WIP: Explore Before Explain: A Quantum Leap in Student Engagement in First-Year Engineering Classes

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***Abstract*— This innovative practice WIP paper addresses the significant challenge of engaging first-year engineering students with diverse technical backgrounds in higher education. At Michigan Tech University, we tackle this challenge by implementing a flipped teaching model supplemented with active discovery team projects. In our approach, nearly 1000 first-year engineering students are equipped with their own Arduino kits from day one of class. With "kits in hand", students can self-select different programming and design challenges. This "choose your own adventure" challenge-set accommodates varying technical experiences, ranging from simple tasks, like creating a single flashing LED using MATLAB and Arduino, to complex projects such as designing multi-axis stoplight systems with left turn lanes and pedestrian crosswalks.**

By offering students autonomy in selecting their project challenges, we observed heightened self-reported levels of engagement, enjoyment, and a deeper sense of utility attributed to the skills acquired from their learning experiences. Moreover, this approach obviates the need to persuade students about the relevance of programming in engineering practice, as they experience it first-hand. Our assessment, reflected in end-of-semester course evaluations, demonstrates a notable shift in student perceptions. The percentage of students strongly agreeing to feeling engaged increased from 14% to 27%, with corresponding shifts observed across agree and slightly agree categories. Similarly, the percentage of students strongly agreeing to enjoying the class rose from 14% to 24%, with discernible decreases in slightly agree, slightly disagree, and disagree responses.

This abstract provides insights into a transformative pedagogical approach that not only enhances student engagement but also fosters a positive learning environment conducive to the development of essential engineering skills. This work is significant because it shares how programs can be scaled to add value and build foundational engineering skills no matter a student's technical background or engineering program enrollment.

***Keywords*— Engineering education, flipped teaching, student engagement, active learning, Arduino**

I. Background

The incoming first-year engineering college student body typically exhibits a fascinating bi-modal preparedness, reflecting a diverse spectrum of technical backgrounds and experiences. One can observe a distinct dichotomy: students who arrive with a solid foundation in STEM disciplines, perhaps having participated in advanced coursework or extracurricular activities, alongside those who may possess limited exposure to technical subjects, yet harbor a genuine enthusiasm for engineering. This bi-modal distribution presents both a challenge and an opportunity for engineering educators, necessitating the development of pedagogical approaches that can effectively engage and support students across this spectrum. Recognizing and addressing this bi-modal preparedness is crucial for fostering inclusive learning environments and nurturing the diverse talents and aspirations of aspiring engineers. Adding to the challenge many students may be well experienced in engineering graphics (technical drawings) but limited experience with computational methods, as others may have the complete opposite experience. Others may have worked with micro controllers for years through experiences such as FIRST Robotics, while others have had limited exposure or opportunities to learn. This represents a great challenge for educators who are tasked with guiding students through their first year engineering experience.

II. Prior iterartions oif first year engineering

Michigan Tech University's First Year Engineering program has been on the leading edge of pedagogical integration. The program has been team and project based since its inception in the fall 2000, following a flipped teaching model since 2010 [1], and full scale integration of near peers mentors since 2017 with its LEAP program [2]. It is well known that both active and flipped teaching enhance student performance [3] [4]. During this time the curriculum, while updated with student relevant topics and projects, was largely taught by explaining theory followed by active application and integration; topics, examples, homework, were homogeneous for all students and presented in a consistent scaffolded progression.

The scaffolded approach helped students with little to no experience develop their skills and build confidence as the course progressed. However, it was found that students with prior experience were left unchallenged. In the classroom, students are assigned into teams of four. Because of the experiential differences each student brings to the course, they are encouraged to help one another. However, these differences also had some students reflecting that they felt underprepared, fostering feelings of doubt that engineering might not be for them.

Over this time period, many of the projects and experiences were limited to the virtual environment. Programs were written in MATLAB with user interfaces and results observed through the computer screens. While students were able to work through these types of engineering problems, there was a clear lack of physical interaction and understanding.

III. Explore before you explain and choose your own adventure

In the fall of 2023, the first-year engineering program cast off the traditional approach of explaining before doing and dove headlong into fostering student exploration prior to in-depth explanation. This approach has been shown to promote exploration and novel discovery [5], results that are desirable in the engineering field. This radical change came with a few concerns that the teaching team was acutely aware of. Most crucially the teaching team did not want to overwhelm any student to the point of fearing they made the wrong educational decisions or not feeling as though they belong within engineering.

During the first week of class, students were handed an Arduino Uno kit, a wiring diagram, and written MATLAB code. Being an experiential flipped classroom, students then built the circuit, plugged in their Arduino and ran the supplied code. This code had a simple "for" loop which activated and deactivated a digital pin on the Arduino board. This pin was wired to an LED. Students were then encouraged to experiment and explore "numbers" or "values" within the code to see the effect they have on the flashing LED. Students changed the starting values, step size, ending values, and pause duration within MATLAB with magical engagement and affirmation results. Every member of the teaching team witnessed the initial and strong hesitation of "never" users turn into "fist bumps" and "high-fives". This first exposure supported growth and inclusion for new users as it helped them develop an operational understanding of "for" loops in MATLAB. Experienced users were able to choose a different task for the day, challenging them to apply their existing Arduino knowledge to more complex problems.

Since a flashing LED is not the most exciting device for students with deeper experiences with microcontrollers, more experienced students were encouraged to modify the MATLAB code and Arduino wiring diagram to make a red-yellow-green traffic light; or a two-road intersection red-yellow-green; or a two road intersection traffic light with left turns and crosswalks. Students choosing these challenges felt the same strong sense of accomplishment as new users did, leaving with a sense that class was meaningful. All challenges were awarded the same points.

These "choose your own adventure" challenges were designed to meet our minimum competency requirements while increasing the sense of independence and inclusion of less experienced students and challenging those with deeper prior experiences. This model of in-session assignment self-selection was continued throughout the semester on a variety of different topics and technologies.

IV. Early results

At the end of the fall semester students were given pertinent questions and were asked to respond using a six-point Likert scale (strongly disagree, disagree, slightly disagree, slightly agree, agree, strongly agree) with no neutral value. All data was collected and stored within proper IRB requirements. For this work in progress paper, we looked at student responses from the fall just prior to this change (Fall 2022) and the semester of the change (Fall 2023). The questions were "I felt engaged in this engineering course." (Table I) and "I enjoyed this engineering course." (Table II). Additional questions asked for student responses using a five-point Likert scale (strongly disagree, disagree, neutral, agree, strongly agree). For this work in progress paper, we looked at the question "I developed skills that will help me learn in future classes" and compared responses from the fall just prior to this change (Fall 2022) and the semester of the change (Fall 2023). (Table III).

Course survey data from the year prior to the new exploratory format were compared with course survey data from the exploratory year using a Pearson's Chi-squared test. Subsequent post-hoc tests were run on strongly agree vs. agree responses.

Table I. Comparison of student responses on end of semester survey question 1.

I felt engaged in this course.	**2022 (n=698)**	**2023 (n=781)**
Strongly Agree	14%	27%
Agree	59%	52%
Slightly Agree	19%	13%
Slightly Disagree	5%	4%
Disagree	2%	3%
Strongly Disagree	1%	1%

Table II. Comparison of student responses on end of semester survey question 2.

I enjoyed this course.	**2022 (n=698)**	**2023 (n=781)**
Strongly Agree	14%	24%
Agree	48%	46%
Slightly Agree	27%	20%
Slightly Disagree	5%	4%
Disagree	5%	4%
Strongly Disagree	1%	2%

Table III. Comparison of student responses on end of semester survey question 3.

I developed skills that will help me learn in future classes.	**2022 (n=698)**	**2023 (n=781)**
Strongly Agree	18%	25%
Agree	62%	58%
Neutral	15%	13%
Disagree	3%	3%
Strongly Disagree	2%	1%

Table I shows a dramatic positive and statistically significant shift with student self-reported course engagement. Students strongly agreeing with the statement went from 14% to 27% ($p<0.01$), with this increase shift coming from students who reported agree or slightly agree. There was no significant change in students who disagreed with the statement. The disagreement scores totaled 8% in both years.

Table II shows the positive and statistically significant shift with student self-reported course enjoyment. Students strongly agreeing with the statement went from 14% to 24% ($p <0.01$), with this increase shift coming from students who reported agree or slightly agree. There was no significant change in students who disagreed with the statement. The disagreement scores totalled 11% in 2022 and 10% in 2023.

Table III continues the trend of positive and statistically significant shifts with student self-reported learning skills that will help them in the future. Students strongly agreeing with the statement went from 18% to 25% ($p=0.01$), with this increase shift coming from students who reported agree or slightly agree. There was no significant change in students who disagreed with the statement. The disagreement scores totalled 5% in 2022 and 4% in 2023.

The results show a statistically significant shift through the “agree” responses toward “strongly agree” ($p < 0.01$) for course engagement and enjoyment. Additionally, results show a statistically significant shift toward “strongly agree” ($p = 0.01$) for believing that they learned skills to help them in future classes.

V. Things to Consider

Lack of prior experience: The faculty teaching team was extremely aware of the high level of anxiety that can occur when introducing new technologies in a classroom where bimodal experiences and preparations are present, especially with electronics and computers. With this in mind, the faculty worked to continually reassure new users as well as challenge developing and experienced users.

Everyone must be engaged: It is critical for each individual student to have the ability and opportunity to participate and develop skills. Because of this, we felt it was important for each student to have their own Arduino kit. Our class is team based, and prior to fall 2023 it was often the most experienced team member doing the work with others just observing. Those who were not experienced were either forced to engage or chose to sit back. With each student getting their own kit, while also able to select their own learning challenge, we were able to help the new users develop their skills and confidence and challenge the experienced users.

Model lifelong learning: It should also be noted that within the faculty team of the first-year program the background skills using microcontrollers varied significantly. This allowed many of the faculty to experience the same challenges faced by students in “real-time”. Often students would ask questions that we as faculty just didn’t know the answer to. We often responded with answers like “I don’t know, but let’s see who can figure it out first.” This modeled an approach to lifelong learning and allowed us to be a “guide on the side” instead of a “sage on the stage”.

Consistent instructional strategy: It is important for this type of instructional method to succeed that all faculty members be aware of the pedagogical model (explore before explain). Additionally, all faculty must be prepared with the facilitation strategies necessary to help facilitate the desired exploration by the students. A faculty member who is not as familiar or not comfortable with this type of learning strategy should be equipped with training in this area.

VI. Future Work

As of this draft, the course evaluation results from the Spring 2024 are being released to faculty. This data will be collected and included in a future paper with additional student and faculty responses. Although not presented in this work in progress, initial data on end of semester faculty evaluations showed increased student biases with faculty gender on perception of preparedness and knowledge base which will also be explored in future work.

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