Hands-On Experimental Robotics: Enhancing Undergraduate Engagement and Research through Iterative Project-Based Learning

Abstract

A persistent challenge in undergraduate engineering education is bridging the gap between theoretical knowledge and practical design expertise. This paper presents a pedagogical model implemented in an upper-level, undergraduate, elective course, *Experimental Robotics*, that replaces a traditional, lecture-based format with a deeply integrated, hands-on curriculum. The core of this model is a sequence of scaffolded, low-stakes experimental modules that progressively build student competency in fundamental subsystems, including actuators, sensor integration, embedded control, and iterative mechanical prototyping. This cumulative learning culminates in a final project where student teams define a novel research question and subsequently design, prototype, and experimentally validate a unique mobile robot under strict budgetary and component constraints. Project development was significantly enhanced by access to the university's Engineering Innovation Hub (EIH), which provided students with state-of-the-art resources, including advanced manufacturing, 3D printing, and fabrication technology. A structured project framework, including a formal proposal, mandatory weekly progress reports, and a final presentation and report formatted as a peer-reviewed research paper, ensures academic rigor. Quantitative evaluation via Course Instructor Feedback (CIF) metrics demonstrates the efficacy of this model, with 95.7% of students reporting that the hands-on methodology facilitated deep engagement and 91.3% rating the instructor's ability to stimulate intellectual interest as "Excellent" or "Very Good," suggesting that this scaffolded, investigative structure effectively fosters the inquiry-based mindset essential for future research and industrial application.

1 Introduction

Undergraduate engineering programs continue to struggle to balance rigorous theoretical instruction with sustained, hands-on design experiences, resulting in a persistent gap between academic preparation and industry expectations.[1,2,3] Traditional curricular models tend to prioritize foundational knowledge and analytical proficiency, often at the expense of authentic engagement with real-world systems and open-ended design challenges.[4] As a result, commonly reported gaps include limited transfer of classroom knowledge to open-ended problems, underdeveloped higher-order skills such as critical thinking and metacognition, and insufficient preparation for the interdisciplinary, systems-level nature of contemporary engineering work.[5,6]

Consequently, graduates may demonstrate strong technical competence while lacking proficiency in interdisciplinary problem-solving, systems-level thinking, and the ability to adapt to rapidly evolving technologies and user-driven constraints. While lecture-based formats efficiently deliver foundational concepts, evidence suggests they often provide insufficient structure and practice for students to independently design, implement, and evaluate engineering solutions, particularly when active-learning approaches are adopted without robust alignment, facilitation strategies, or appropriate scaffolding.[7,8]. These limitations have prompted increasing calls for curricular shifts toward more integrated, user-centered, and agile educational approaches that better reflect contemporary engineering practice.[8,9]

In response, engineering education has increasingly emphasized *active and experiential pedagogies*, including problem-based learning (PBL), project-based learning (PjBL), challenge-based learning, and inquiry-based learning, to better align curricula with professional practice.[9,10,11] Recent systematic reviews indicate that PBL/PjBL can improve integration of theory and practice, teamwork, innovation, and real-world competencies when embedded within coherent instructional designs and supported by assessment practices that encourage iteration and reflection.[9,10,11] Across engineering domains, these approaches are frequently associated with improved student satisfaction, practical competence, and deeper conceptual understanding, particularly when students confront realistic design trade-offs and justify decisions using empirical evidence.[5,6,12]

Concurrently, *hands-on and experimental learning* has been highlighted as essential for developing students' ability to connect models to physical systems, execute and interpret experiments, and gain confidence in applying abstract concepts.[13,12] Frameworks that explicitly scaffold experimental competency, progressively transitioning students from guided activities to independent inquiry, report strong outcomes in both achievement and student perceptions, especially when course activities emphasize structured reflection, documentation, and repeated testing.[13,6] Complementing this, interdisciplinary project-oriented curricula have been shown to support creativity and higher-order thinking when students must coordinate across technical domains and iterate under realistic constraints.[14]

Within Electrical and Computer Engineering (ECE) and closely related fields, there is growing interest in blended and active learning models that combine physical computing, robotics, and modern fabrication resources with structured assessment and feedback.[15,16,17] Such approaches are frequently associated with increased engagement, motivation, self-efficacy, and self-directed learning, particularly when supported by careful instructional design and iterative assessment.[18,8] However, comprehensive reviews also highlight persistent challenges, including misalignment between intended and enacted active-learning designs, insufficient scaffolding for novice designers, and limited integration of research-like inquiry within standard undergraduate coursework.[8,9,11]

Taken together, prior work motivates the need for replicable, course-level instructional models that: (i) systematically scaffold experimental and design competencies; (ii) explicitly integrate research questioning, prototyping, and experimental validation; (iii) leverage institutional resources such as makerspaces and innovation hubs; and (iv) document learning gains using both quantitative and qualitative evidence.[13,15] While active and blended learning strategies are well established, fewer studies describe how these approaches can be coherently integrated into a single course that treats research formulation and validation as core learning objectives rather than optional or extracurricular activities.

Building on these strands, this paper introduces and evaluates a project-driven *Experimental Robotics* course that replaces a traditional lecture-forward format with a sequence of scaffolded, hands-on experimental modules culminating in a research-style final project. In contrast to task- or competition-based projects, student teams are required to formulate a novel research question, design and prototype a robotic system under strict constraints, conduct experimental validation, and synthesize their findings in the form of a conference-style technical paper.

This paper makes three contributions to ECE education. First, it presents a practical instructional design for an upper-level robotics course structured around iterative experimentation, subsystem integration, and a final project centered on original research questions. Second, it describes an assessment framework that combines structured project milestones with university-administered course feedback data to quantify student engagement and perceived learning effectiveness. Third, it provides implementation details intended to support adoption and adaptation in other ECE and robotics contexts, including considerations related to resource constraints, instructional staffing, and the role of makerspace infrastructure.

The remainder of the paper is organized as follows. The methods section details the course structure, experimental modules, project framework, and assessment instruments. The results section reports quantitative course feedback outcomes and summarizes qualitative themes from student responses. Finally, we discuss implications for hands-on robotics education, limitations of the study, and recommendations for replication and scaling.

2 Methodology

2.1 Course Context and Learning Objectives

Experimental Robotics is positioned as an upper-level undergraduate elective intended to serve as a bridge between foundational coursework in circuits, controls, and mechanics, and open-ended research or capstone design experiences. Students entering the course typically possess theoretical exposure to embedded systems and robotics concepts, but limited experience integrating these components into functioning, experimentally validated systems. This course was explicitly designed to address this gap by emphasizing physical prototyping, system-level debugging, and empirical performance evaluation. Fig. 1 illustrates the scaffolded progression of instructional phases and project activities across the semester.

The primary learning objectives of the course are threefold. First, the course seeks to develop technical synthesis and practical competency across integrated robotic subsystems. While traditional undergraduate curricula often present robotics as a series of isolated mathematical or computational concepts, this course requires students to integrate mechanical fabrication, actuation, sensing, and embedded control into a single, cohesive physical system they select. By operating within the university's Engineering Innovation Hub, students confront the "real-world" friction and non-linearities of physical hardware, moving beyond idealized simulations. This objective is centered on the transfer of knowledge, requiring students to solve complex engineering problems where theoretical predictions must be reconciled with the stochastic

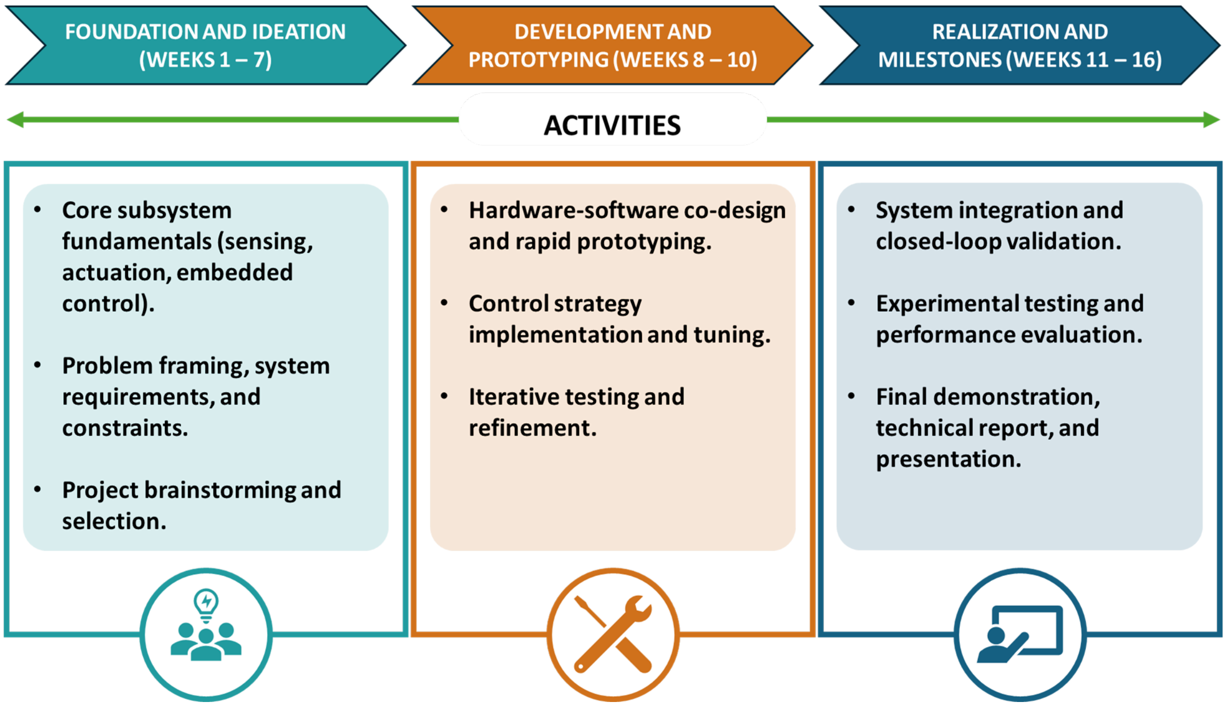

Figure 1: **Conceptual overview of the scaffolded instructional framework used in the Experimental Robotics course.** The course progresses from foundational subsystem instruction and problem framing (Weeks 1–7), through hardware–software co-design and iterative prototyping (Weeks 8–10), to full system integration, experimental evaluation, and research-style dissemination via final demonstrations, technical reports, and presentations (Weeks 11–16).

realities of physical environments.

Second, the curriculum is designed to facilitate the contextualization of foundational knowledge within research-oriented frameworks. A primary goal is to bridge the ”theory-practice divide” by requiring students to function as investigators rather than just builders. Students are guided to formulate testable hypotheses regarding robotic performance, design controlled experimental protocols, report their findings through a weekly reporting framework, and present results in a format consistent with peer-reviewed engineering literature. The course ensures that students can connect their academic background (e.g., control theory, circuit theory, or kinematics) to the standards of the engineering research community.

Third, the course focuses on helping students become persistent problem-solvers who can work through technical setbacks. A major goal is for students to stop seeing a broken robot as a “failure” and instead see it as a valuable lesson that shows them exactly what needs to be fixed. The course requires students to carefully investigate why their mechanical parts, electronics, or software did not work, and then use their test results to prove why their new design is better. This process is supported by weekly progress updates and constant hands-on help from the instructor and teaching assistants during lab time. By the end of the course, students develop a reliable method for solving problems that helps them bridge the gap between their textbook knowledge and the messy, high-pressure reality of professional engineering.

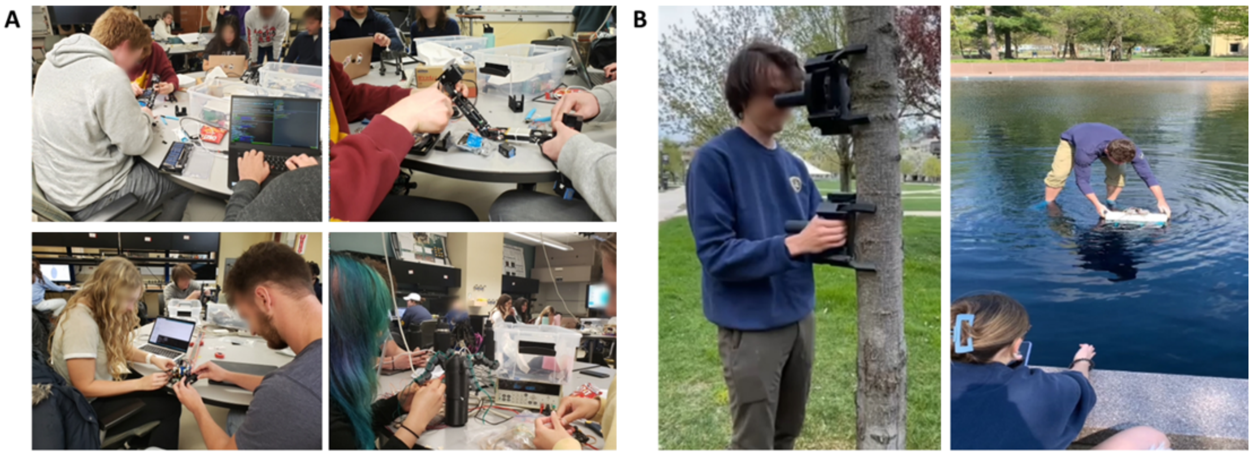

Figure 2: **Integration of collaborative and field-based learning environments.** (A) Structured classroom environment demonstrating the co-located, peer-based collaborative assembly phase of the robotic systems. (B) Representative field experiments evaluating robotic performance in diverse real-world environments: (left) a tree-climbing robot undergoing vertical locomotion trials on natural bark surfaces; (right) a stingray-inspired aquatic robot testing in a pool.

2.2 Organization of the Hands-On Curriculum

The learning environment for the course is intentionally designed to foster a culture of collaboration and practical inquiry. Moving away from the traditional lecture hall model, the classroom utilizes round tables to facilitate teamwork and dedicated workbenches equipped for soldering and hardware assembly (Fig. 2A). This studio-style layout, supported by on-site storage for power supplies, mechanical and electronic components, allows student teams to transition between conceptual planning and physical prototyping. This "open-access" environment mirrors a professional engineering laboratory, providing students with the autonomy to manage their resources and workspace.

To ensure the curriculum is responsive to the specific needs of each cohort, the course begins with a diagnostic assessment phase. During the first week, students complete surveys detailing their technical backgrounds, such as prior experience with microcontrollers, CAD software, and fabrication, alongside their personal learning objectives. The instructor uses this data to calibrate the complexity of weekly assignments and in-class activities, ensuring the material remains challenging yet accessible for students with varying levels of prior experience.

A critical component of the curriculum is the "inspiration phase," typically occurring during the first two weeks. This period is designed to broaden students' technical vision and catalyze project ideation by exposing them to a diverse array of robotic systems. This is achieved through the presentation of state-of-the-art research from contemporary literature, the instructor's own research portfolio, and successful case studies from previous course iterations.

The foundational core of the curriculum is built upon a sequence of scaffolded experimental modules. This structure is designed to incrementally build technical proficiency while managing the inherent complexity of robotic systems. Rather than front-loading theory through abstract lectures, each module introduces a narrowly scoped concept that is immediately reinforced through physical experimentation. Each module follows a consistent instructional cycle: a brief conceptual overview, a guided in-class activity, and a reflective component where students analyze their system's performance and document its limitations. Early modules focus on isolated subsystems, such as actuator characterization and sensor calibration, while later modules require the integration of mechanical design, embedded programming, and feedback control.

The transition toward independent research begins early in the semester. By the third week, students form collaborative groups to identify a specific research problem and propose a corresponding robotic system. During this phase, teams present their preliminary concepts to the class. The instructor provides critical feedback to ensure these projects remain focused and feasible within a single-semester timeline, helping students narrow their scope from broad ideas to achievable engineering goals. To guide the creative process, the instructor establishes an annual project theme, such as *Bioinspired Robotics* or *Environmental Monitoring*, which provides a thematic framework for student research questions.

To support this multi-layered instructional design, the course utilizes the Canvas learning management system as a central repository for all instructional materials, including lecture notes, technical documentation, and project milestones. By serving as both a resource hub and the primary communication channel, Canvas provides students with a transparent and structured roadmap of the semester, ensuring that all technical requirements and announcements are consistently accessible for reference.

Table 1: Alignment of project milestones with learning objectives and ABET student outcomes.

Project Phase	**Targeted Learning Objectives**	**ABET Student Outcomes**
Early system integration	Develop the ability to translate a conceptual system architecture into a functional robotic platform by selecting, assembling, and integrating sensing, actuation, and control components.	(1) Solve complex engineering problems; (2) Apply engineering design within constraints
Foundational control and behavior implementation	Implement and validate basic control strategies and motion behaviors, emphasizing algorithmic reasoning, parameter tuning, and performance trade-offs.	(1) Problem solving; (6) Experimentation and data analysis
Hardware–software validation	Diagnose and resolve integration challenges through structured testing, debugging, and iterative refinement of embedded software and hardware interfaces.	(6) Conduct experiments and interpret data; (7) Acquire new knowledge independently
Experimental evaluation and analysis	Design and execute controlled experiments to evaluate robotic system performance under varying conditions; analyze data to support evidence-based conclusions.	(3) Communication through data and analysis; (6) Experimentation and interpretation; (5) Teamwork
Research synthesis and dissemination	Synthesize technical results into a professional oral and written presentation, articulating design rationale, limitations, and future research directions.	(3) Communicate effectively; (4) Ethics & Professionalism; (7) Lifelong learning

2.3 Design of Experimental Modules and Activities

The experimental modules were intentionally designed as low-risk, repeatable activities that encourage exploration rather than optimization. Students are provided with a constrained set of components and a fixed budget, requiring them to make informed trade-offs related to performance, reliability, and manufacturability. These modules were designed to reduce cognitive load by isolating specific robotic subsystems, allowing students to achieve mastery in discrete technical domains before integration. Also, the constraints mirror real-world engineering limitations and prevent reliance on overly complex or cost-prohibitive solutions.

Representative modules include actuator benchmarking under varying loads, sensor fusion for state estimation, and open-loop versus closed-loop motion control. Importantly, students are not evaluated solely on successful task completion, but on their ability to interpret experimental data, identify failure modes, and propose justified design revisions. This assessment philosophy reinforces the value of experimentation as a learning tool rather than a means to a predetermined outcome.

The alignment between project milestones, targeted learning objectives, and ABET student outcomes is summarized in Table 1. Outcome definitions follow the ABET Engineering Accreditation Commission criteria for the 2025–2026 accreditation cycle[19], which emphasize complex problem solving, experimental design and interpretation, effective communication, teamwork, and the ability to acquire new knowledge independently.

2.4 Iterative Final Project and Research Integration

In the second half of the semester, the curriculum transitions to a PjBL model, where instructional scaffolding is systematically “faded” to empower student autonomy. During this eight-week phase, student teams are required to apply their modular knowledge to a self-defined research problem, shifting the classroom dynamic into an active studio environment. This structure allows the instructor and teaching assistants to provide real-time, personalized technical guidance as teams navigate the complexities of their custom robotic systems.

The final project serves as a capstone experience that synthesizes prior learning into an open-ended design challenge. Teams must propose a novel robotic system or experimental task, such as autonomous navigation via a legged robot in unstructured terrain, subject to strict limitations on budget ($150), form factor, and available components. These constraints are designed to prioritize originality in system integration and mechanical design over the procurement of expensive, off-the-shelf solutions. This phase is heavily supported by the Engineering Innovation Hub (EIH), where access to 3D printing and CNC fabrication enables a “fail-fast” methodology. This environment allows students to rapidly test mechanical assumptions and refine their designs based on empirical performance data.

To maintain academic rigor during this open-ended transition, the course employs a structured reporting framework that emphasizes metacognition and experimental discipline. Rather than providing simple status updates, each student must individually submit weekly progress reports that document failure analyses and justify design iterations based on experimental evidence. This process culminates in a formal presentation and technical paper formatted to the standards of a peer-reviewed conference submission. For this final deliverable, students are required to articulate a clear hypothesis, define their design parameters, and detail the components of their robotic platform. Furthermore, they must establish objective performance metrics and execute experimental protocols to validate system behavior through repeated trials (Fig. 2B).

This multi-layered instructional design is supported by the Canvas Learning Management System, which serves as the central infrastructure for the course. By acting as a transparent repository for technical documentation, lecture notes, and project milestones, the platform provides a structured roadmap for the students. This ensures that all technical requirements and communication remain consistently accessible as the course moves from foundational guided modules to independent, team-based research.

2.5 Assessment Methods and Data Collection

Student learning and engagement were evaluated using a combination of direct and indirect assessment methods during the Spring 2025 offering of the course. The course enrolled 25 undergraduate students, primarily upper-division majors in Electrical and Computer Engineering and closely related programs. The class consisted predominantly of juniors and seniors, reflecting the course's positioning as an advanced elective intended to bridge foundational coursework and capstone or research experiences. Students worked in teams of 2-3, resulting in a total of nine project groups. The enrolled population included both male (16) and female (9) students, with gender representation broadly consistent with departmental demographics. No individual demographic identifiers were used in analysis, and all assessment data were handled in accordance with institutional review and privacy guidelines.

Direct assessment measures included graded reports, project milestones, final system demonstrations, and technical presentations. These were evaluated using structured rubrics emphasizing system integration, experimental rigor, data analysis, and clarity of technical communication. Indirect assessment relied on university-administered Course Instructor Feedback (CIF) surveys, which capture student perceptions of engagement, instructional effectiveness, and learning outcomes using standardized Likert-scale items administered at the end of the term.

Quantitative CIF data from the Spring 2025 offering were aggregated and analyzed to identify trends related to student engagement, perceived learning effectiveness, and instructional impact. In addition, open-ended survey responses were reviewed to contextualize numerical results and to identify recurring themes related to hands-on experimentation, autonomy in design decisions, and exposure to research-oriented practices. Together, these data sources provide a complementary view of both measured performance and student perceptions of the learning experience.

3 Results

3.1 Example Student Projects

This section presents case studies of two distinct student projects conducted during the Spring 2025 Experimental Robotics course. These projects exemplify the pedagogical integration of bio-inspired design and empirical validation, showcasing how students translate complex natural mechanisms into functional robotic platforms. By selecting biological models with specialized locomotion strategies, specifically saltatorial and radially symmetric movement, students were challenged to navigate the transition from theoretical modeling to iterative prototyping and rigorous experimental testing.

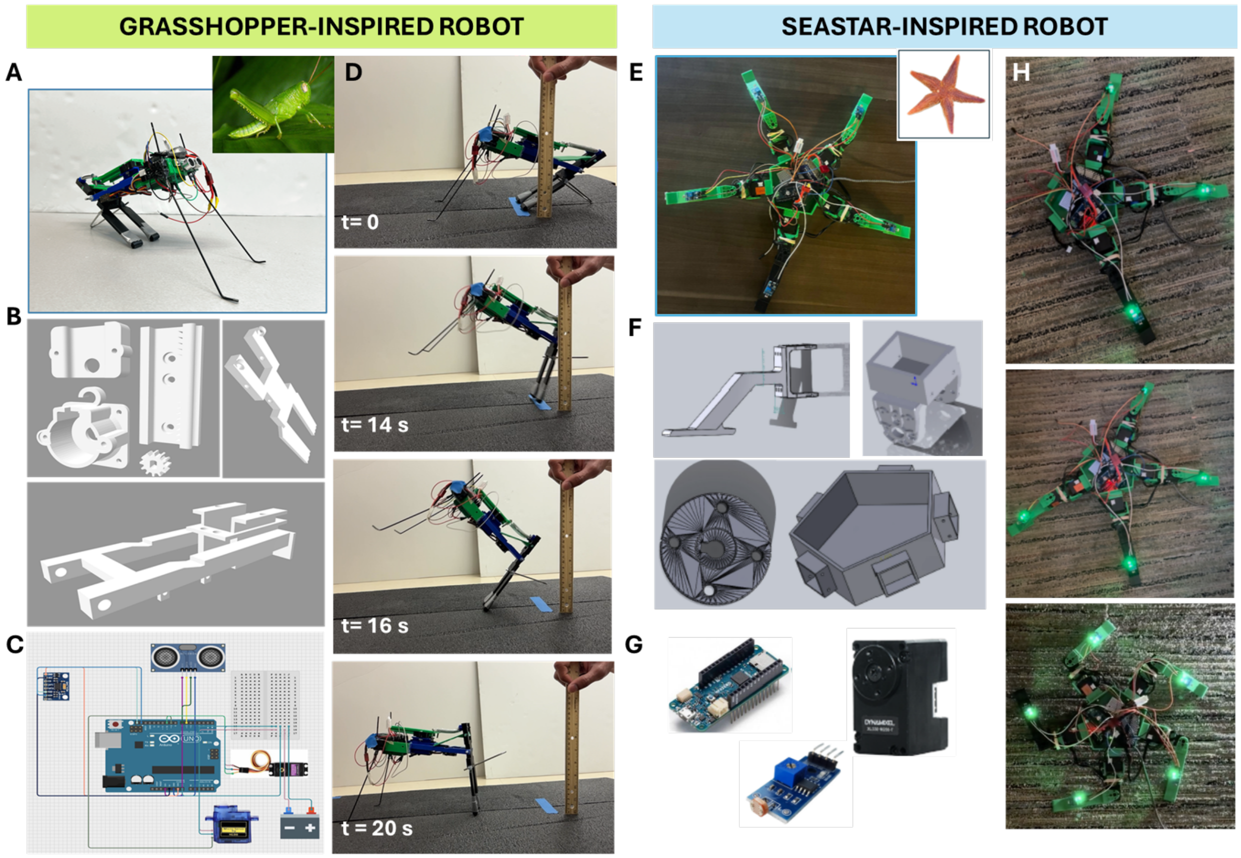

Figure 3: **Example student projects from the Experimental Robotics course.** (A-D) Grasshopper-inspired Robot. (A) final physical prototype; (B) CAD assembly of the mechanical components designed in SolidWorks, highlighting the spring-loaded catapult mechanism; (C) circuit schematic of the electronic control system; and (D) snapshots of experimental trials evaluating jumping performance on a foam surface. (E–H) Seastar-inspired radially symmetric robot: (E) final physical prototype; (F) CAD model detailing the modular dual-servo revolute joints and central body; (G) electronic sensing, actuation, and control units; and (H) experimental gait analysis demonstrating mobility across various limb configurations (three, four, and five legs). The names of the students who completed the projects are listed in the Acknowledgments section.

The first project explored saltatorial locomotion, drawing inspiration from the "double-hinge" catapult mechanism characteristic of grasshopper hind limbs, which facilitates rapid energy storage and release (Fig. 3A-D). The student team hypothesized that the extensibility of mechanical tension springs would directly correlate with increased initial acceleration and enhanced jumping performance, aiming for a target jump height-to-mass ratio of 0.02 cm/g. Their 500g prototype utilized a 3D-printed chassis controlled by an Arduino Uno, featuring a high-torque continuous-rotation servo for spring tensioning and a secondary mini-servo for rapid latch release. An ultrasonic sensor was integrated to enable autonomous "chase" behavior. While the autonomous logic was validated with average forward jumps of 16.8 cm, experimental results identified optimal performance on high-friction surfaces at launch angles between 40° and 50°. However, the system achieved a height-to-mass ratio of only 0.002 cm/g, falling short of the hypothesis due to the unforeseen inertial impact of the 3D-printed mass and center-of-gravity distribution challenges.

In the second project (Fig. 3E-H), students investigated the structural resilience and decentralized navigation of the common starfish (*Asterias rubens*). The study focused on replicating the species' radial symmetry and independent limb coordination to maintain mobility despite significant limb loss. The researchers hypothesized that a rigid-bodied robotic system could effectively emulate these biological traits, adapting its locomotion gaits following the removal of one or more limbs. The resulting robot featured a 3D-printed pentagonal chassis equipped with five modular, magnetically attached arms. Each arm utilized dual Dynamixel servo motors to provide two degrees of freedom and integrated light-dependent resistors (LDRs) for phototactic navigation. Experimental data demonstrated the robot's success in autonomous light-seeking; while rotational efficiency peaked at 25° per step with all five legs, the robot maintained robust forward mobility (8.9 to 12.7 cm per step) even when reduced to three- or four-legged configurations, successfully validating the hypothesis regarding limb-loss adaptability.

Both of these example projects demonstrate the efficacy of bio-inspired paradigms in fostering a deep understanding of robotic systems. By grounding their designs in biological principles, students were forced to confront real-world engineering trade-offs between complexity and reliability. The grasshopper project highlighted the mechanical challenges of high-power energy release, while the starfish project emphasized the benefits of modularity and redundancy. Collectively, these results underscore the value of an experimental curriculum where students must reconcile initial hypotheses with the physical realities of their prototypes, leading to a more nuanced grasp of both mechanical design and autonomous control.

3.2 Course Instructor Feedback Report

This section evaluates the pedagogical efficacy of the *Experimental Robotics* curriculum using Spring 2025 Course Instructor Feedback (CIF) metrics. The evaluation specifically examines the impact of the scaffolded, hands-on experimental model on student engagement and learning outcomes. Notably, while initial background surveys indicated that approximately 85% of students had no prior experience in robot construction, the scaffolded curriculum successfully enabled them to design and build fully functional robotic systems by the conclusion of the term.

The primary objective of this pedagogical model was to bridge the theoretical-practical divide through a sequenced series of low-stakes modules focusing on actuators, sensor integration, and embedded control. This transition to a deeply integrated, active-learning curriculum proved to be a primary driver of student satisfaction. Quantitative analysis supports this conclusion, with 95.7% of students reporting that the hands-on methodology facilitated deep intellectual engagement. Qualitative feedback corroborated these findings; students indicated that the early-semester modules were instrumental in developing the technical competencies required for the high-stakes final project. This cumulative structure successfully facilitated a shift from theoretical comprehension to practical application, with 95.6% of the cohort rating the instructor's effort to facilitate mastery as "Excellent" or "Very Good."

To maintain high academic rigor while fostering independent research, the course utilized a

Table 2: **Course Instructor Feedback Summary: Experimental Robotics (Spring 2025)**

Evaluation Category	Excellent	Very Good	Good	Satisfactory
Fairness and Impartiality	91.3%	8.7%	0.0%	0.0%
Stimulation of Interest	82.6%	8.7%	4.3%	4.3%
Effort to Help Mastery	73.9%	21.7%	0.0%	4.3%
Promotion of Critical Thinking	73.9%	21.7%	0.0%	0.0%
Clarity of Communication	65.2%	30.4%	4.3%	0.0%
Instructor's Preparation	65.2%	21.7%	13.0%	0.0%
Usefulness of Feedback	60.9%	21.7%	17.4%	0.0%
Overall Organization	56.5%	26.1%	13.0%	4.3%

Note: Based on a 92% response rate (23/25 students). Scores represent the percentage of total respondents.

structured assessment framework involving formal project proposals, mandatory weekly progress reports, and a final report formatted according to peer-review standards. This investigative framework aimed to cultivate an inquiry-based mindset essential for engineering design. Students expressed a strong appreciation for the personalized feedback provided during the iterative design phase, with 82.6% rating the utility of instructor feedback as "Excellent" or "Very Good." Notably, despite these high marks, student requests for even more frequent and direct feedback on weekly reports reflect a high level of student investment in navigating the complexities of open-ended research questions.

The efficacy of this pedagogical approach is underscored by the instructor's success in stimulating curiosity and analytical inquiry. CIF metrics reveal that 91.3% of students rated the instructor's ability to stimulate intellectual interest as "Excellent" or "Very Good," while 95.6% of respondents confirmed that the course effectively promoted creative and analytical thinking. These results are particularly significant given the perceived rigor of the course; while 56.5% of students characterized the intellectual challenge as "Extremely High" or "Very High," the overall course rating remained exceptionally high at 89.6% "Excellent" or "Very Good," with a perfect composite median of 5.0/5.0. Collectively, these data suggest that a scaffolded, investigative structure not only achieves primary educational objectives but also inspires superior student performance and perceived value in an elective engineering context.

The additional questions answered in the course instructor feedback reveal that the course is characterized by high student engagement and voluntary enrollment (Fig.4). Students reported putting in significant effort, with the vast majority labeling the quality of their work as "Somewhat High" to "Extremely High." This dedication aligns with the comparison data for similar courses taught in the department, where most students commit between 2-7 hours of study per week outside of class. Interestingly, the course is overwhelmingly populated by students taking it as an elective rather than a strict requirement, suggesting that the high level of effort is driven by genuine interest rather than academic obligation.

4 Conclusion

The outcomes of this course underscore the significant pedagogical value of embedding iterative experimentation and constraint-driven design within the undergraduate robotics curriculum. By

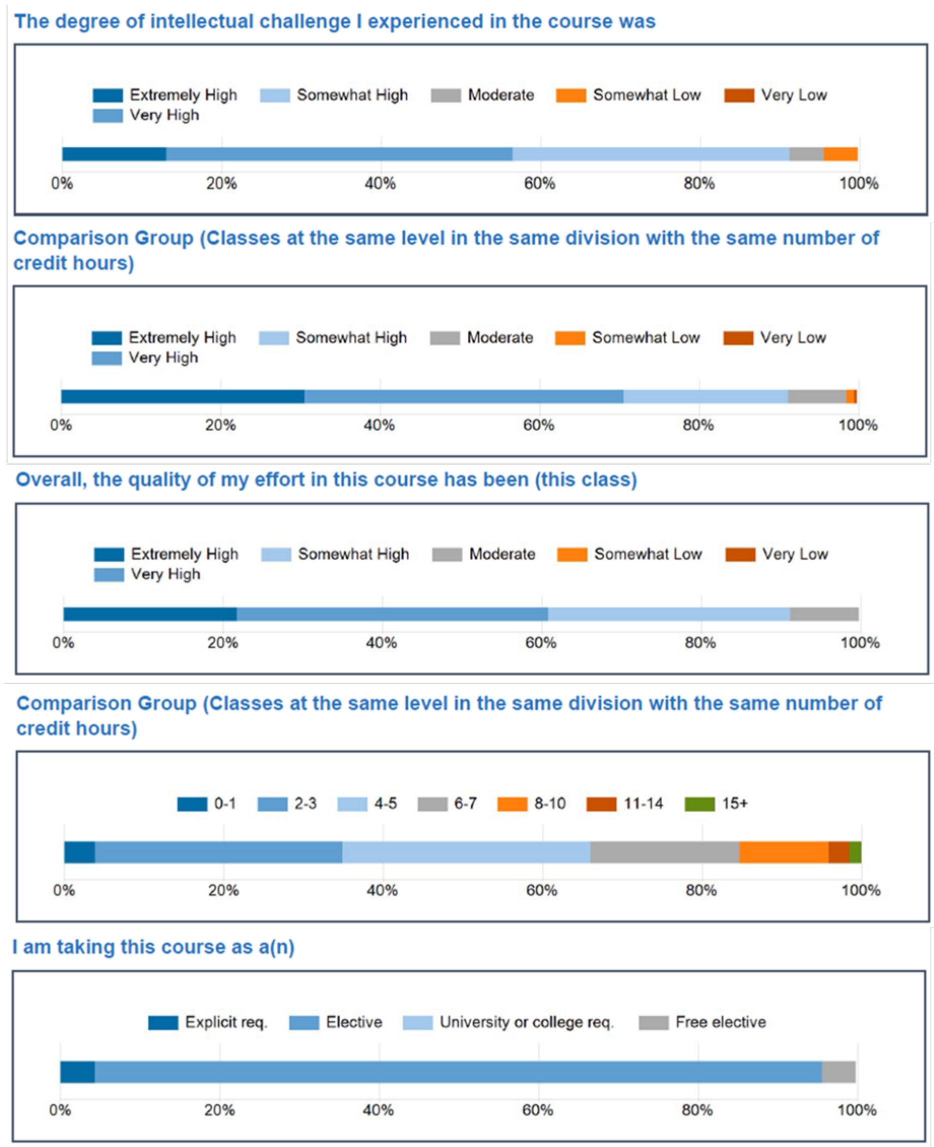

Figure 4: **Other evaluation parameters given in the instructor feedback report.** The chart illustrates the percentage of "Excellent" (dark blue) and "Very Good" (light blue) ratings across eight pedagogical categories, demonstrating a combined positive rating exceeding 80% in all areas, with the highest marks in fairness and student interest. Based on a 92% response rate (23/25 students). Scores represent the percentage of total respondents.

prioritizing research-style deliverables over standardized laboratory exercises, this model successfully bridges the gap between theoretical knowledge and authentic engineering practice. Students are repositioned from passive consumers of known solutions to active investigators, constructing technical knowledge through a recursive cycle of prototyping, failure, and reflection.

The quantitative and qualitative results affirm the profound impact of this accessible, iterative learning cycle. This approach stands in contrast to traditional pedagogical models that often isolate theoretical derivation from physical implementation. By the conclusion of the course, students demonstrated not only core technical proficiencies but also a robust, investigative design competency, specifically, the ability to independently formulate, execute, and validate a research-driven engineering project.

Ultimately, the principles of scaffolded learning and research integration presented in this paper provide a versatile and replicable framework for advancing hands-on curriculum innovation. While implemented here within a robotics context, these underlying strategies are broadly applicable across diverse engineering disciplines seeking to foster an inquiry-based mindset. Future work will explore the longitudinal impacts of this model on student retention, sustained research participation, and overall preparedness for advanced capstone or graduate-level investigations.

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