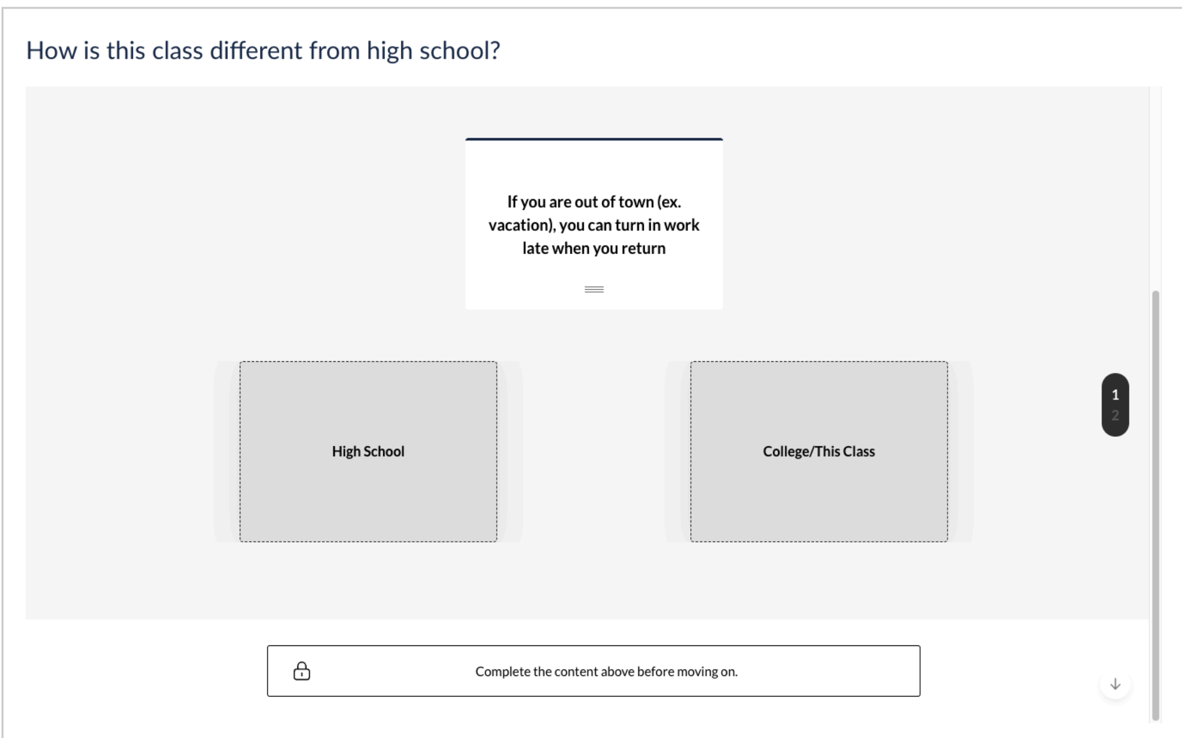
Week 0 Orientation Module

One key challenge for students with little exposure to college-level courses is a lack of awareness of what is expected of them. In conversations with practitioners familiar with the K12 setting, many described constantly reaching out to students to remind them of deadlines, monitoring grades on students' behalf, or being told by administrators that they were required to accept late work without penalty. These differences in practices would often lead to confusion for students enrolled in the Discover program, who came in with conflicting expectations based on their prior educational experiences.

To address this challenge, a mandatory "Week 0" orientation was created for students to complete before the start of the course. The module detailed what was expected of students in the course and emphasized the differences between high school classes and college classes. One interactive activity required students to read statements and determine if they applied to high school or college classes, with statements such as, “If you miss class, the instructor will give you the work you missed (Correct response: High School)” and “Students, not parents, should email the instructor with concerns about grades (Correct response: College/This Class).” (See Fig. 6). Students had to complete all module items and pass a course readiness quiz to unlock the rest of the course materials. The course readiness quiz was an additional measure to re-emphasize key expectations to students, such as the late work and live session attendance policies.

Figure 6

College Readiness Activity During Week 0 Module



Note: Students drag and drop the statement to the applicable high school or college setting.

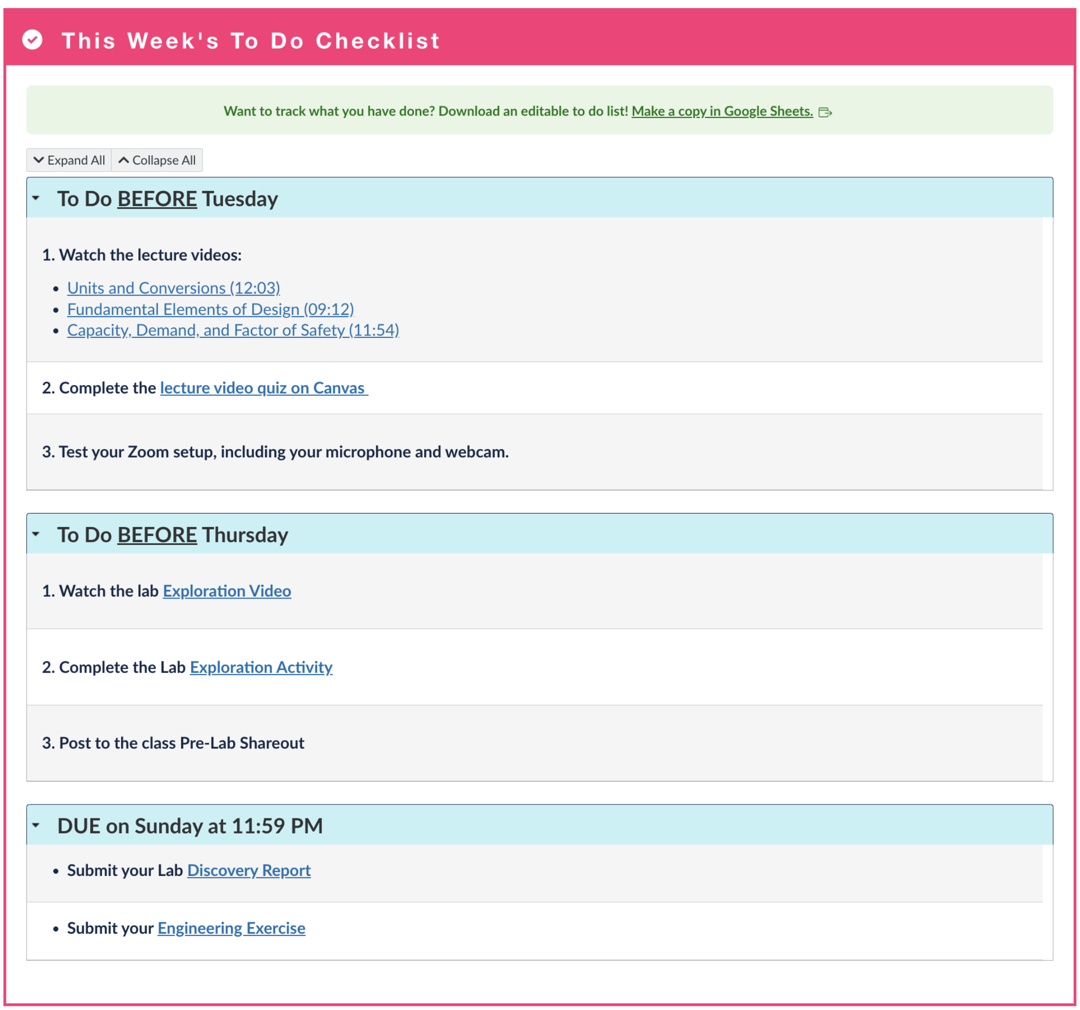
These additional measures proved to be successful in ensuring that all students were aware of the course policies and expectations. This was evidenced in the reduction of unexcused late/missing work and students’ proactive communication with the instructional team. Additionally, when asked to describe what they were most nervous about in the course during the “Meet Your Classmates” orientation activity, many students referenced surprise about assignment deadlines and late work policies. This indicated that without explicit measures to set student expectations, many students would likely be unaware of policies and practices that are oftentimes assumed to be known in a college setting.

Course Structure

Due to the fast nature of a quarter system-based course, it was crucial that students stay on top of their work so they did not fall behind. To support students who may not be accustomed to the course pace and workload, the course utilized a fixed schedule that required students to engage in coursework a minimum of three times a week. Assignments were broken down into smaller components that built towards larger end-of-week deliverables. Each module included a Weekly Overview with checklists of due dates and deliverables to help students organize their work (Fig. 7). This fixed course structure helped create a predictable cadence for students and distribute coursework into manageable chunks.

Figure 7

Weekly To-Do List Example in Canvas



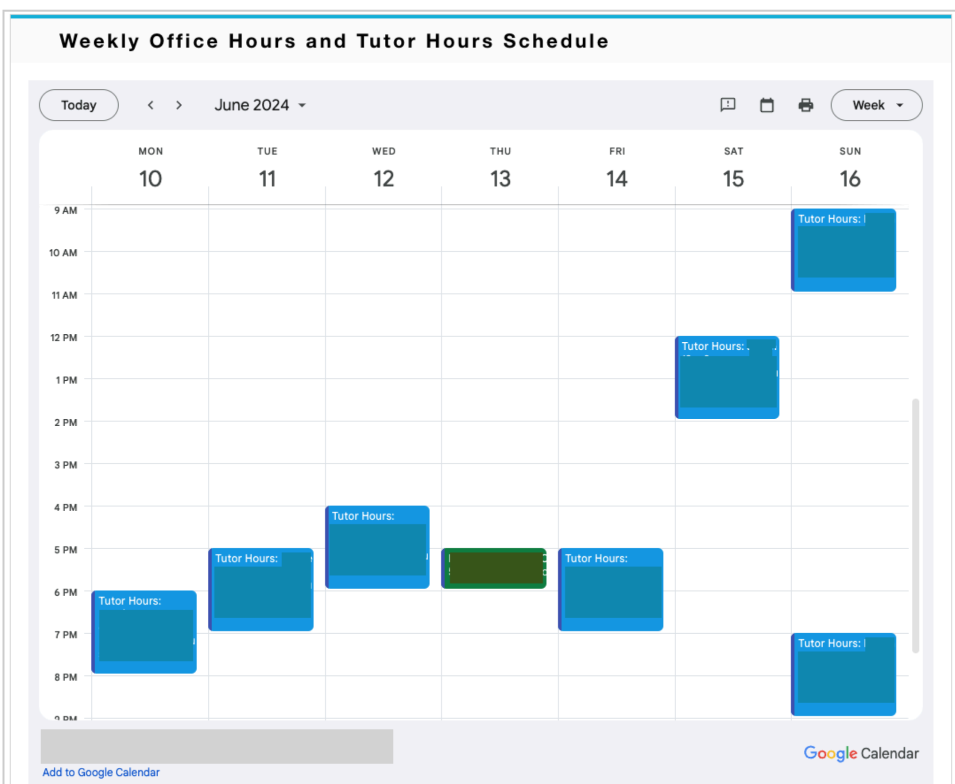
Drop-In Tutoring Sessions

The students enrolled in the course came from different school districts and had varied degrees of prior engineering and mathematics education. The course utilized a peer tutoring model to provide supplemental support for students with differing abilities and confidence levels in foundational prerequisite knowledge. These tutoring sessions offered low-stakes opportunities for students to build foundational skills not explicitly taught in the course materials and get support with homework problems, labs, and the design project.

Five current undergraduate Structural Engineering student tutors and one Instructional Assistant (IA) were hired onto the instructional team. Course tutors, the IA, and the course instructor held regularly scheduled tutoring sessions via Zoom, providing students with seven weekly two-hour help sessions. The sessions were intentionally spread throughout the week to accommodate student availability and hosted later in the evening to avoid potential scheduling conflicts with other summer activities. Additional sessions were scheduled toward the end of the week to accommodate the increased demand leading up to assignment due dates. The weekly tutoring schedule is shown in Fig. 8.

Figure 8

A Typical Office Hours / Tutor Hours Schedule



Note: This schedule was hosted via Google Calendar

To help students feel comfortable joining tutoring sessions, a "Meet the Tutoring Team" page with photos and brief introductions for each tutor was included in the course orientation. Additionally, course tutors regularly attended live sessions and directly interacted with students individually and through small breakout sessions to help build a sense of trust and rapport with them. Finally, a small amount of extra credit points was offered to students who regularly attended tutoring sessions to incentivize utilization.

Student Self-Efficacy Beliefs and Sense of Belonging

Addressing Common Anxieties in Engineering

A key factor when designing this course was increasing student self-confidence about their ability to succeed in engineering. Left to their own devices, students with low self-efficacy beliefs may attribute academic struggles to a deficiency in personal competence or attributes. As discussed in [25], "nervousness before performing a task lowers one's self-efficacy toward the impending task, and the weakened sense of self-efficacy intensifies the worries and negative affect while one performs the task, further lowering the efficacy toward it." To increase student self-confidence and sense of belonging in engineering, course materials included explicit strategies to make concepts in engineering more accessible to students who may experience low self-efficacy beliefs.

Social persuasion from a credible and competent source, the instructor, is another effective way to improve student self-efficacy. As part of the Week 0 orientation, students reviewed an introductory video in which the instructor made statements reminding students that failure is not necessarily a reflection of one's competence as an engineer: “We want you to learn to fail. Failure is part of the learning process.”

These statements directly targeted students with low self-efficacy and content-specific anxiety, such as with mathematics. The course orientation video primed students to reframe potential misconceptions or self-beliefs that might otherwise serve as barriers to engineering. When discussing what attributes make a good engineer, the instructor stated: “Sometimes you think you have to be very strong at math and science, and yes, that is a fundamental skill, but it’s a learnable skill… Strong engineers are people that are…interested in how things work… and are willing to try things and iterate on their designs.”

Peer Role Modeling

One of the principal factors influencing one's perceived self-efficacy comes from vicarious experiences of success through the observation of role models [8]. The undergraduate tutors, who were a part of the diverse tutoring team, served as powerful role models to the enrolled high school students. Special considerations were made to ensure that the makeup of the tutoring team was representative of the diverse student body in the course. Course tutors had a variety of backgrounds, races, and genders, including first-generation student status, LatinX student status, and first-year student standing. In addition, the Tutoring Team also hosted a live panel discussion where students could ask any questions related to engineering, college, or both. This direct exposure to enrolled students of similar ages and backgrounds was a key strategy to increase students' sense of belonging in engineering. The tutors also served as relatable and realistic examples of potential pathways into engineering.

By integrating themes of sense of belonging, self-regulation, self-efficacy, learning motivation, and hands-on online labs, the course created a comprehensive learning environment that develops both engineering knowledge and crucial STEM skills in an online setting.

Methodology

This study employed a mixed methods approach to investigate the impact of the course design and implementation strategies on student engagement, self-regulation, and self-efficacy in a novel online engineering course for high school students. The research design integrated both qualitative and quantitative elements to provide a comprehensive understanding.

Qualitative Data

The comprehensive evaluation of the Summer 2024 program session, conducted by Discover program staff, provided a multi-faceted assessment of the program's effectiveness and impact. The evaluation process incorporated several key components such as enrollment data analysis allowing observation in trends in student registration, demographics, and course selection patterns, a post-course survey that had an impressive 95% response rate (178 out of 188 program completers) and offered a robust dataset reflecting student experiences, satisfaction levels, and perceptions of the program, dropout interviews of four students who left the program to provide valuable insights into potential challenges or barriers that led to attrition, and a focus group with five program completers that allowed for in-depth, qualitative feedback on various aspects of the program. The overall positive outlook from students indicates that the program was generally well-received and effective in meeting its objectives.

However, a limitation of this study is the current inability to include student survey data and focus group results due to pending additional consultations with the University Office of IRB Administration. If approved, some of these valuable student perspectives may be included in the final paper as well as future iterations of this research, which would provide direct insights into student experiences, challenges, and perceptions of the course.

Quantitative Analysis

Quantitative academic performance data included students' grades, assignment completion rates, tutoring hour attendance, and synchronous session attendance. These metrics provided objective measures of student engagement and performance throughout the course.

Academic Performance and Completion Rates

The Summer 2024 online engineering course, offered free of charge to high school students, demonstrated a nuanced pattern of enrollment, attrition, and success. Initially, 53 students enrolled in the course, with 39 ultimately completing it, resulting in a 74% completion rate. This completion rate was consistent across the four courses offered during the summer session, indicating a broader trend rather than an issue specific to this course.

The majority of student dropouts occurred early in the course duration, with 14 students (26%) not completing the program. The primary reasons cited for attrition were time constraints, difficulty of the material, and competing summer obligations. This early attrition pattern suggests that some students may have underestimated the course's demands or faced unexpected challenges in balancing the coursework with other commitments.

Despite the initial attrition, the course demonstrated remarkable success in retaining and supporting students who persisted beyond the early stages. Among the 39 students who continued, 97.5% successfully passed the course, with only one student receiving a D grade because they did not do any of the individual engineering exercises (homework). This low DFW (D, F, Withdraw) rate of 2.5% among persisting students indicates that the course structure, support systems, and content were highly effective in facilitating student success once students committed to the program. The grade distribution for the course was as follows:

Table 1
Final Grade Distribution (N = 39)

Grade	Percentage	Number of Students
A	79%	31
B	15%	6
C	2.5%	1
D	2.5%	1

The high proportion of A and B grades (94% of students) indicates a strong overall performance in the course. This success rate is supported by the observation that most assignments were completed on time, contributing to the high marks achieved by students. Assignments were graded by tutors using Gradescope, integrated with the Canvas learning management system. The instructor provided rubrics to ensure consistent and fair assessment across all submissions.

The observed two-phase pattern of engagement, initial attrition followed by high retention and success, highlights the importance of early intervention strategies and clear communication of course expectations during the enrollment phase. Additionally, the strong performance of persisting students underscores the effectiveness of the course's support systems and instructional design for those who overcome initial challenges. As this pattern was consistent across the summer session's courses, it suggests that program-wide strategies could be beneficial in addressing early dropout issues while maintaining the high standards and support that led to success for continuing students.

Tutoring Hours Attendance

The implementation of tutoring hours proved to be a significant component of the course, with substantial student engagement. On average, approximately 53% of enrolled students made regular use of these tutoring sessions, indicating that more than half of the class consistently sought additional support and guidance.

Notably, during peak weeks, attendance at tutoring sessions reached impressive levels, with up to 92% of enrolled students participating. This high attendance rate suggests that:

- Students found the tutoring sessions valuable for their learning and progress in the course.
- The timing and content of these sessions were well-aligned with student needs, particularly during challenging periods of the course.
- The course structure successfully encouraged and facilitated access to additional support.

The fluctuation in attendance, from an average of 53% to peaks of 92%, likely correlates with the course's rhythm, such as approaching deadlines, more challenging topics, or preparation for major projects or assessments. This pattern indicates that students were proactive in seeking help when they perceived a greater need for support.

The high utilization of tutoring hours underscores the importance of providing accessible, additional learning support in online engineering education. It also suggests that the course design effectively communicated the value of these sessions and created an environment where students felt comfortable seeking help.

Live Session (Lecture and Lab) Attendance

The course employed Peardeck to monitor attendance for both live lectures and lab sessions, revealing high levels of student engagement in synchronous activities. For the live lectures, a total of 10 sessions were held, with students allowed to miss two without a grade penalty. The average attendance was impressively high at 9.33 out of 10 lectures, with 95% of students (37 out of 39) attending 8 or more lectures. Similarly, the lab sessions, which totaled 9, followed the same attendance policy, allowing two absences without penalty. The average lab attendance was equally strong at 8.1 out of 9 sessions, with 92% of students (36 out of 39) participating in 7 or more labs. These robust attendance figures demonstrate a strong commitment from students to engage in synchronous learning activities. The consistently high average attendance for both lectures and labs suggests that students found these sessions valuable and were motivated to attend regularly, often exceeding the minimum requirements to avoid grade penalties. This level of participation indicates the effectiveness of the course design in encouraging active student involvement in real-time learning experiences.

The strong academic performance of students in this online engineering course is particularly noteworthy when compared to recent outcomes in a similar college-level course taught to freshmen. Despite maintaining the same level of rigor and college-level content, the high school students in this online program achieved even higher grades and performance metrics than their college counterparts. This remarkable outcome can be attributed to the modified support structure implemented in the online course.

The course design retained the challenging college-level material but enhanced the learning environment through:

- Regular synchronous sessions with high attendance rates
- Accessible tutoring hours with significant student utilization
- Structured online labs and hands-on projects
- Consistent engagement through tools like Peardeck

These elements, combined with the course's overall design, created a supportive yet rigorous learning environment. The result was a cohort of high school students who not only met the demands of college-level engineering content but also excelled beyond expectations. This success underscores the potential of well-designed online STEM education to prepare high school students for college-level work effectively. It also highlights the importance of robust support systems in online learning environments, demonstrating that with the right structure, high school students can rise to the challenge of advanced engineering coursework.

Challenges, Limitations & Future Work

The high academic performance of students in this course, with grades predominantly in the A and B range, demonstrates that high school students are indeed capable of engaging with and excelling in college-level engineering content when provided with appropriate support and structure. This success underscores the potential for targeted engagement and outreach programs to encourage these talented students to pursue careers in structural engineering and other STEM fields. The course results highlight a crucial insight: when we provide robust support systems, focus on building students' self-efficacy, and carefully scaffold challenging material, students are capable of achieving far more than traditional educational boundaries might suggest. This approach not only enhances their current academic performance but also builds a strong foundation for future success in engineering disciplines. The course's outcomes serve as a compelling argument for the value of investing in advanced STEM education opportunities for high school students, potentially broadening the pipeline of future engineers and innovators.

The implementation of this course provided valuable insights for future iterations. Based on initial feedback from the teaching team, several key observations and recommendations emerged, which will be further refined once the results of the teaching team survey are fully analyzed.

One significant challenge was the summer scheduling, which highlighted the need for more flexible course structures to accommodate students' varied summer commitments. This suggests that future iterations might be better suited to run during the academic year. The importance of a Week 0 live orientation became evident, proving crucial for setting expectations and familiarizing students with the online learning environment. Throughout the course, maintaining student engagement required ongoing attention to motivational factors, with the introduction of extra credit opportunities emerging as an effective tool for some students.

However, it's important to note that research suggests offering rewards that students do not perceive to be salient to the task can adversely affect motivation. There is a risk that students might value the extra credit more than engagement in tutoring and subject mastery, which the extra credit was meant to encourage [26]. The teaching team observed times when students attended tutor hours but did not ask any questions or engage in the discussion just to earn the extra credit opportunity. This highlights the need for careful consideration of motivational strategies to ensure they align with the course's learning objectives and do not inadvertently undermine intrinsic motivation for the subject matter.

The online environment necessitated high-touch facilitation, requiring a large instructional team to provide adequate support. This underscores the importance of allocating sufficient resources for staffing in future iterations. Additionally, the distribution of lab kits presented significant challenges in terms of cost and logistics, emphasizing the need for substantial budget and administrative support. As an alternative, future iterations might consider using free or common household materials for labs, which could prove to be a more sustainable and equitable approach.

As we prepare for the next iteration of the course, including a February run, we have identified several opportunities to enhance our research and gather more comprehensive data. A key area for improvement is the direct assessment of students' self-efficacy beliefs in engineering, which will be addressed through the implementation of pre- and post-course surveys. These surveys will measure changes in self-efficacy and provide valuable insights into the course's effectiveness in building students' confidence in their engineering abilities.

Our primary focus will be on introducing and evaluating modifications to the course structure and content, accompanied by preliminary observations of their impact. A significant addition to our study will be the involvement of a second instructor and their teaching team, offering a fresh perspective on the course's effectiveness. We plan to conduct focus groups with this new cohort to gain deeper insights into their experiences and impressions.

For future offerings of the course, we are developing a comprehensive student survey that will explicitly address the five key themes central to our course design and implementation. These themes include fostering a sense of belonging, supporting self-regulation skills in the online learning environment, enhancing self-efficacy in engineering, promoting learning and motivation through innovative online pedagogies, and evaluating the effectiveness of online laboratory experiences. To measure the impact of our course more accurately, we will implement both pre- and post-course surveys. This approach will allow us to assess changes in students' self-efficacy beliefs and other key metrics throughout the course.

This expanded data collection strategy, incorporating multiple perspectives from students, instructors, and teaching teams, and using both qualitative and quantitative methods, will provide a more robust understanding of our course's effectiveness and areas for improvement. By doing so, we aim to gain a comprehensive view of the course's impact on student learning and engagement in online engineering education, ultimately contributing to the development of more effective STEM education opportunities for high school students.

Future work will concentrate on:

- Developing cost-effective, accessible lab materials
- Optimizing synchronous and asynchronous learning activities
- Enhancing peer-to-peer interaction online
- Exploring partnerships for hands-on experiences
- Investigating the course's long-term impact on students' STEM career choices

These efforts aim to continually improve the course's effectiveness in inspiring and preparing high school students for engineering careers, creating a more accessible, engaging, and impactful online STEM education experience.

Acknowledgments

The authors would like to acknowledge their Discover UC San Diego partners for course, program, and assessment support.

References

1. S. Reber and E. Smith, "College Enrollment Disparities: Understanding the Role of Academic Preparation", January 2023 [Online], Brookings Center on Children and Families, Available: https://www.brookings.edu/wp-content/uploads/2023/02/20230123_CCF_CollegeEnrollment_FINAL2.pdf, [Accessed Dec. 12, 2024])
2. M. Kurlander, S. Reed and A. Hunt, "Improving College Readiness: A Research Summary and Implications for Practice", *Policy Analysis for California Education*, August 2019, [Online]. Available: https://edpolicyinca.org/publications/improving-college-readiness-research-summary-and-implications-practice, [Accessed Dec. 12, 2024]
3. J. B. Wandler and W. J. Imbriale, "Promoting undergraduate student self-regulation in online learning environments", *Online Learning,* vol. 21, no. 2, 2017
4. E. Delen and J. Liew, "The Use of Interactive Environments to Promote Self-Regulation in Online Learning: A Literature Review", *European Journal of Contemporary Education*, vol. 15, pp. 24 – 33, 2016.
5. D. May, I. Jahnke and S. Moore, "Online laboratories and virtual experimentation in higher education from a sociotechnical-pedagogical design perspective", *Journal of Computing in Higher Education, vol.* 35, pp. 203-222, August 2023 [Online]. Available: https://doi.org/10.1007/s12528-023-09380-3. [Accessed Dec. 13, 2024].
6. Van den Beemt, S. Groothuijsen, L. Ozkan and W. Hendrix, "Remote labs in higher engineering education: engaging students with active learning pedagogy" *Journal of Computing in Higher Education, vol.* 35, pp.20–340, August 2023 [Online]. Available: https://doi.org/10.1007/s12528-022-09331-4. [Accessed Dec. 13, 2024].
7. A. Bandura, *Self-efficacy: The exercise of control.* W. H. Freeman, Henry Holt & Co.: Times Book, 1997.
8. F. Pajares, Self-efficacy beliefs in academic settings. *Review of Educational Research,* vol. 66, no. 4, pp. 543–578, Winter 1996.
9. B. J. Zimmerman, "Self-efficacy: An essential motive to learn", *Contemporary Educational Psychology,* vol. 25, no. 1, pp. 82–91, 1999. [Online]. Available: https://doi.org/10.1006/ceps.1999.1016. [Accessed Dec. 12, 2024].
10. J. R. Power, D. Tanner and J. Buckley, "Self-efficacy development in undergraduate engineering education", *European Journal of Engineering Education,* pp. 1 - 25, July 2, 2024, [Online]. Available: https://doi.org/10.1080/03043797.2024.2368149. [Accessed Dec. 12, 2024]
11. L. L. Wu, C. Fischer, F. Rodriguez, G. N. Washington, and M. Warschauer, "Project-based engineering learning in college: associations with self-efficacy, effort regulation, interest, skills, and performance," *SN Social Sciences*, vol. 1, no. 12, p. 287, Dec. 2021.

12. A. Wang, L. Van Den Einde, and N. Delson, "Gotta Catch 'Em All: Learning Graphical Communications through an Introductory Hands-on Design-Build-Test Project in a Hybrid Learning Environment".in 2023 *ASEE Annual Conference and Exposition*, *Baltimore, Maryland*, *June 25 – 28, 2023*, ASEE PEER, 2023.
13. M. F. Ercan and R. Khan, "Teamwork as a fundamental skill for engineering graduates", in Proceedings of the 2017 *IEEE 6th International Conference on Teaching, Assessment, and Learning for Engineering (TALE),* pp. 24-28, doi: 10.1109/TALE.2017.8252298, 2017.
14. D. B. Hamidreza & K. Knight, "Exploring Student Academic Motivation and Perceptions of Teamwork and Communication" in *Proceedings of 2021 ASEE Virtual Annual Conference*, 2021, [Online]. Available: https://strategy.asee.org/37146, [Accessed Jan. 3, 2025]
15. J. Larmer, J. Mergendoller, and S. Boss, *Setting the Standard for Project Based Learning*, Alexandria, VA, ASCD Press, 2015
16. P. Petrov and T. Atanasova, "Enhancing STEM Education Through Project-Based Learning Combined with Virtual and Augmented Reality", ICERI2022 Proceedings, pp. 5730-5736, 2022.
17. N. Zhang and Y. Liu, "Design and implementation of virtual laboratories for higher education sustainability: a case study of Nankai University," *Frontiers in Education,* vol. 8, art. no. 1322263, Jan. 2024.
18. G. S. Mason, T. R. Shuman, and K. E. Cook, K. E., "Comparing the effectiveness of an inverted classroom to a traditional classroom in an upper-division engineering course", *IEEE Transactions on Education*, vol. 56(4), pp. 430-435, 2013.
19. C. H. Crouch and E. Mazur, "Peer Instruction: Ten years of experience and results". *American Journal of Physics*, vol. 69(9), pp. 970-977 20, 2001.
20. A. P. Fagen, C. H. Crouch, and E. Mazur, "Peer Instruction: Results from a range of classrooms". *The Physics Teacher*, vol. 40(4), pp. 206-209, 2002.
21. P. Heller and M. Hollabaugh, "Teaching problem solving through cooperative grouping. Part 2: Designing problems and structuring groups". *American Journal of Physics*, vol. 60(7), pp. 637-644, 1992.
22. Y. Demirel, "Effective teaching and active learning of engineering courses with workbook strategy", in *Proceedings of the 2004 American Society for Engineering Education Annual Conference & Exposition*, 2004.
23. E, Kjolsing and L. Van Den Einde, "Using Isomorphic Questions, the Statics Concept Inventory, and Surveys to Investigate the Benefits of and Student Satisfaction in a Hybrid Learning Environment*", American Society of Engineering Education (ASEE) Annual Conference and Exposition*, June 14 – 17, 2015, Seattle, WA.
24. Y. Demirel, "Effective teaching and active learning of engineering courses with workbook strategy", in *Proceedings of the 2004 American Society for Engineering Education Annual Conference & Exposition*, 2004.

25. H. S. Ahn and M. Bong, “Self-Efficacy in Learning,” in *The Cambridge Handbook of Motivation and Learning*, K. A. Renninger and S. E. Hidi, Eds. Cambridge University Press, 2019, pp. 63–86.
26. J. A. Bates, J. A., “Extrinsic reward and intrinsic motivation: A review with implications for the classroom”, *Review of Educational Research*, vol. 49(4), pp. 557–576, 1979.