Redefining Achievement: A Longitudinal Study of Undergraduate Researchers' Perceptions of Assessment

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1. Introduction

1.1. Engineering Practice and Undergraduate Assessment

Preparing engineering students for professional practice in today's era requires not only mastery of disciplinary and technical knowledge taught in formal coursework, but also the development of adaptive, reflective, and self-regulated learning skills [1]. Traditional undergraduate assessment structures, anchored in well-defined problems with known solutions often emphasize technical correctness and final submissions, leading students to equate achievement with task completion. In contrast, engineering work in professional contexts is inherently open-ended: problems are ill-structured, constraints evolve continuously, partial solutions persist across timelines, and progress frequently depends on judgment, negotiation with stakeholders, and iterative adaptation [2]. These characteristics complicate the simple notions of success and require engineers to continuously assess progress in the absence of clear or well-defined endpoint goals.

Such conditions place heightened demands on metacognitive processes, including planning, monitoring, and evaluating one's own learning and performance across the extended period of task being performed. Engineers must make sense of incomplete information, justify decisions under uncertainty, and revise goals as project contexts or constraints change - activities that are fundamentally metacognitive in nature. Developing these skill sets during undergraduate education as a student is therefore critical for preparing them to navigate the realities of professional engineering practice.

1.2. Need for Longitudinal Insight

In today's engineering education landscape, curricula often provide limited mechanisms and insights into how students interpret and evaluate their own learning across sustained, personal experiences. While capstone courses, internships, and undergraduate research experiences offer valuable exposure to applied engineering work, they are frequently bounded by institutionally imposed time frames, have predefined project scopes or deliverables, and are often framed by faculty or industry mentors rather than students, which constrains the openness of the problems that students experience [3]. As a result, students have relatively few opportunities to repeatedly engage with questions of progress, success, and learning as projects evolve over time. In particular, there remains a scarcity of studies that examine how students redefine success, justify progress, and evaluate their standing as they engage repeatedly with open-ended engineering tasks that unfold across multiple semesters.

1.3. Prior Work and Gap Addressed

Prior work by the authors [4], [5] examined a multi-semester undergraduate research program designed to emulate key features of professional engineering practice. That study documented how participation in the program supported undergraduate development of professional competencies aligned with industry-identified gaps, including discursive fluency, contextual judgment, adaptability, and leadership, along with many other key parameters. It further characterized the structural features of the program, such as student leadership, interdisciplinary collaboration, and vertical integration, that appeared to scaffold the development of these competencies. While this prior work established *what* skills students reported developing and *which program structures* supported those outcomes, it did not examine how students themselves conceptualized and evaluated achievement as their work progressed. In particular, questions remain regarding how students interpret success, assess learning, and frame progress when engaging in sustained, open-ended engineering research that lacks clearly defined endpoints.

1.4. Purpose and Contribution of the Present Study

Building on this foundation, this study shifts focus from observed outcomes to how students conceptualize and evaluate their own achievement and standing over time. Using longitudinal self-assessment data collected across multiple reflective submissions over two academic semesters, this work examines how students' perceptions of achievement evolve within a sustained, open-ended engineering research context. Specifically, it explores how students frame progress, justify success, and engage metacognitively with their learning as project conditions evolve and responsibilities change.

By foregrounding students' reflective narratives and examining changes across time, this study responds to two interrelated needs in engineering education research. First, it addresses a growing imperative to better understand metacognitive development within authentic learning environments. Second, it contributes longitudinal evidence capturing how students' self-interpretations of learning and achievement change through sustained engagement with complex engineering work. The findings of this study aim to inform assessment design, curricular structures, and undergraduate research models that more closely align educational experiences with the realities of professional engineering practice.

2. Background

2.1. Undergraduate Research Experiences in Engineering Education

Undergraduate research experiences (UREs) have been widely recognized as high-impact practices in engineering education, supporting student engagement, persistence, and development of technical and professional skills. Prior studies have shown that participation in UREs can strengthen students' research competencies, critical thinking, and sense of belonging within engineering disciplines [6]. In addition, sustained research engagement has been associated with improved retention and persistence, particularly when students are involved early in their academic careers [6], [7].

Despite these documented benefits, many traditional URE models remain limited in duration and scope. Faculty-directed research projects are often bounded by academic semesters or summer programs, with narrowly defined objectives and deliverables. While such structures provide valuable exposure to research methods, they may constrain opportunities for students to experience continuity, evolving responsibility, and ownership over extended periods of work. As a result, students may have limited opportunities to reflect on how learning and achievement unfold over time within complex, ill-structured engineering problems. More recent work has called for URE models that emphasize vertical integration, continuity across cohorts, and student agency [8]. Vertically integrated research structures, in which students at different academic levels contribute to persistent projects, create conditions for knowledge transfer, peer mentorship, and progressive responsibility. These features more closely resemble professional engineering environments and offer a promising context for examining how students interpret learning and achievement across extended engagements.

2.2. Metacognition and Reflective Assessment in Engineering Education

Metacognition refers to an individual's awareness of their own learning process and their ability to predict future performance [9], [10]. Although many frameworks of metacognition have been developed over time, the current literature shows a general agreement on two main components: the awareness of cognitive processes and the self-regulation of said processes. The awareness of cognitive processes encompasses the declarative, procedural, or conditional knowledge required to complete a learning task. On the other hand, the self-regulation of the process encompasses planning, monitoring, or evaluating the learning task [11], [12], [13].

Research has found that implementing metacognitive approaches in learning allow students to transfer knowledge between contexts more easily [9]. This makes metacognition an interesting framework to adopt when evaluating student's achievement in undergraduate research. In fact, various studies have found a positive relationship between metacognitive ability and problem solving, particularly with ill-structured problems [14], [15], [16]. Moreover studies show that the use of metacognitive strategies and metacognitive reflection improve students' research skills like planning, monitoring, and evaluating a research problem [17]. Veenman [18] posits that science education integrates the development of metacognitive skills through scientific reading, science problem-solving, scientific inquiry, and scientific writing; activities which are all present in the research process. Studies also show that group work supports metacognition because it encourages students to verbalize their thinking to discuss ideas [12]. This highlights the alignment between conducting research and the development of metacognitive skills.

Reflective and self-assessment practices have been shown to support metacognitive development by making learning processes visible to students and instructors alike [19].

Structured reflection can prompt students to articulate claims about their learning, justify those claims with evidence, and examine challenges, uncertainty, and growth. When embedded intentionally, reflective assessments can shift students' focus from product-oriented outcomes toward process-oriented understandings of learning and progress. However, much of the existing engineering education literature examines metacognition and reflection at isolated points in time, such as within a single course or at the conclusion of a project. There remains a limited understanding of how students' metacognitive framing-and their definitions of achievement-evolve longitudinally as they engage repeatedly with open-ended engineering work. Longitudinal reflective data, particularly in authentic research contexts, offers a valuable yet underexplored opportunity to examine these developmental trajectories.

2.3. The English-to-Engineering (E2E) Program

The E2E program at Virginia Tech provides a distinct context for examining longitudinal development in students' perceptions of achievement and learning. Developed in collaboration with industry partners through the Pratt & Whitney Center of Excellence, the program was designed to address gaps in undergraduate preparation identified by both faculty and industry stakeholders. The E2E program engages undergraduate students from multiple academic levels and disciplinary backgrounds in multi-year research projects centered on sustainability in aerospace propulsion. Participation is open to students across the university for all majors, with selection based on interest and motivation rather than prior disciplinary expertise. This structure intentionally supports interdisciplinary collaboration and allows students to contribute diverse perspectives to technically complex engineering challenges.

A defining feature of the program is its emphasis on student-driven research projects. Unlike traditional UREs where faculty serve as principal investigators, E2E positions students as project leaders responsible for defining research directions, managing project progress, and coordinating team activities. Faculty mentors and industry experts act as coaches, providing guidance and feedback while preserving student ownership of decision-making processes. Students typically dedicate 3–5 hours per week to project work, participate in weekly meetings, and engage with external stakeholders throughout the academic year. Through this design, [blinded for review] creates an environment in which learning is not confined to task execution but extends to judgment, coordination, communication, and reflection-capabilities that are central to professional engineering practices.

2.4. The E2E Program Cycle

A key structural element of the E2E program is its recurring, multi-year activity cycle as illustrated in Figure 1. Rather than following a linear progression from project initiation to completion, E2E operates through repeated cycles of recruitment, onboarding, project planning, execution, reflection, and dissemination. Each cycle builds on prior work, with research projects persisting beyond the involvement of any single cohort of students.

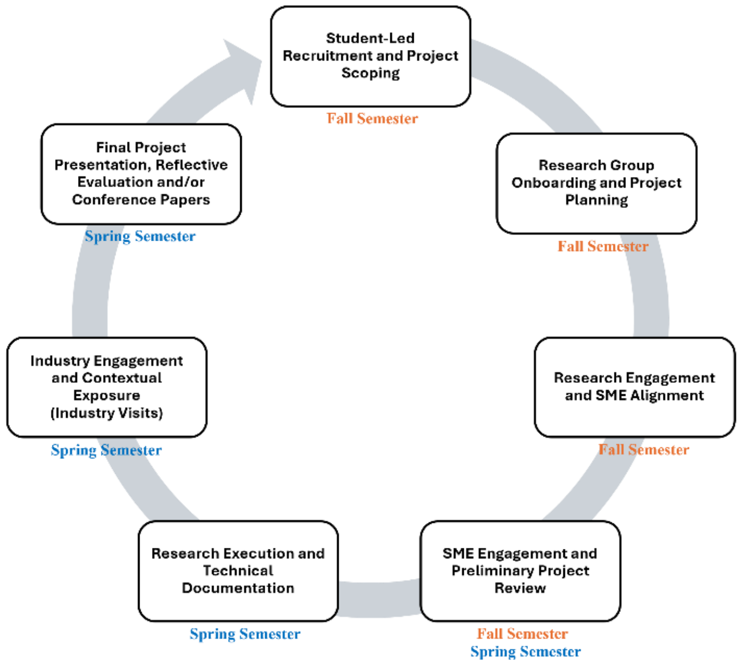

Figure 1: The E2E program yearly cycle

As shown in Figure 1, each program cycle begins in the Fall semester with *student-led recruitment and project scoping*, during which returning students identify ongoing project needs, recruit new members, and collaboratively refine research directions. This phase establishes early student ownership and requires participants to articulate project goals, constraints, and expectations-often to audiences with varying levels of technical familiarity. Newly recruited students then engage in *structured onboarding and project planning*, where knowledge transfer occurs through documentation, peer-mentoring, and collaborative goal setting. These activities require both new and returning students to reflect on prior decisions, assess project status, plan future work under uncertainty, and overall, work together. Following onboarding, students enter a phase of *research engagement and subject-matter expert (SME) alignment*, in which they conduct technical work while identifying and coordinating with faculty mentors and industry SMEs. This alignment ensures technical relevance while preserving student leadership in decision making. Students subsequently present early progress by late fall or early spring semesters, through the *SME engagement and preliminary project reviews*, receiving formative feedback that often necessitates re-evaluation of the scope, assumptions, refinement of research questions, and adaptation of technical approaches. As projects mature, students focus on *research execution and technical documentation*, producing reports, analyses, and artifacts that capture both results and rationale. Documentation serves not only as a record of technical progress but also as a mechanism for continuity, enabling future cohorts to inherit and extend prior work. Students also participate in *industry engagement and contextual exposure*, such as site visits or external interactions, which situate their research within professional engineering environments and prompt reflection on relevance, constraints, and stakeholder perspectives.

Each cycle concludes with a *final project presentation and reflective evaluation* during the spring semester, during which students communicate outcomes, assess progress relative to evolving goals, and identify future directions for subsequent cohorts. Importantly, this endpoint is not a termination of the project but a transition point within the larger program cycle. Returning students assume increased responsibility in mentoring and leadership roles, while departing members transfer ownership through documentation and onboarding processes. This cyclical structure creates repeated, natural opportunities for reflection and self-assessment, as students must continuously define what constitutes meaningful progress in the absence of fixed endpoints. By requiring students to repeatedly plan, monitor, evaluate, and reframe their work across semesters, the E2E program cycle closely mirrors the conditions of professional engineering practice in industry. Hence, by leveraging the structural and pedagogical features of the E2E program it provides a unique opportunity to investigate how undergraduate students conceptualize and evaluate their own learning over time and also presents itself as a well-suited context for examining longitudinal changes in students' perceptions of achievement and metacognitive engagement, which is the focus of the present study.

3. Methods

3.1. Participants

The participants for this study were selected using purposeful sampling based on their participation in the E2E program and the completeness of their assignment submissions. Purposeful sampling involves strategically selecting participants whose experiences align with the goals of the study [20]. Since the goal of the study was to explore the changes in student perceptions over time, the eligibility criteria included students in the E2E program who had submitted a reflective assignment at every stage of the program. Out of the entire pool of students participating in the program, 9 students submitted all five reflective assignments between the Fall 2024 and Spring 2025 semesters. All data collected was fully anonymized, and the participants were given pseudonyms to allow for longitudinal analysis. Institutional review board (IRB) approval was obtained to perform the study.

3.2. Data Collection and Analysis

Data for this study were collected through a series of required, individual assignments submitted through a learning management system as part of an undergraduate research program. The assignments were designed to elicit students' self-assessment of learning relative to the student learning outcomes (SLOs) stated in the course syllabus. Self-assessments were supported by self-evident artifacts intended to demonstrate learning and by reflective prompts addressing challenges, constraints, and growth. In addition to the stated SLOs, students were invited to identify transferable learning outcomes that extended beyond course-defined outcomes.

Data were collected at five points across two academic semesters: Fall 2024- Beginning of Semester (BOS), Fall 2024 – Mid-Semester (MOS), Fall 2024 – End of Semester (EOS), Spring 2025 – Mid-Semester (MOS), and Spring 2025 – End of Semester (EOS). All submissions were individual rather than team-based and were stored in anonymized form for longitudinal analysis. Although the specific assignment prompts evolved over the course of the two semesters, they all shared the same underlying structure. Students were asked to 1) articulate claims about their learning or progress towards specific SLOs, 2) provide stand-alone evidence intended to demonstrate that learning, and 3) reflection on challenges, uncertainty, or constraints encountered throughout the research process. In all assignment prompts. ambiguity and partial progress were explicitly noted as natural aspects of undergraduate research rather than framed as deficits.

The Fall 2024 BOS instrument was forward-looking rather than reflection in nature, thus different from the other instruments used here. Students were asked to develop an individual assessment plan describing how they intended to meet the SLOS and what artifacts they anticipated they would use to justify claims about learning, how those artifacts would be assessed, and what criteria would determine success. From an instructional design perspective, analysis of the Fall24 BOS data suggested that future-oriented planning was not sufficiently scaffolded in the research program at that time [5]. These artifacts reflected abstract aspirational thinking rather than actionable assessment plans and were particularly complicated for students to complete in an open-ended and evolving research program. As a result, beginning of semester planning assignments were discontinued as required course assessments in Spring 2025 as instructional supports had not yet been adequately established.

Fall 2024 MOS and EOS instructions tasked the students with a performance-based reflection rather than a forward-looking planning assignment. The mid-semester instrument was framed as a formative assessment, asking students to document demonstrated learning, remaining gaps, and plans to adjust to close those gaps. The EOS instrument was similarly reflective but was framed as a summative assignment in which students primarily made claims of SLO achievement with provision of evidence. The Spring 2025 MOS and EOS mirrored the Fall semester formative-summative pairing but did not include the BOS planning phase. Spring instruments provide a standardized template to align submission structure across students.

The data were analyzed using a thematic analysis approach to identify emerging themes around the student submissions. As prescribed by Braun and Clarke [21], there were two main phases within the thematic analysis. First, a codebook was generated to identify patterns among the student submissions. A priori codes were available following the findings of previous research [5] as well as the metacognition literature. To supplement the a priori codes, all four researchers individually performed emergent coding with a sample of the data. Researchers then met to reach consensus amongst the codes and their definitions. After the codebook was developed, the student artifacts were analyzed line-by-line focusing on the students' descriptions of their learning process and metacognitive skills, research challenges and achievements, and future plans. The second stage of thematic analysis was to determine the themes that arose from the codes. The codes and data excerpts from the analysis were used to identify themes and patterns across the data.

3.3. Limitations

The data in the study are derived from required, self-reported assignment. Although students were required to support their claims of learning with stand-alone evidence, the data reflects students' own interpretations of their learning process and progress. Responses may be influenced by confidence or strategic framing, especially since end-of-semester submissions were tied to grading. Although the inclusion of artifacts of learning mitigates some of the self-reporting risks, there is still a degree of variability in what students considered adequate or compelling evidence.

4. Results and Discussion

Four broad themes emerged from the analysis. The first theme grouped codes that showcased the students' learning process and they became experts in their field. The second theme included themes where the students applied their newfound knowledge to perform research tasks. The third theme integrated codes that showed the students sense of overcoming challenges. Finally, the fourth theme included codes focused on teamwork, particularly those that discussed the transfer of knowledge to new members.

4.1. Learning and Becoming Experts in their Field

There were three codes that highlighted the students' process of becoming an expert in their field: acquisition of field language, discursive code switching, and metacognition.

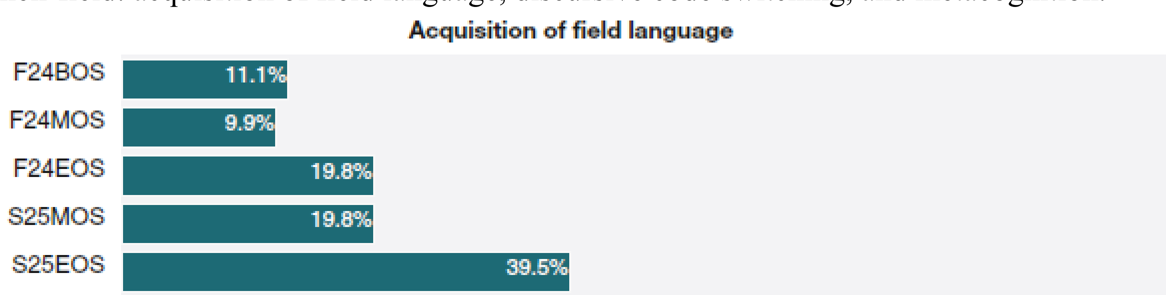

Figure 2: Results for the Acquisition of Field Language Code

Acquisition of field language focused on instances when the student demonstrated the ability to use discipline or domain-specific language. Based on the coding, the participants acquired language specific to their project as time went by.

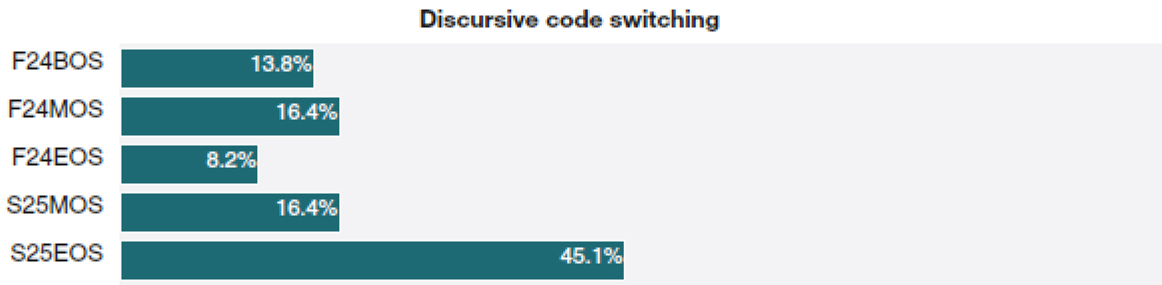

Figure 3: Results for the Discursive Code Switching Code

One of the main goals of the [blinded] program is for students to be able to communicate their research to broad audiences. The *discursive code switching* code highlighted instances when students were able to adapt domain specific language to a diverse audience in a way that is comprehensible or accessible. The results show that, through the semesters, students feel more confident discussing their research with their peers, faculty mentors, and industry connections. One student reported that this was beneficial when talking with industry connections. He said: "I held a meeting with [our mentor] of Pratt and Whitney and was able to keep up with his explanations on how engines work in NPSS and accurately describe the roadblocks encountered during our own modeling."

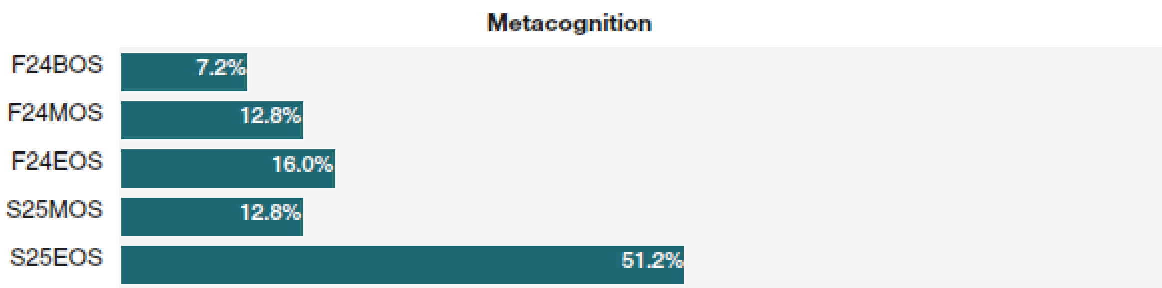

Figure 4: Results for the Metacognition Code

The *metacognition* label was used when students reflected on their learning process or knowledge acquisition. Students were able to acknowledge the new knowledge they've acquired throughout their participation in the research project and can project different ways in which they will use it in the future. For example, one participant said, "Through this project, we have expanded our understanding of combustion elements and airflow in engines. Now, we are leveraging this knowledge to modify turbofan components and incorporate hybrid electric technology into our model."

The outcomes of this theme demonstrate how students use metacognitive skills to become experts in their field. Throughout the two semesters, students evaluated their progress as they moved from being uncomfortable discussing their research with multidisciplinary groups to becoming confident at the end of their project. Their own perception at the end of the spring semester indicates that they have developed the ability to switch and communicate across diverse audience as they gained more confidence on their own knowledge. The analysis shows gradual progress that culminated in high achievement by the end of the spring semester.

4.2. Using their Expertise to Conduct Research

There were two codes that highlighted how students applied their metacognitive skills to conduct research. *Contextual judgement* focused on choosing or deciding methods, parameters, or models based on the research context and *situational awareness* focused on the accurate recognition of contextual constraints. Both codes are part of the metacognitive skills necessary to perform research.

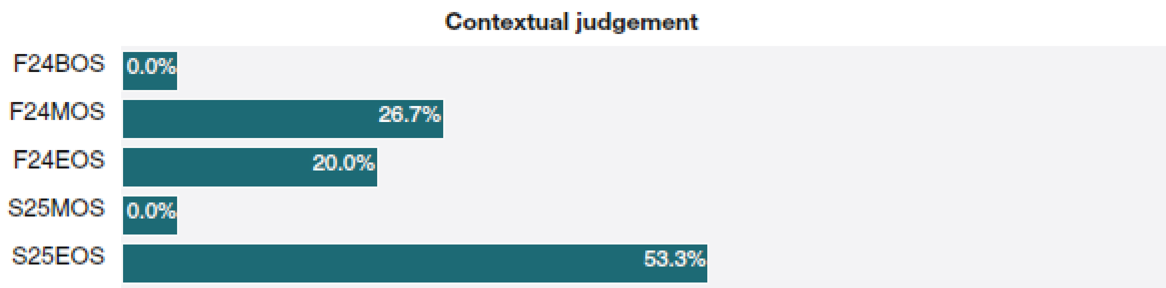

Figure 5: Results for the Contextual Judgement Code

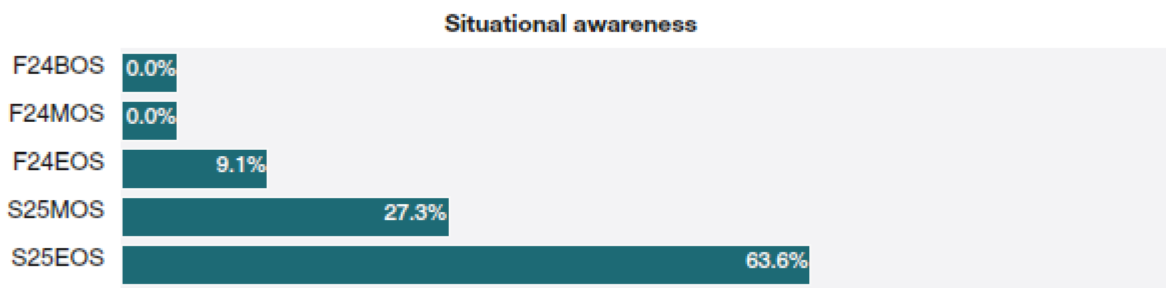

Figure 6: Results for the Situational Awareness Code

From these figures, the students' use of metacognitive skills is not linear. By taking part in a multi-year research project, the students go through a re-evaluation phase where they reconsider the project goals and their own capabilities. Towards the end of the spring semester, they become aware of project contextual constraints. For example, one student commented on how the weather created unexpected delays in their testing plans. They said, "Regarding testing, the snowy weather twice pushed back training of new members of the DMA and TGA machines, making it more difficult for us to staff our scheduled lab sessions." They go on to describe how the team had to pivot and have various team members step up to fill vacancies when needed. Other teams experienced delays when ordering parts and reflected on those issues as lessons learned for the future.

The results for this theme showcase the students' experience of conducting research and progression. They describe an elevated contextual judgement and situational awareness in terms of complex or ambiguous circumstances. In this program, students work on the previously on-going project, identify the gaps in the completion of the project and then make informed decisions on the future direction of the work under the mentorship of faculty and industry. These gaps or challenges may arise due to delays in lab equipment, logistics/administrative issues or project changes due to delays in data collection. The results show that students made the most progress towards gaining expertise to perform research during the spring semester, as was the case for the previous theme.

4.3. Overcoming Obstacles

There were two main codes that encompassed the feeling of overcoming obstacles. First, *handling complexity or ambiguity,* highlighted students' ability to work on ill-defined problems or unexpected outcomes. The second code, *response to challenges*, measured the students' adaptability after encountering a challenge. From the metacognitive perspective, these two codes focus on the self-regulation process of learning.

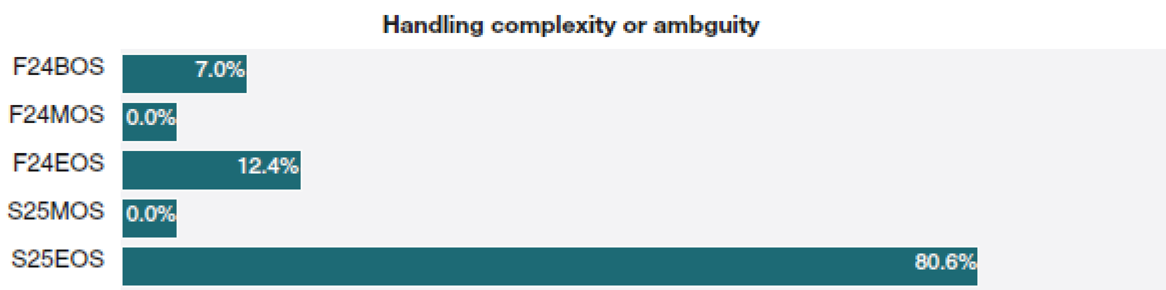

Figure 7: Results for the Handling Complexity or Ambiguity Code

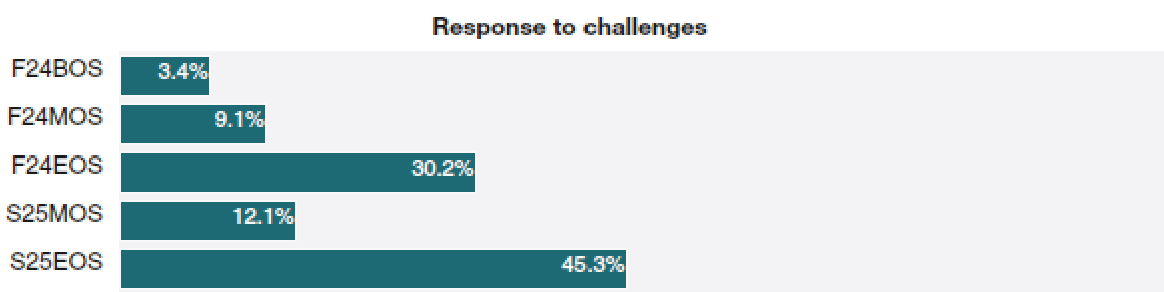

Figure 8: Results for the Response to Challenges Code

As seen from Figure 7 and Figure 8, students' self-reflection tends to happen towards the end of the semester. Although they are encouraged to discuss the challenges they have faced throughout the research process for every assignment, most of the students chose to discuss it in detail only during the EOS assignments. Many of the challenges students faced were related to the process of conducting research on a topic they were initially unfamiliar with. One of the participants explained this when "A key challenge this semester was learning to navigate an unfamiliar domain, electrostatics, which falls outside traditional aerospace coursework. I initially struggled to understand voltage applications and safety constraints, but regular meetings with ECE faculty helped me build confidence."

The delay in the response to challenges might be explained by the activity cycle of the program. Since students start analyzing the ambiguity of the ongoing project after inheriting it from previous students, their experience with challenges might be delayed until the spring semester. Once they begin to perform research, they learn to adapt by managing the complexity of their research task and securing material resources. Because of the vertically integrated nature of the project, the students interact with participants with different skill sets and skill levels to evaluate the team progress to determine next steps. Students demonstrated a capability to overcome challenges throughout the program to fully realize their own potential and understand the circumstances that supported their learning. Thus, by the end of the spring semester, they developed a deeper understanding of their own potential and assumed increasing responsibility within their projects.

4.4. Progressive Responsibility and Vertically Integrated Teams

The E2E program was developed around the idea of progressive responsibility and vertically integrated teams where more senior students would take on leadership roles and recruit newer members as needed. Therefore, many of the codes that arose followed a theme of teamwork and plans for the team's future.

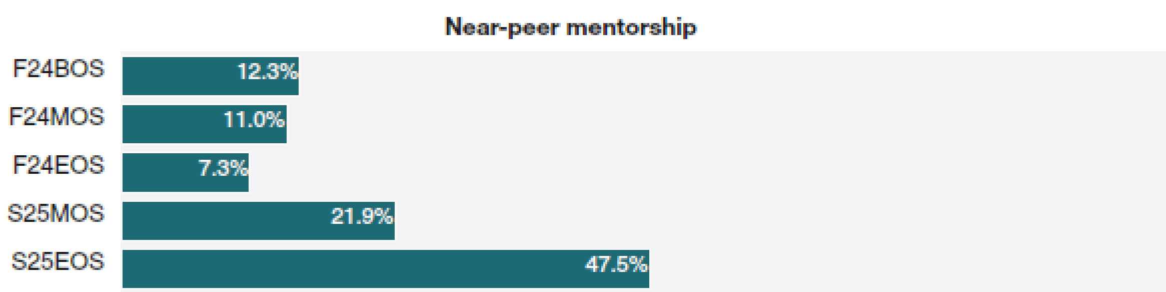

Figure 9: Results for the Near-Peer Mentorship Code

The *near-peer mentorship* code focused on guidance given to or received from a peer. This included teammates as well as other students in the program who are part of other teams. There is a clear difference between the fall and spring semesters that might be tied to the recruitment cycle. Since new students are recruited during the fall semester, it is possible that the majority of the onboarding and mentorship starts during the spring semester. During the Spring 2025 MOS survey, one of the students said: "While I have learned much more information in my classes, many of our newer members have not encountered these concepts yet. I remember being in their position, struggling to understand the significance of different values and ratios. To help bridge this gap, I have been using notes from my classes to explain the parameters we need to measure, ensuring that our less experienced members have the necessary background knowledge to better contribute our research.” This supports the idea that some of the near-peer mentorship happens as part of the onboarding process for new members.

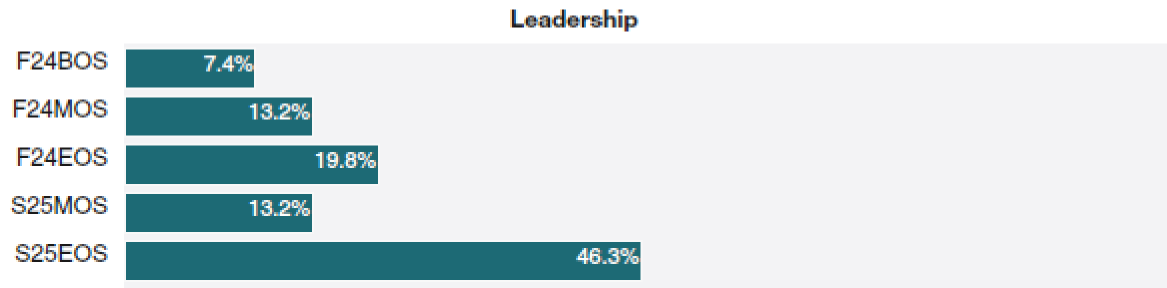

Figure 10: Results for the Leadership Code

The *leadership* code looked at how and when students lead their teams towards their project goals. Based on the vertically integrated nature of the program, it is expected that students will gain experience with leadership positions as they become senior members of their groups. The students’ experiences with leadership roles are varied with some taking the lead on a literature review and others working to “overcome being a micro-manager”.

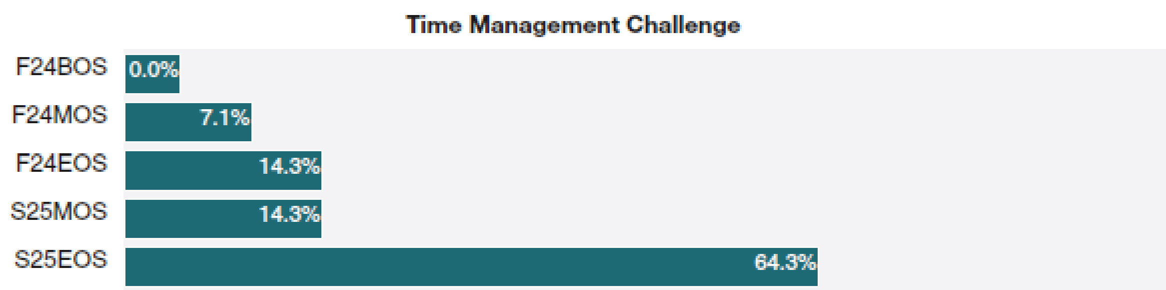

Figure 11: Results for the Time Management Code

The *time management challenge* code focused on how the students adjusted their schedules between their research responsibilities with the program and other classes or commitments. The results show that, as time passed, time management became a bigger challenge for students. Based on their responses, one of the main reasons for this is that they are moving into higher academic standing courses that require more time and effort on their part. Although all of the nine students were of sophomore standing or higher during the Fall 2024 semester, it is clear that their availability for extracurricular activities was reduced as time went by. Another challenge that students faced was having overlapping activities. One student shared that they “could not be present for most of the [program] and [Alternative Engine Cycles] meetings since all [their] classes were scheduled between 3-8 pm”. Similarly, another student said that they could not be present for most of the presentations since they had a course during those times. While student participation in the program can positively impact their learning, it is still a voluntary activity and therefore students must learn to balance their time with their required curricular activities.

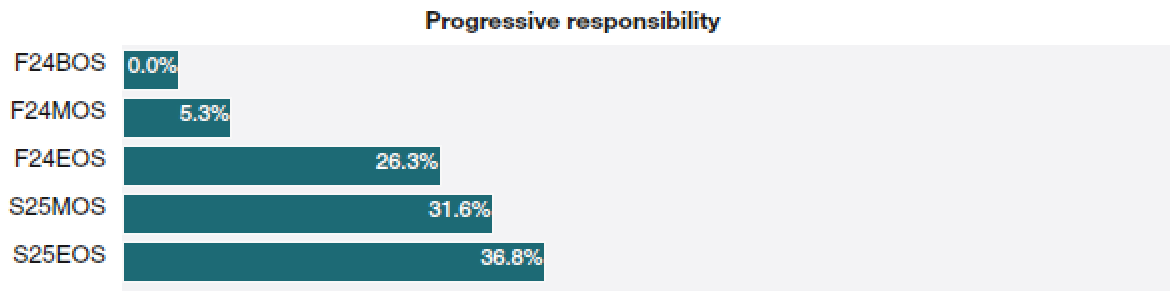

Figure 12: Results for the Progressive Responsibility Code

As discussed previously, the E2E program is organized around the ideas of progressive responsibility and vertically integrated projects. In this case, the *progressive responsibility* code looked for an increase in autonomy, task complexity, or accountability over time. Because of the nature of the code, it was expected that the results would increase throughout the longitudinal assignments.

This theme showcased the progressive nature of the program and the skills that students learn by slowly taking on leadership roles. Current members of the program recruit new students, onboard them, and transfer their knowledge and lessons learned. Along the way, they teach them about teamwork and practice their own leadership skills. The results at the end of the two-semester period show students to have displayed a high level of metacognitive awareness, clearly recognizing their learning process and transferring that knowledge onto others. As they gain expertise, they also develop leadership skills and confidence to make critical judgments about their team's direction.

5. Conclusion

This research presented a longitudinal study using qualitative data, collected over two semesters, related to students' perception of their achievement. The students continually assessed the progress of their projects and their evolving goals during their participation in the E2E program. The results section was divided into four themes, with each category of relevant concepts related to the metacognition theory of learning. The results show that participating in the program helped students engage in the learning process and solve ill-structured problems within the teams in effective ways. Thus, the program's multidisciplinary team projects engage students in varied and integrated ways, enabling them to synthesize knowledge, reflect on their thinking, and develop a deeper understanding of complex topics. This allows students to develop metacognitive skills that support knowledge transfer in complex settings. Although this work has showcased the benefits of participating in a vertically integrated undergraduate research experience for a select group of students, more work needs to be done to understand the impact on the larger participant population and during a longer timeframe, particularly after they have graduated from the program and transition into industry or academia.

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