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Exploring Engineering Students' Learning Experiences After Participating in a Mastery- and Project-Based Learning Intervention

Dr. Sophia Vicente, Elizabethtown College

Sophia Vicente (she/her) is currently a Postdoctoral Associate with Elizabethtown College and the Greenway Center for Equity and Sustainability. She has over 6 years of experience studying, teaching, and working alongside engineering students and faculty. Sophia is a former Science & Technology Policy Fellow at the National Academies of Science, Engineering, and Medicine and with this background, she is passionate about connecting research, practice, and policy. She holds a PhD in Engineering Education and MEng in Industrial and Systems Engineering from Virginia Tech as well as a BS in Industrial Engineering from Penn State.

Dr. Sara A. Atwood, Elizabethtown College

Dr. Sara A. Atwood is the Dean of the School of Engineering and Computer Science and Professor of Engineering at Elizabethtown College in Pennsylvania. She holds a BA and MS in Engineering Sciences from Dartmouth College, and PhD in Mecha

Dr. Kurt M Degoede, Elizabethtown College

Professor of Engineering and Physics, Elizabethtown College. His research interests in biomechanics include developing clinical instruments for rehabilitation. Dr. DeGoede teaches upper-level undergraduate mechanical engineering using a Mastery-Based assessment model and design courses and first-year multidisciplinary courses.

Rebecca Holcombe

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Introduction

As calls have increased to promote active learning, project-based learning has been recommended as an experiential pedagogical methodology in engineering education to support the development of real-world skills among students [1]. Additionally, mastery-based assessment has emerged as a grading approach to effectively assess learning in engineering classrooms [2] and for students to reframe failure as an opportunity to learn [3]. While there is a significant amount of literature on project-based learning [1] and recent literature on the promise of mastery-based assessment in engineering education, there are fewer papers that focus on the intersection of applying the project-based learning approach with the mastery-assessment technique [2],[3].

In Fall of 2023, a one-semester pilot program was conducted which focused on project-based learning and mastery assessment. An overarching goal of the project was to explore the impact of these approaches on engineering students in a "study away" context. As part of the broader project, the research team conducted semi-structured interviews with the previous participants one year after the pilot semester.

The purpose of this work-in-progress paper is to qualitatively explore engineering students' learning experiences after participating in a project-based learning, mastery-assessed intervention program. Specifically, we explored students' perceptions of their experience and learning one year after participating in the intervention. We sought to answer the following research questions:

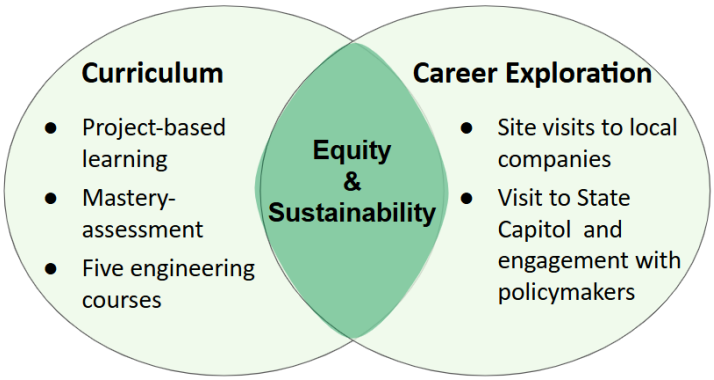
> **RQ1:** How do students describe returning to the "traditional classroom" in Spring of 2024 after their participation in the program?
> **RQ2:** How do students describe their summer internship experience in Summer 2024 after their participation in the program?
> **RQ3:** How did students describe learning across their experiences?

Background

Program Context

The broader project involved a partnership between a small Mid-Atlantic college and a Northeastern educational non-profit to design and execute an innovative, immersive engineering education "study away" program. The focus on the pilot semester in Fall 2023 was to deliver an innovative hands-on engineering curriculum and allow students to engage in career exploration. On the curriculum side, this was conducted through project-based learning and mastery-assessment. Students took five engineering courses during the semester including: Circuits Analysis, Circuits Analysis Laboratory, Statics, Calculus III, and Physics II. On the career exploration side, the students engaged in site visits, called "career treks," to local engineering employers and visited the State Capital Building while the legislature was in session to engage with local policymakers. Equity and sustainability were integrated throughout the program design and course content. Additional detail regarding the program design can be found in previous work [4]. The diagram below illustrates major focus areas of the program.

Figure 1. *Major Areas of Program Focus*



From the overarching study, previous research has been shared exploring engineering identity, failure, and mastery-based assessment [3]-[5]. The results of the prior research and this work-in-progress paper will be used to inform a second pilot semester in Spring 2025.

Literature Review and Framework

In alignment with continued calls for active learning and for the integration of professional skills into the engineering curriculum, there has been a significant increase in research on project-based learning in engineering over the past 20 years [1]. Scholars claim that both problem-based and project-based learning originated from the reform universities and the new educational models established between 1965 and 1975 [6]. Furthermore, project-based learning has been promoted as a promising practice to meet the needs of the 21st century and build critical skills for engineering [1], [7].

In comparison, the techniques of mastery-based assessment and mastery-based learning are newer to the engineering classroom. Mastery-based assessment including the grading and performance evaluation activities that aims to measure mastery or competency. Mastery-based assessment has also been applied as "standards-based grading" [2]. Mastery-based assessment often goes hand-in-hand with mastery-based learning or mastery learning. Mastery-based learning originated from Bloom [8], [9], who adapted Carroll's [10] model of learning [11]. Mastery-based assessment differs from the traditional classroom approach in that students are able to attempt mastery multiple times and the focus is on demonstrating mastery or full understanding of a topic before moving forward. Traditional assessment in comparison is assessed on a 0-100 scale, is typically a one-time assessment of knowledge, and is often delivered through high-stakes quizzes or exams.

Engineering education scholars have found that standards-based grading or mastery-based assessment can be effectively used to assess project-based courses [2]. Furthermore, in a systematic review focused on mastery learning in engineering undergraduate courses Perez and Verdin [12] found that there were six mastery learning evaluation metrics common across the studies they reviewed including (1) exams, (2) final exams, (3) quizzes/assessments, (4) homework, (5) class activities, and (6) projects. They further found that "most of the implementations used two forms of evaluation metrics to assess students' mastery" and the most common evaluation metrics used were exams in combination with quizzes, homework, or the

final exams [11]. The review demonstrated that projects are not as commonly used as an assessment tool in engineering courses that use mastery-based learning. Based on prior work, there is promise for the application of mastery-based assessment in project-based learning contexts and this work-in-progress paper will explore the application of project-based learning and mastery-based learning.

Methods

For this work-in-progress paper, we used an exploratory qualitative approach to answer the research questions and gain a deeper understanding of students' experiences one year after participating in the program. This paper builds on prior studies conducted by the research team [3]-[5] to collect retrospective data and explore the students' perceptions of the longer-term impacts after the intervention.

Participants

Due to the small sample size and identifiability of participants, we will share an overview of participant characteristics and will use gender neutral pseudonyms (Alex, Jordan, Riley, and Taylor) when referring to participants in the results. All four participants were either engineering majors or had an engineering minor and their concentrations included Mechanical Engineering, Civil Engineering, and Business with an Engineering Minor. Three of the four students were in their second year enrolled at [Partner Institution] and one of the students was a visiting student at [Partner Institution] in their third year at [Other Institution]. After participating in the pilot program, three of the four students participated in a paid summer or fall internship, and all four students persisted in their engineering major or minor coursework.

Data Collection and Analysis

We conducted four semi-structured interviews approximately one year after they participated in the program. Each interview was conducted virtually and lasted approximately one hour. The protocol for the semi-structured interviews can be found Table 1.

Table 1. *Protocol Questions*

Target Information	**Interview Guiding Questions**
Program reflection	Can you tell me a little about your experience with the program and overall, how you feel now about that semester?
Reflection on coursework post-program	Can you tell me what you have been doing in the months since participating in the program? ● Follow up: How did your courses go in the Spring about returning to the main campus? ● Follow Up: Can you describe similarities and differences between your Spring 2024 semester and your Fall 2023 program experience?
Reflection on internship and work post-program	Do you feel that your experience last fall influenced your Summer 2024? If yes, in what ways?
Reflection on internship and work post-program	If you had an internship this past summer, ● What did you learn about engineering work from your

	internship? ● Do you feel that the Greenway program prepared you or was useful for your internship? Why or why not? ● Can you describe similarities and differences between your internship and the Greenway experience?

The interviews were transcribed and analyzed using thematic analysis [12], [13]. Specifically, we engaged in the six phases of thematic analysis including: (1) data familiarization, (2) generating initial codes, (3) searching for themes, (4) reviewing themes, (5) defining and naming themes, and (6) producing the report [12]. To ensure research quality, we leveraged Walther and colleagues' [14] framework for quality in interpretive engineering education research as a guide for our study.

Preliminary Results

From the preliminary results, we found that all of the previous participants strongly felt that GCES influenced their approach to their Spring coursework and those who engaged in internships during the summer following GCES felt that they were able to apply their learning at work. They attributed their perceptions to the mastery-based assessment and project-based learning.

Returning to the Traditional Classroom

In discussing their return to the traditional engineering classroom in the semester following the pilot program, several students discussed feeling more confident and having a better understanding of their learning. In terms of confidence, the students discussed feeling motivated and more confident in their ability to learn in the traditional classroom, attributing these feelings to the support system they had built. For example, Riley shared:

> "*I was very motivated in them [Spring courses]. I was very like I would ask questions. I would dedicate so much time to just immersing myself in the curriculum and . . . and going over topics multiple times to make sure that I had no questions about them. Me and the other [Pilot program] students who were at [Main Campus] would meet up and go over everything cause we had grown very close. So, it definitely . . . that support system followed me to [Main Campus].*"

Additionally, several students described having a better understanding of what steps to take when they were not doing well with a particular course or topic or topic. They also elaborated and discussed an example of not doing well on an exam in a more "traditionally taught" course in the Spring but being able to identify where they went wrong. Further on in their interview, Riley shared how they got points off on a traditional exam and how they were able to learn from the experience in a Spring course. They stated,

> "*It wasn't because we didn't understand what was going on, but because we didn't have that second chance of going back and saying, 'Okay this is this is a non-conceptual error, let me adjust this and resubmit it.*"

Internship Experiences

In discussing applying to and completing engineering internships after the pilot program, students felt that the intervention provided direct and indirect support for engineering

internships. In terms of direct support, one of the students directly obtained an internship from a company that they conducted a site visit at during the program. From the site visit, the student applied to the company, received an offer, and returned for a summer internship. The student who received and participated in the internship spoke about this direct benefit during the interview. Alex explained,

> "*I can't understate that this was the . . . the only place that got back to me really at all was because I had visited them through [Program]. . . But [Program] helped me get those advantages in a way that just being at [Main Campus] would not have, because it's all about who you know, to get internships really. And [Program] made sure that I knew people who could help me.*"

Additionally, during the interviews with the other three students they each shared the story of their peer, Alex, obtaining an internship as an example of the support the program had on professional development.

In terms of indirect support, all of the students felt that the professional skills they built during the program were useful for applying to and engaging in internships. Taylor described applying the professional skills they built in the program broadly, explaining

> *"Going into summer, starting at [Engineering Company], I have had a great experience there, and I have utilized a lot of the ideas within [program], and have been able to take my learning in current courses and apply that to my job and vice versa. My position is engineering intern. So, I'm working with engineers in the work environment, working directly on projects and Kaizens and I have gotten to utilize my skills that I've learned and grown from [Center] both during [program] and after [program]."*

Furthermore, previous participants shared how the intervention helped them to become more confident communicators and public speakers during interviews and in their internships. For example, Alex shared how they used the communication and presentation skills they built during their internship:

> "*One of the things we did at [Center] a lot was we had to do presentations which definitely helped during my internship because I had to do a few of those. And we did more of them at [Center] than I've been doing otherwise [at Main Campus]. It's a very important skill to have to be able to speak it to a group.*"

Learning Across Their Experiences: Self-Regulated Learning and Professional Skill Development

Across their experiences after the intervention program, students emphasized how the program influenced their learning in the traditional classroom and at work. In the classroom, students described feeling more motivated and confident in their ability to learn, often describing self-regulated learning practices [15]. The previous participants attributed learning about themselves as learners to the mastery-based assessment they experienced in the intervention. At work and during internships, students described applying the professional skills they learned during the intervention to their roles and making connections between the intervention at work. The previous participants attributed their professional skills to the project-based learning approach in the intervention. Through the interviews and preliminary results, we found that the

intervention supported students' learning about both themselves as learners and themselves as engineers.

Interestingly, while most participants shared that they were not as initially drawn in by the sustainability focus of the program, all of the students interviewed said they were considering sustainability or "green energy" in their future careers. This finding demonstrates that while it may not have been participants' primary reason for choosing the program, the sustainability mission of the program is still a key component.

Recommendations and Future Work

This work-in-progress paper set out to qualitatively explore engineering students' learning experiences after participating in a project-based learning, mastery-assessed intervention program. We found that students felt that they grew as learners and as engineers. Furthermore, previous participants felt that mastery-based assessment supported their learning about themselves as learners in the classroom and project-based learning supported their professional skill development for work.

Based on this work we have two primary recommendations for future program iterations. Recommendation 1 is for the program to "Continue hands-on, project-based, mastery-assessed learning and consider ways to incorporate sustainability." This recommendation is grounded in students' perspectives on learning about themselves as learners and as engineers. Furthermore, all four participants discussed a stronger interest in sustainability after participating in the program, therefore, it will be important to maintain this important aspect of the program. Recommendation 2 is for the program to "Set aside time for reflection in the upcoming iteration as it was an important element of learning in both course content and career development." This recommendation is supported by the previous participants' strong ability to reflect on themselves as learners and as engineers. One year later, the students demonstrated behaviors associated with self-regulated learning and reflection is a key practice in building these skills. Due to the nature of qualitative research, these recommendations may be transferable to other contexts but are not generalizable.

This work-in-progress began to explore the reflections on the participants' coursework, internship, and engineering experiences post-intervention. In terms of practice, the findings from this work will inform a second pilot semester. In terms of research, future work will compare across students who participated in the intervention and students who remained at the main campus.

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