2026 ASEE ANNUAL CONFERENCE June 21–24, 2026 | Charlotte Convention Center, NC
Host Sponsor UNC Charlotte
Paper ID #51856

Work In Progress: Strategies for Hybrid, Hands-on Courses in Robotics, Embedded Systems, and IoT

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Abstract

This project investigated the design and implementation of two novel graduate-level introductory courses in Embedded Systems and Robotics. These courses were unique in both format and delivery, as they combined a flipped classroom approach with a hybrid learning model. Lecture material was delivered asynchronously through pre-recorded videos, while on-campus students engaged in weekly hands-on lab sessions that emphasized discussion, demonstrations, and guided troubleshooting. Distance learning students received identical lab kits (including microcontrollers, resistors, MOSFETs, motors, servos, and robot chassis) and participated by watching recordings of the in-person lab sessions, supplemented by online office hours for additional support.

The central goal of this project was to explore effective methods for teaching hands-on, hardware-intensive engineering courses in a hybrid environment. Because such lab-based courses were rarely accessible to distance learning students, this teaching model represented a departure from traditional approaches. By documenting both successes and challenges, this work aimed to contribute a case study to the engineering education community that highlighted the opportunities and pitfalls of hybrid, hardware-based instruction.

To inform the case study, baseline data were collected at the beginning of the semester using a student poll designed to measure prior experience, skills, and familiarity with embedded systems and robotics. Additionally, weekly feedback surveys captured student perceptions of their learning experiences, challenges, and engagement throughout the course. This iterative feedback loop not only supported continuous course improvement during the semester but also provided critical insights for the analysis.

The outcomes of this work were twofold: (1) a reflective case study documenting the implementation and lessons learned, and (2) the groundwork for a more comprehensive, research-driven investigation in subsequent years into pedagogical strategies for hybrid hardware laboratory instruction.

1 Introduction

The engineering laboratory has long been recognized as a foundational component of undergraduate and graduate education, serving as the primary site where students reconcile abstract theory with physical reality. As Feisel and Rosa [1] argue, the fundamental goal of engineering education is to prepare students to manipulate energy, materials, and information for the benefit of humankind; a task that requires a "knowledge of nature" traditionally forged through tactile experimentation. However, the delivery of these hands-on experiences faces a significant modern challenge: the rapid and sustained shift toward distance education. According to a 2023 report by the National Science Board [2], the percentage of students enrolled exclusively in distance education more than doubled between 2019 and 2020, rising from 18% to 45%. While this trend was accelerated by the COVID-19 pandemic, it is sustained by broader structural shifts in higher education, including a growing institutional reliance on professional Master of Engineering (M.Eng.) programs and a student preference for part-time, employer-funded degrees that allow for continued full-time employment [2].

1.1 Potential for and Current Limitations of Take-Home Lab Kits

In the context of hardware-intensive subjects such as robotics and embedded systems, providing distance learners with parity in the laboratory remains a complex pedagogical problem. Existing approaches often rely on virtual simulations or remote-access laboratories. While simulation can effectively balance student workload and affect [3], and remote experimentation is a pragmatic alternative to in-person attendance [4], these methods often distance the student from the "direct manipulation" and sensory feedback essential for mastering cyber-physical systems [5]. Recent studies suggest that "lab-at-home" hardware kits may offer a more robust alternative, as they preserve the physical debugging experience and reduce the "black-box" effect often associated with screen-mediated remote access [5]. Nevertheless, as Oliver and Haim [6] observe, a transition to take-home kits may introduce secondary challenges, particularly regarding the loss of physical coordination between peers, the weakening of oral communication skills, and the need for new methods of ethical verification in assessment. These pedagogical concerns are further exacerbated by the proliferation of generative artificial intelligence (AI) tools, which can automate the production of lab reports, code, and mathematical solutions, often bypassing the student's need for conceptual understanding. As highlighted by Hon [7], this emerging paradigm has created a dichotomy where some students leverage AI to deepen their engagement, while others may disengage through an over-reliance on these tools, necessitating novel instructional strategies that prioritize authentic learning over automated output.

1.2 Overview of Research Methods

To establish a baseline understanding of the student cohort, an initial background survey was administered during the first week of classes. The survey was designed to capture students' academic backgrounds, including current degree program and undergraduate degree program for graduate students, as well as their prior exposure to key technical topics covered in the courses. A series of Likert-scale questions assessed students' self-reported familiarity with embedded systems and robotics concepts, including experience with hands-on hardware kits, basic circuit knowledge, and foundational mathematical topics such as linear algebra. The survey also probed students' motivations for enrolling in the course, perceived relevance to future academic or professional goals, and their expectations and hopes for the learning experience. The survey was administered as an informal Google Form completed outside of class. Collectively, these responses provided a baseline characterization of students' technical preparation, interests, and expectations, and enabled the instructor to gauge the cohort's familiarity with core concepts that would be essential for successful engagement with the course material. Weekly surveys were conducted by asking students to report how long the spent on each assignment and if/how they used AI to complete the assignment. Students include this information at the end of their weekly lab reports.

As this is a pilot study and a work-in-progress, specific demographic data, such as gender balance, specific industry representation, and geographic distribution, was not collected, as Institutional Review Board (IRB) approval was not sought for this preliminary phase. However, future research projects building upon this work will seek formal IRB approval to collect and analyze these demographic factors, allowing for a more nuanced investigation into how gender and professional background influence engagement in hybrid hardware labs.

1.3 Purpose Statement and Research Questions

Our current effort serves as an exploratory response to these challenges within the Systems Engineering department at Cornell University. We have developed two novel, one-credit hybrid courses: SYSEN 5411 - Introduction to Robotics and SYSEN 5412 - Creating Solutions with Embedded Systems. These courses were designed to provide hands-on exposure to cyber-physical systems for a diverse cohort of M.Eng. students. Our student body includes both on-campus students and distance learners who are largely working professionals. These students come from varied disciplinary backgrounds, ranging from traditional engineering to finance and business.

These research questions arose out of the process of developing these courses. This work outlines very preliminary efforts to begin addressing them and lays the foundation for a more formal study to dig into these questions in greater depth:

1. To what extent do standardized "at-home" hardware kits achieve technical and pedagogical parity between local and remote students?
2. How do periodic oral assessments influence student engagement and serve as a tool for ensuring academic integrity in the age of generative AI?
3. Does the flipped classroom format create a perceived increase in parity between on-campus and distance learning students?

We describe the structural design of these courses and provide justifications for our pedagogical decisions based on initial student background surveys. As a work in progress, this paper does not claim definitive educational efficacy; rather, it documents our implementation strategies and initial observations to lay the groundwork for a longitudinal study on the impact of this hybrid hardware-based model.

2 Course Background, Assessment Strategy, and Workload Management

The study was conducted across two one-credit modules: SYSEN 5411 (Introduction to Robotics) and SYSEN 5412 (Creating Solutions with Embedded Systems). As a pilot offering, the assessment structure of SYSEN 5411 and 5412 was designed to be iterative, allowing for real-time adjustments based on student feedback and engagement levels. This section details the management of student workload and the deployment of oral exams as a tool for ensuring academic integrity and authentic engagement.

2.1 Course Overview

In accordance with institutional guidelines for one-credit modules, the courses were designed to require approximately two to three hours of work per week outside of class. To monitor this, weekly surveys were conducted regarding the time spent on assignments.

In the embedded systems course (SYSEN 5412), workload remained consistent with these targets; students reported an average of three hours per week, with experienced students occasionally completing tasks in one to two hours. However, the robotics course (SYSEN 5411) exhibited a significantly larger spread, with some students reporting up to seven or nine hours in a single week. Analysis of these outliers revealed that the primary drivers of excessive workload were "friction points" in hardware debugging. For example, some students spent multiple hours debugging logic errors that were eventually traced to hardware brown-outs caused by low battery voltage. This simple issue was identifiable by an instructor in seconds and simply required swapping out the AA batteries in the robot.

To mitigate this frustration and maintain the intended credit-load parity, the instructor reiterated a "two-hour rule," encouraging students to seek assistance via office hours if a hardware issue persisted beyond a reasonable timeframe. Furthermore, to compensate for the higher-than-expected cumulative workload in the robotics module, the final project was transitioned from a mandatory requirement to an optional enrichment activity.

Despite the differences in mandatory status, both courses featured a cumulative project designed to synthesize the semester’s technical topics.

- **Robotics (Bug Obstacle Avoidance):** Students were tasked with developing an algorithm to navigate from one location to another while avoiding an obstacle in an unknown location. This required the integration of kinematics, ultrasonic sensing, signal processing, and feedback control loops.

- **Embedded Systems (Smart Alarm Clock):** Students built a functional alarm clock with a set of base requirements: time-keeping, dual alarm settings, and a snooze function. Additionally, students were required to implement two custom features, such as LED light control, temperature/humidity sensing, or touchless "wave-to-snooze" triggers. This project necessitated the integration of digital/analog I/O, hardware and software interrupts, and I2C/SPI digital communication.

To further reduce workload and maximize student learning experience, student lab reports required to be less than one-half page excluding graphs and diagrams. Students were instead instructed to record video demonstrations of labs working. As part of the video demonstrations, they walked through the results of the lab and verbally explained their work. This allowed students to spend less time writing technical reports and more time building and debugging their robot or embedded system.

3 Student Background, Demographic Analysis, and Resulting Curricular Choices

To effectively design a hybrid laboratory experience, it was first necessary to understand the technical baseline and motivational drivers of the student cohort. This section outlines the demographic composition of the courses and the data-driven justifications for the resulting curricular choices.

3.1 Cohort Composition and Institutional Context

The study was conducted across two one-credit modules: SYSEN 5411 (Introduction to Robotics) and SYSEN 5412 (Creating Solutions with Embedded Systems). The combined enrollment consisted of 44 graduate students, primarily from the Master of Engineering (M.Eng.) program in Systems Engineering. A defining characteristic of this cohort is the structural split between on-campus (OC) and distance learning (DL) tracks.

The 17 DL students are largely working professionals employed in roles such as systems engineering, project management, and product manager. For these students, the M.Eng. degree is often a multi-year, part-time endeavor funded by their employers. In contrast, the 27 on-campus students generally pursue the degree as a full-time, one-year program. Observations throughout the semester indicated a "priority gap" between these cohorts: while DL students often viewed these hands-on modules as a welcome, high-interest break from their daily professional responsibilities, OC students frequently managed these one-credit courses alongside a heavy load of higher-credit core requirements.

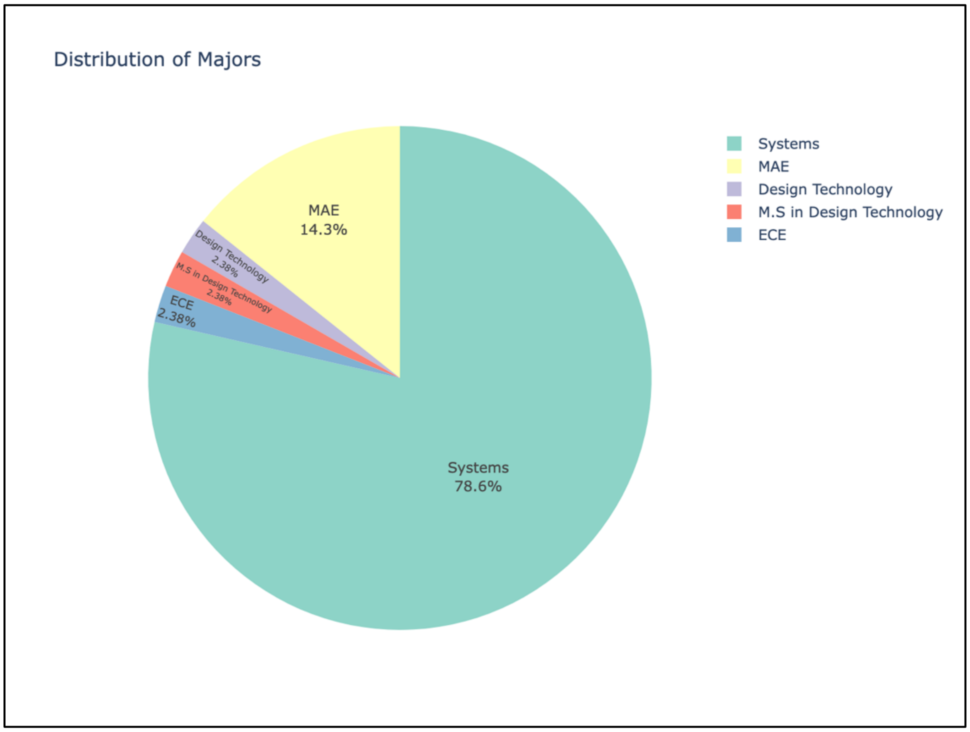

Figure 1: Distribution of majors of combined SYSEN 5411 and 5412 students.

3.2 Technical Baseline and Language Selection

A pre-course survey was administered to gauge prior proficiency in programming and hardware integration. The data revealed a significant skew in programming experience: 41 of the 44 students (93%) reported familiarity with Python, whereas only 12 had experience with C and 20 with C++. Furthermore, 19 students (43%) identified as hardware novices who had never programmed a microcontroller.

These findings directly informed the selection of MicroPython as the primary instructional language. While C and C++ remain industry standards for embedded systems, the goal of these modules is to provide a "systems-level" application experience rather than a fundamental course in low-level syntax. Utilizing MicroPython allowed the vast majority of students to leverage their existing Python knowledge, thereby reducing the "syntax hurdle" and ensuring that the 1-credit workload remained manageable. This approach ensured that students could focus their cognitive load on system logic, such as sensor integration and control loops, rather than memory management or complex compilation toolchains.

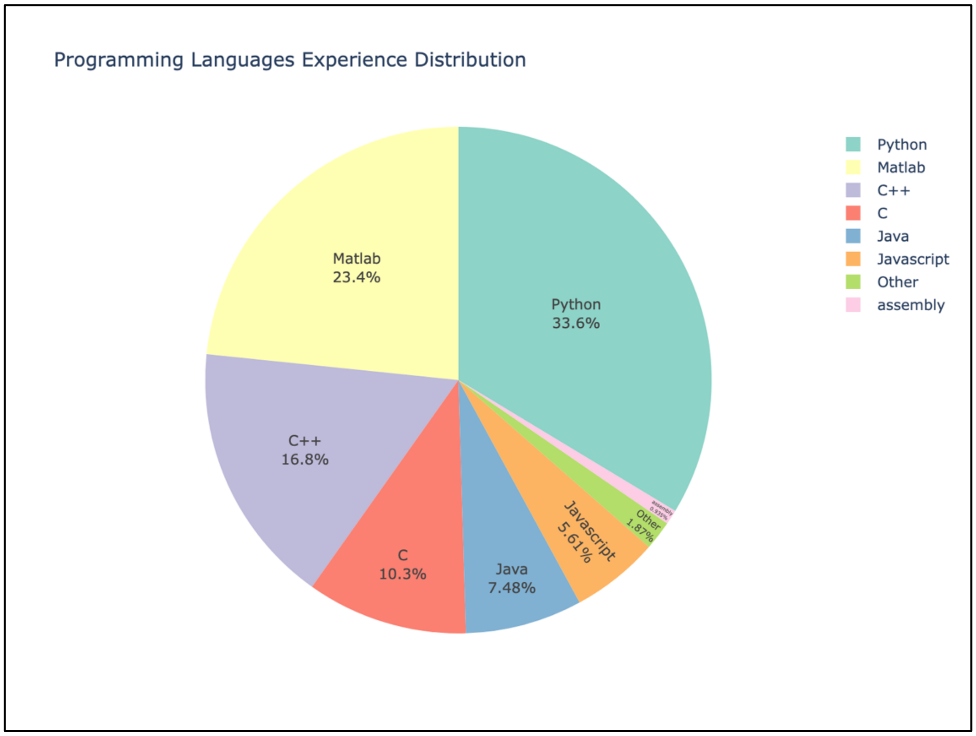

Figure 2: Distribution of programming languages that students had familiarity with. Note that many students were familiar with more than one language.

3.3 Hardware Selection: Accessibility and Parity

The choice of hardware kits was governed by the need for parity between local and remote students. To ensure that DL students did not feel disadvantaged by the lack of on-campus laboratory infrastructure, we selected kits that required no specialized tools (e.g., soldering irons or oscilloscopes) and offered robust online documentation.

For the robotics course, the XRP (Experiential Robotics Platform) was selected. The XRP was specifically designed for "at-home" education; it requires no tools for assembly and uses a web-based IDE for code developing, eliminating the need for complex local software installations. Furthermore, the XRP is part of a popular online ecosystem (Experiential), providing students with additional tutorials beyond the instructor's recordings. For the embedded systems course, we utilized the SunFounder Raspberry Pi Pico Starter Kit, which provides standard breadboard components and a wealth of pre-written MicroPython examples. These commercial kits provided a dual benefit: they reduced the "troubleshooting load" for students and reduced the instructional burden by offering existing community tutorials that allowed the instructor to focus on higher-level design concepts.

3.4 Student Motivation and the "Maker" Identity

Qualitative analysis of student motivations highlighted a strong desire for physical engagement. When asked what motivated them to enroll, 12 students explicitly used terms such as "tinkering," "making," "building," or "hands-on." One student in the robotics course noted:

> "I signed up for this class because I want to gain more hands-on experience in robotics, and I believe the most solid way to learn is by building and programming robots directly... Since robotics is an interdisciplinary field, I see this course as a valuable opportunity to expand my knowledge... and strengthen my ability to work across different aspects of robotic systems."

Another student in the embedded systems course echoed this sentiment, citing the "practical relevance to (their) professional career" and the "hands-on approach and focus on a culminating project" as primary motivators. Overall, 30 students (68%) identified "hands-on implementation" as the aspect they were most excited to learn. However, this enthusiasm was tempered by anxiety among distance learners. Two DL students specifically voiced concerns regarding the viability of a remote hardware lab.

The course employed a flipped classroom model. Lectures were delivered asynchronously, while weekly on-campus sessions focused on live demonstrations and troubleshooting. By recording these sessions and providing robust asynchronous support through Ed Discussion, where peer-to-peer assistance was incentivized through participation points, the course sought to bridge the gap between the isolated remote learner and the collaborative on-campus lab environment.

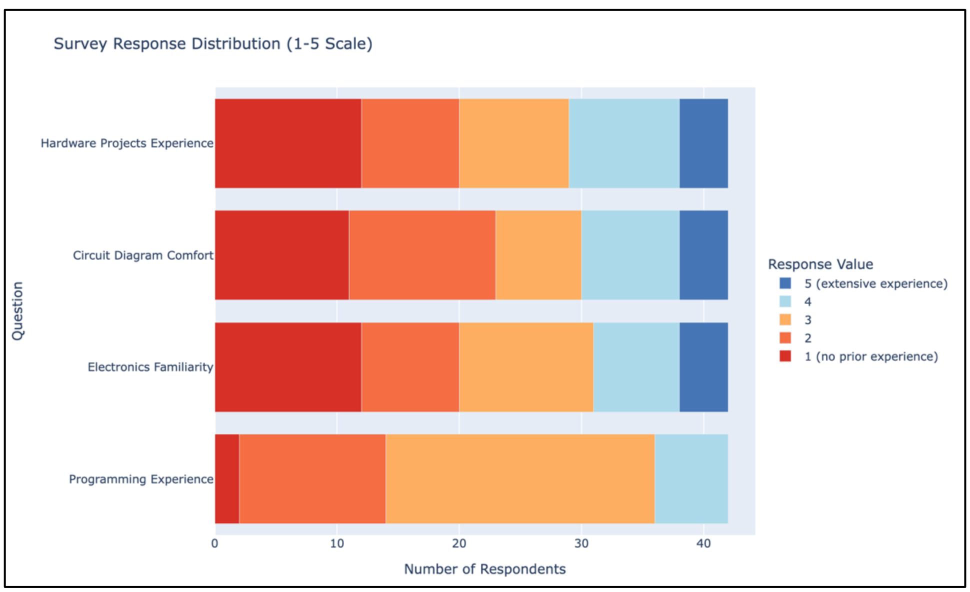

Figure 3: Students ranked their familiarity with various topics on a scale of 1 to 5. The questions were posed as follows: "What is your level of experience with hands-on hardware projects? (eg.

maker-space, hardware labs)", "How comfortable are you reading circuit diagrams or wiring schematics?", "How familiar are you with basic electronics (resistors, LEDs, breadboards, power supplies)?", and "How much prior programming experience do you have?"

4 Results

As this project represents a "Work in Progress," our preliminary results are primarily qualitative and observational, derived from weekly workload surveys, student engagement on digital forums, and the pilot implementation of oral exams.

4.1 Oral Exams as an AI-Mitigation and Engagement Tool

Throughout the semester, a discrepancy in engagement was observed: distance learning (DL) students in the robotics course appeared highly active, whereas those in the embedded systems course showed lower participation in office hours and online forums. Given the risk that generative AI tools can allow students to produce functional code and lab reports without deep conceptual understanding [7], an oral exam was implemented in the embedded systems course to verify authentic learning.

The oral exam took the form of a 20-minute Zoom meeting conducted after the initial planning phase of the final project. Students were required to present their documentation, including use cases, system requirements, and a state machine diagram, prior to beginning implementation. The exam focused on three core inquiries:

- **User Interaction:** How the student envisioned the user interface and experience.
- **System Mapping:** How the proposed use cases translated into specific requirements and state machine transitions.
- **Implementation Strategy:** Rationalizing the choice of specific techniques, such as the use of polling versus hardware interrupts or the selection of specific sensors.

Regarding scalability, conducting three 20-minute exams a semester per student is a significant time investment; however, as these classes increase in size, these exams can be effectively conducted by Teaching Assistants to maintain this relational touchpoint. The exam time can be further reduced asking students to prepare a 7 minute presentation and leave 3 minutes for questions, bringing the oral exam time down to 10 minutes per student.

The oral exams in the embedded systems course proved to be a critical "relational touchpoint." Beyond verifying academic integrity against generative AI shortcuts, these 20-minute sessions allowed the instructor to identify foundational gaps that were not apparent in submitted code. For instance, the correlation between incomplete weekly labs and poor performance in the oral "design review" was nearly absolute. Furthermore, the workload data from the robotics course (SYSEN 5411) highlighted a critical instructor intervention: the "two-hour rule" for hardware debugging. Identifying that novice students were spending up to nine hours on simple power-related "brown-out" issues allowed for a dynamic adjustment of the final project requirements, ensuring the course remained viable as a one-credit module.

In addition to these structural findings, the flipped classroom format received universally positive feedback in both the midterm and final course evaluations. Students reported that the asynchronous delivery of lecture material provided necessary flexibility for their schedules. From an instructional standpoint, prerecording the lectures allowed the instructor to dedicate the synchronous discussion sections almost entirely to hands-on demonstrations and troubleshooting. This shift enabled more detailed visualizations of hardware implementation, which students identified as a key factor in their ability to successfully complete the labs.

The oral exams yielded unexpected insights into the differences between the student tracks. Contrary to initial concerns about distance learner disengagement, the DL students (predominantly working professionals) demonstrated significantly higher levels of engagement and creativity than their on-campus counterparts.

The DL cohort tended to be more ambitious, integrating difficult or unusual features into their alarm clocks and viewing the project as a creative "break" from their professional duties. In contrast, on-campus students, often burdened by the heavy workload of a full-time M.Eng. schedule, tended toward "minimal viable product" implementations. The oral exams successfully identified students who had missed foundational concepts in earlier labs, as their inability to explain the logic of a hardware interrupt or a state transition correlated strongly with incomplete weekly assignments. Ultimately, the oral exam proved to be a vital relational touchpoint for distance learners, transforming the final assessment from a solitary coding task into a mentored design review.

4.2 Student Engagement with Generative AI

Data from the first lab provided specific quantitative insights into how students utilized generative AI. The distribution of AI usage was as follows:

- 36.4% of students reported not using AI in any way.
- 30.3% of reported AI use cases were for debugging hardware or software issues.
- 15.2% used AI for material comprehension.
- 6.1% used AI for learning code syntax.
- 6.1% used AI for understanding prewritten code.
- 6.1% used AI for writing new code.

Notably, usage for conceptual or analytical purposes was rare compared to troubleshooting. This pattern of usage suggests that students viewed AI primarily as a tool for overcoming technical "friction points", such as syntax errors or troubleshooting hardware configurations, rather than a substitute for learning the theoretical underpinnings of the course. This finding reinforces the utility of oral exams, as students could use AI to navigate the "how" of implementation while still being required to demonstrate the "why" of their systems-level design in person.

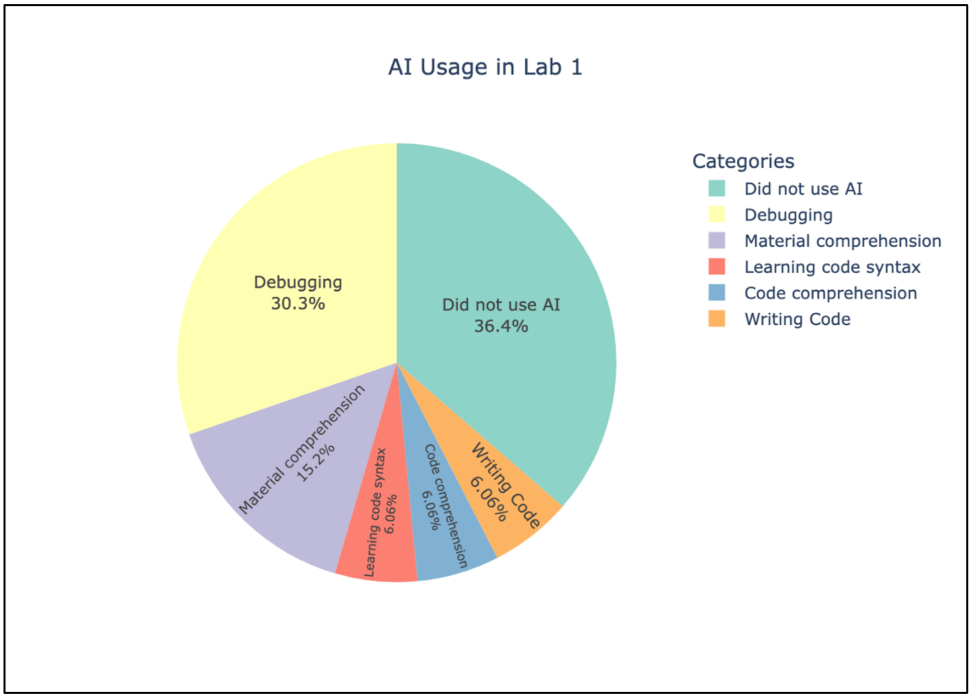

Figure 4: Reported uses for AI by students after completing the first lab report. Note that some students reported more than one use of AI.

4.2 Future Work and Curricular Integration

Building on this pilot, several structural changes will be implemented in the next iterations of the courses and the study:

- **Workload Optimization (Robotics):** Future versions will provide more robust prewritten boilerplate code to shift student focus from low-level debugging to systems integration.
- **Mandatory Oral Assessment Schedule:** We will implement a tiered oral exam schedule where each student participates in three 10-15 minute individual sessions (Checkpoint 1: Weeks 1-4; Checkpoint 2: Weeks 5-8; Final Project Review).

- **Formalizing Friction Data:** We will systematically log and categorize hardware versus software debugging "friction points" as part of a formal data collection effort in future studies.
- **Alternative to Peer Learning:** We hypothesize that periodic oral exams, by requiring students to "teach" their design logic to the instructor or TA, may serve as a viable alternative for driving deep learning in asynchronous environments.
- **Formal Assessment of AI Interaction:** We plan to implement a more rigorous survey to categorize student AI usage as either "augmentative" or "bypass," correlating these behaviors with oral exam performance.
- **IRB-Approved Demographic Analysis:** Future iterations will seek formal approval to analyze how industry background and gender influence success in these hybrid hardware labs.

5 Conclusion

This Work-in-Progress paper has detailed the design and implementation of two introductory, hybrid, hardware-intensive courses for graduate systems engineering students. Our preliminary experience suggests that achieving parity between on-campus and distance learners requires more than just identical hardware; it requires a pedagogical framework that addresses the unique motivations of the professional learner and the pervasive influence of generative AI.

Our findings highlight three primary contributions to hybrid hardware instruction. First, the flipped classroom model provided the asynchronous flexibility necessary for professional learners while reallocating synchronous time toward high-value demonstrations and troubleshooting. Second, the deployment of standardized, "tool-less" hardware kits successfully minimized logistical friction, allowing students to focus their cognitive effort on systems-level integration rather than component acquisition. Finally, the implementation of oral exams transformed the assessment process from a potential site of AI-assisted disengagement into an authentic design review and mentorship opportunity. While challenges in workload calibration persist, these strategies provide a robust foundation for a more comprehensive study on the efficacy of hands-on engineering education for the modern working professional.

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