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[NSF IUSE] Flipped Learning for Enhanced Project-Based Learning in Cyber-Aerial Computing: Privacy Protection and Security Enhancement

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Abstract

This work-in-progress paper reports on an exploratory study examining a flipped project-based learning (FPBL) instructional framework designed to bridge software programming and hardware engineering through drone-centric computing. Implemented in an upper-level computer science (CS) course, the FPBL curriculum engaged students in hands-on projects integrating Python programming with physical drone systems. Preliminary findings indicate high student engagement and successful development of practical software–hardware orchestration skills, with all students completing the required projects. While students valued the hands-on, real-world focus, results also highlight the need for clearer alignment between flipped learning materials and in-class project activities. These findings inform future iterations of FPBL design and suggest its potential to support workforce-relevant competence building in emerging computing domains.

Motivation for the Educational Intervention

While computer science education often focuses on abstract software environments, the emerging Sky-of-Privacy-Things (SoPT) requires a workforce that understands the physical constraints of hardware. First, students must move beyond pure code to understand how autonomous movement and remote control via smartphones impact hardware sensors and privacy. Second, there is a growing industrial demand for engineers who can operate unmanned aerial vehicles (UAVs) with high efficiency and safety while managing the complexities of infrastructure-less networks. Finally, drones are increasingly used in civil and commercial sectors [1], necessitating a curriculum that treats them as integrated systems where technical failure has immediate societal and ethical consequences [2]–[5].

Year 1 Design: The FPBL Approach

We designed a 16-week elective course that employs a module-based structure to scaffold technical complexity, guiding students from basic programming toward increasingly sophisticated hardware integration. The course uses flipped project-based learning (FPBL) to integrate flipped learning and project-based learning, allowing students to acquire foundational knowledge before class and engage in collaborative, hands-on projects during in-class sessions.

1. Flipped Technical Instruction

To maximize limited in-class instructional time for hands-on lab work, the project adopts a flipped learning approach in which core technical content—such as drone-centric cybersecurity and UAV flight dynamics—is delivered through short, targeted instructional videos outside of class. This design responds to the reality that traditional lecture-heavy formats leave insufficient time for experiential, practice-based learning with physical systems. By shifting foundational content delivery online, classroom time can be fully dedicated to interactive, lab-based activities using small-scale drone testbeds. The videos are intentionally designed to be concise—typically ranging from 3 to 10 minutes—and include embedded quizzes to check for understanding, promote active engagement, and provide formative feedback to students. This structure supports individual, self-paced study while ensuring that students arrive in class prepared to apply concepts through collaborative, hands-on experimentation.

2. Project-Based Learning

For the labs, we designed three interconnected learning modules and four progressively sequenced projects—ranging from Project 0: *HelloDrone!* to Project 3: *SkySensor*—to scaffold students' transition from basic programming and hardware assembly to more sophisticated software–hardware orchestration. The modules and projects are intentionally structured to begin with simple, conceptually accessible ideas and programming tasks—such as basic drone control, sensor feedback, and fundamental hardware setup—and gradually advance toward more complex, integrated systems involving autonomy, perception, and sensor-informed collision avoidance. This progressive design allows students to build confidence with both the physical assembly of drone components and the underlying software tools before tackling increasingly challenging problems, ensuring that they develop a deep, iterative understanding of how software commands interact with hardware to produce reliable physical behaviors in real-world robotic systems. Formative evaluations and pilot tests were used to refine the design prior to this phase.

3. Bridging Code to Hardware

The curriculum explicitly supports students' transition from software to physical systems in three ways. First, students program drones as autonomous agents that use sensor data to execute pre-programmed movements. Second, projects emphasize "privacy-preserving" behaviors, requiring students to design and implement hardware responses to simulated adversaries. Third, instruction addresses how drones communicate through multi-hop relays and sensor networks, requiring students to develop a deep understanding of hardware-based communication protocols.

Year 2 First Implementation: Fall 2025

We implemented three learning modules and their flipped learning materials with 20 undergraduate CS students. It is important to note that, due to space and hardware limitations, we divided students into two groups (A and B) and paired them for lab activities. We transformed a regular classroom into a functional drone lab equipped with small-scale testbeds, enabling up to 10 students at a time to participate in hands-on activities (see Figures 1 and 2). While this arrangement necessarily limited the amount of time each group could spend in the lab, it allowed us to maximize available space and increase overall course capacity. To accommodate this structure, Group A engaged in flipped learning activities on Tuesdays while Group B participated in lab sessions, with the groups alternating roles on Thursdays.

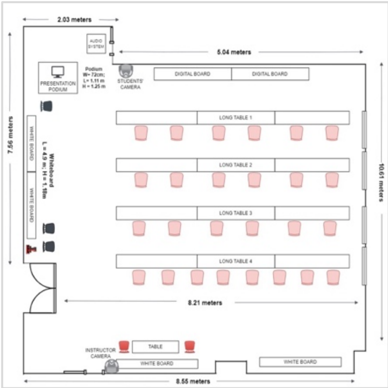

Figure 1: Layout of Typical Classrooms

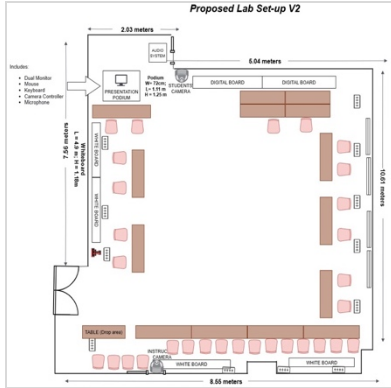

Figure 2: Layout of Our Drone Lab

Data Collection and Analysis

This study is part of a larger design-based research study that employed a mixed-methods approach to examine the effectiveness of the FPBL instructional framework. Multiple data sources were collected to capture students' learning experiences, perceptions, and instructional practices across the duration of the course. Quantitative data were collected through student surveys administered at three time points: at the start of the course (pre), mid-semester (mid), and at the end of the course (post). The surveys measured students' motivation, perceptions of learning experiences, and engagement with FPBL components over time. Qualitative data were collected through focus group interviews with students, semi-structured interviews with the course instructor, lab observations, and analysis of student artifacts (e.g., project deliverables, lab reports, and reflective responses). Focus group interviews focused on further understanding students' experiences and perceptions of FPBL, including its strengths, challenges, and perceived impact on learning and collaboration. Instructor interviews offered perspectives on course design decisions, instructional implementation, and observed student engagement. Observations documented instructional practices, student interactions, and the alignment between flipped learning activities and in-class project work. Student artifacts were collected to assess evidence of learning, application of concepts, and collaborative problem solving.

Our data analysis is still underway. Descriptive statistics are currently being used to explore patterns and trends across the three survey administrations, with further analyses planned as data interpretation continues. Qualitative data analysis is currently underway using a directed content analysis approach. Interview transcripts, observation notes, student artifacts, and open-ended survey responses are being coded iteratively to identify recurring codes, categories, and eventually themes related to the implementation and perceived effectiveness of FPBL. The coding process is informed by both deductive categories aligned with the FPBL framework and inductive themes emerging from the data. Triangulation across data sources is being used to enhance the credibility and trustworthiness of the analysis. Together, the ongoing quantitative and qualitative analyses aim to develop a comprehensive understanding of how FPBL functioned in this instructional context and to inform future refinements of the instructional framework.

Summary of Preliminary Findings

1. Overall Perceptions of the FPBL Experience

Preliminary findings indicate that students were generally positive about their overall experience with the FPBL framework. Students reported high levels of engagement (N=20, M=4.10 out of 5, SD=1.16) and expressed appreciation for the course structure, particularly the emphasis on hands-on, project-driven learning (e.g., Student 1: "*I honestly really liked all the labs as it allowed me to learn something new that i haven't experience yet…. I definitely do believe this course enhanced my skills in cyber aerial computing. It allowed me to understand that when it comes to troubleshooting, it also takes account of the actual hardware and allowing to fix those issues through the code or the drone. this course allowed me to learn something new that I've never done before.*"). Many students noted that FPBL supported active participation and helped them connect course content to real-world applications. Instructor perspectives also evolved over the course of the semester. Although the instructor initially expressed uncertainty about FPBL, he reported growing confidence in the approach and recognized its potential to enhance undergraduate education by promoting experiential, practice-oriented learning.

2. Student Learning Outcomes

Early evidence suggests that FPBL supported meaningful student learning, particularly in the development of practical skills involving the orchestration of software (i.e., Python programming) and hardware (i.e., drones). Because the primary learning outcomes focused on successful project completion—specifically, operating drones to accomplish required tasks—all students were able to successfully complete the assigned projects in time. Students reported that project-based activities helped them build confidence in applying concepts to authentic tasks and strengthened their understanding of course content (e.g., Student 2: "*I think the course did enhance my skills in cyber-aerial computing. Although I knew some stuff about cybersecurity, this course taught me well above what I thought I knew. Then I was able to implement my knowledge into projects that helped me grasp what I was learning and use it to better my critical thinking.*"). Students demonstrated strong academic performance on the exam, with scores clustering near the maximum (M=13.56 out of 15, SD=1.04), suggesting high mastery of assessed content. In contrast, the flipped-learning quiz scores (M = 3.30 out of 5, SD = 2.27) indicate moderate student endorsement of the flipped learning experience, with substantial variability in responses. This variability suggests that while many students perceived the quiz-embedded videos as supportive of their learning, others experienced challenges or inconsistencies, highlighting the need for stronger alignment between flipped materials and in-class project activities to ensure a more uniformly positive learning experience. Nonetheless, the instructor observed increased student engagement and deeper involvement in hands-on activities compared to more traditional instructional formats. These findings suggest that FPBL may effectively support competence building through sustained, real-world project experiences if the connection between the two instructional components is made more explicit and intentionally aligned.

3. Strengths and Areas of Improvement

While students expressed overall satisfaction with the FPBL approach, some identified areas for improvement. A recurring concern was the need for clearer and more explicit alignment between the flipped learning components and the in-class project-based activities. Students noted that explicit connections between pre-class video and reading content and lab or project sessions would enhance coherence and learning. On the other hand, the instructor emphasized the importance of appropriately leveling and calibrating the scope of the projects, especially noting the need to include more challenging tasks. He indicated that he had somewhat underestimated some students' prior experience and that student proficiency levels varied considerably across the class.

Discussion

Taken together, these preliminary findings suggest that FPBL is a promising instructional framework for supporting undergraduate learning in complex, technology-rich domains such as cyber-aerial computing. Students' generally positive perceptions, strong engagement, and successful project completion indicate that combining flipped learning with hands-on, real-world projects can effectively foster practical competence and applied problem-solving skills. At the same time, the variability in students' perceptions of the flipped learning components highlights a critical design consideration: the need for more intentional and explicit integration between pre-class materials and in-class project activities. When connections between videos, readings, and lab work were not clearly articulated, some students experienced fragmentation in their learning experience, which may have limited the full potential of FPBL to support motivation and coherence. Instructor reflections further underscore the importance of iterative refinement, particularly in calibrating project difficulty to accommodate diverse prior experiences while maintaining appropriate challenge. These findings align with prior work emphasizing that the effectiveness of FPBL depends not only on the presence of flipped and project-based elements, but also on the quality of their alignment and scaffolding [6] [7].

Implications of Next Implementation and Future Research

As an exploratory phase of a design-based research effort, this study provides early evidence to inform future iterations of FPBL design, suggesting that clearer instructional alignment and differentiated project complexity may further strengthen student learning and engagement. In the next implementation, in-class instruction and instructional materials will be revised to more explicitly connect flipped learning resources with in-class project activities, ensuring that pre-class content directly prepares students for hands-on tasks. Project scopes will also be adjusted to better accommodate variation in students' prior experience by incorporating tiered challenges and optional extensions. Future research will examine how these design refinements influence students' motivation, learning outcomes, and collaboration over time, as well as explore the transferability of FPBL to other computing and engineering contexts.

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