

INTERACTIVE ROBOTICS AND MAKER CULTURE IN ENGINEERING EDUCATION: A CASE STUDY

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Abstract

This paper presents a case study on the implementation of interactive robotics as a pedagogical strategy for engineering students at the University of the State of Amazonas (UEA), in partnership with the Samsung OCEAN Digital Fabrication Laboratory (DFL). The study is grounded in the STEM (Science, Technology, Engineering, and Mathematics) framework and the principles of Maker Culture, aiming to develop technical competencies and foster student engagement as a strategy to mitigate academic dropout in the early stages of the program. The intervention adopted Project-Based Learning (PBL), involving a sample of more than 60 students and 20 mentors, impacting approximately 80 UEA students, who led the development cycle of a real-world technological product. The most recent project used as a methodological reference in this study is a robotic health monitoring system. The device integrates sensors for measuring vital signs, such as body temperature and oxygen saturation, also an interactive interface and communication with mobile applications via the MQTT protocol. The process, conducted over eight months, was structured into two evolutionary phases: the first focused on technical training (3D modeling and printing, electronics, and PCB design), and the second was dedicated to system prototyping and integration. A central pillar of the methodology was peer learning, in which senior scholarship students acted as technical mentors. Data collection was carried out through weekly meetings, including performance evaluation and result analysis conducted at the laboratory. The results indicate that the transition from theoretical abstraction to physical prototyping enhances knowledge retention and student motivation. The study concludes that the integration of university–industry innovation infrastructure with active learning methodologies constitutes a scalable model for modernizing engineering education.

Keywords: *STEM, educational robotics, active methodologies, maker culture, engineering education.*

1. Introduction and literature review

Engineering education in Brazil faces persistent challenges related to high dropout rates, a phenomenon particularly pronounced during the early stages of undergraduate studies. Incoming students often encounter complex curricular structures with limited immediate practical application. In this context, it is essential to bridge the gap between students and meaningful engagement with science and technology in their social and practical dimensions from the very first year of study (Pinheiro, Silveira, & Bazzo, 2007).

The evolution of this pedagogical model requires a shift from purely traditional instructional methods to constructionist approaches, in which learning becomes more effective when students are actively engaged in building tangible products. This movement, grounded in Maker Culture and the “democratization of invention” through digital fabrication (Blikstein, 2013), enables students to develop functional prototypes by integrating digital design with physical fabrication. Such environments, known as makerspaces, have become essential ecosystems for experimentation and academic innovation (Albuquerque & Cavalcante, 2023).

This approach is based on the premise that students should take control of technology to explore their own thinking and become “epistemologists” (Papert, 1980). In the technological context, this is operationalized through the STEM (Science, Technology, Engineering, and Mathematics) framework, which integrates these fields to address complex problems (Honey, Pearson, & Schweingruber, 2014).

To structure this integration, Project-Based Learning (PBL) provides a framework in which projects serve as the primary vehicle for knowledge acquisition (Thomas, 2000). Particularly in introductory (cornerstone) courses, PBL fosters design thinking and the development of critical engineering skills (Dym, Agogino, Eris, Frey, & Leifer, 2005).

This model is further strengthened by peer learning, in which mentorship from senior students to first-year students creates a zone of proximal development, translating technical language into more accessible forms (Topping, 2005). This dynamic promotes creativity by balancing real-world projects, personal engagement, and peer collaboration (Yuan & Bowen, 2018). The present paper describes a case study conducted at the School of Technology of the University of the State of Amazonas (EST/UEA), in collaboration with Samsung OCEAN, demonstrating how this synergy can bridge the gap between academic theory and the demands of Industry 4.0.

2. Methodology

The present research is characterized as a qualitative case study conducted at the Samsung OCEAN Digital Fabrication Laboratory (DFL) in Manaus, in collaboration with the University of the State of Amazonas (UEA). The primary objective was to evaluate the impact of interactive robotics on the engagement and retention of first-year engineering students at the School of Technology (EST).

The study sample comprised approximately 80 UEA students, including more than 60 early-stage students and a group of 20 mentors. Participants were selected based on their voluntary interest in engaging in research and community outreach projects. The support structure was based on a peer learning model, involving senior mentors, undergraduate research fellows with technical expertise in digital fabrication. These mentors were organized into three areas: mechanics, electronics, and programming, and acted as facilitators and mediators of practical knowledge.

The study was conducted over an eight-month period, structured into two evolutionary macro-phases.

2.1. Phase 1 - Technical training

This phase focused on establishing the foundational knowledge required for prototyping. Students participated in practical, hands-on workshops covering 3D modeling and printing, fundamentals of electrical circuits, Printed Circuit Board (PCB) design, and the use of additive manufacturing equipment.

2.2. Phase 2 - Ideation and prototyping

In this stage, students applied the acquired competencies to the development of real-world technological systems. The primary object of analysis was a robotic health monitoring system focused on the integration of hardware and software for the collection and transmission of biometric data via the MQTT protocol.

Data collection for evaluating the pedagogical intervention was conducted systematically within the laboratory environment through weekly follow-up meetings, technical performance assessments, and continuous analysis of each team's outcomes. The evaluation criteria included proficiency in solving complex problems, autonomy in the use of digital fabrication tools, and resilience in addressing challenges inherent to the development of functional prototypes.

3. System development (design and construction)

The robotic health monitoring system was conceived as an intelligent device for collecting, processing, and displaying pediatric screening parameters. The primary technical objective of this intervention was to enable students to integrate multiple engineering domains, such as electronics, mechanics, and computer engineering, into a single functional and cohesive system.

3.1. Hardware and electronic architecture

The system architecture was based on a microcontroller with native wireless connectivity, enabling data transmission to cloud platforms or mobile devices. Unlike purely local approaches, the MQTT (Message Queuing Telemetry Transport) protocol was adopted to ensure robust and scalable communication with external applications. The main integrated subsystems, illustrated in Figures 1 and 2, include:

- Biometric Sensors: Modules for measuring body temperature, heart rate, and blood oxygen saturation.
- Interaction Interface: A local display (OLED) that enables real-time data visualization.

- Printed Circuit Board (PCB): Designed and fabricated by the students with mentor support, ensuring connection reliability and a compact device design.

Figure 1. Detailed layout of the customized Printed Circuit Board (PCB) in the design environment, highlighting the routing and component placement for processing signals from oximetry, heart rate, and temperature sensors.

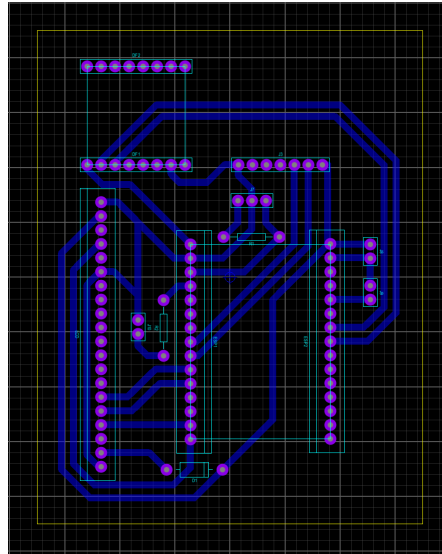
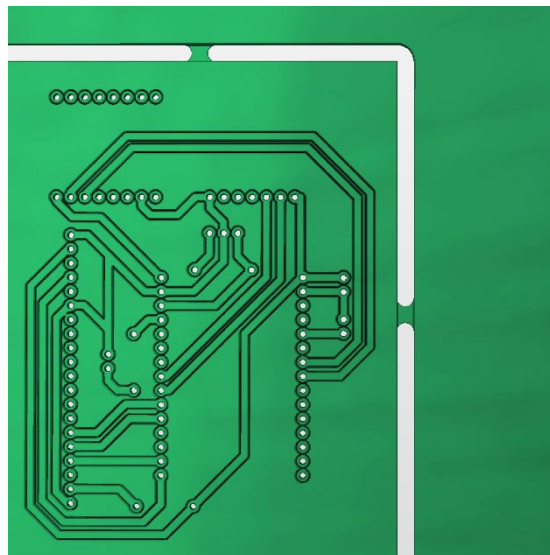


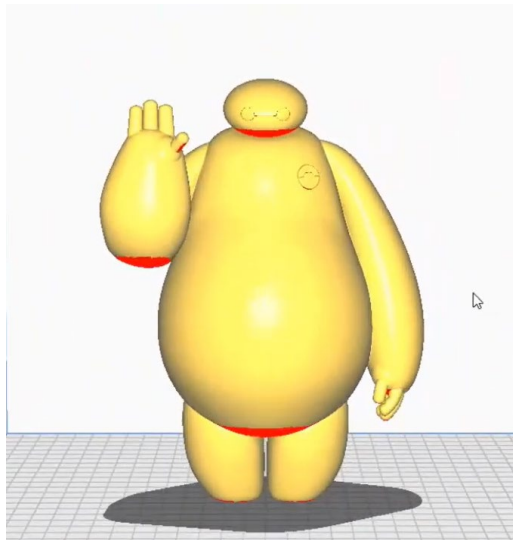
Figure 2. Fabricated Printed Circuit Board (PCB), showing the finalized physical layout for processing signals from oximetry, heart rate, and temperature sensors.



3.2. Mechanical structure and maker design

Following the principles of Maker Culture, the system's internal functional modules were entirely developed by the students using 3D modeling software. In contrast, the external design intended to humanize care and engage patients, was selected and obtained from digital repositories. Both components were fabricated through additive manufacturing, as illustrated in Figure 3. This process enabled students to develop a practical understanding of concepts such as dimensional tolerances, material properties, and Design for Assembly (DFA). This stage was crucial for transforming the electronic circuitry into an integrated, functional, and visually appealing product.

Figure 3. Front view of the functional health monitoring prototype in slicing software, highlighting the preparation of the project's aesthetic model for 3D printing.



4. Results and discussion

The analysis of the results was based on the systematic observation of student engagement and the technical validation of the outputs developed in the laboratory. The methodology applied at the Samsung OCEAN DFL demonstrated a high level of technical and scientific development, with projects reaching sufficient maturity to be presented at regional, national, and international academic conferences and exhibitions. These track achievements support the conclusion that the transition from theoretical concepts to physical prototyping not only contributes to student retention but also enhances the technical rigor of the solutions developed by first-year students.

It was observed that the shift from purely conceptual instruction to practical experimentation acted as a catalyst for student motivation. By engaging in hands-on development of real-world applications, students developed a clearer understanding of the practical role of an engineer. The primary functional outcome of this approach is a prototype of an assistive robot designed for pediatric hospital screening. The system was designed to interact with patients through guided dialogue, supporting the assessment process while promoting a more engaging experience for children. As illustrated in Figure 4, the device performs real-time acquisition and display of biometric data through its local interface, validating the integration between hardware and software.

Figure 4. Final prototype in operation, demonstrating the simultaneous measurement of vital parameters and the display of data, integrated into a design focused on pediatric care.



The peer learning model emerged as a fundamental pillar for student retention. The 20 senior mentors not only supported the technical execution, assisting with the implementation of conversational logic and sensor integration, but also fostered a welcoming environment that reduced the communication barriers typically experienced in the early semesters. For the more than 60 first-year students, this dynamic resulted in an accelerated learning curve and increased self-confidence to continue their academic journey.

Student engagement was further evidenced by a retention rate exceeding 93% among participants in the activities conducted at the Samsung OCEAN DFL, surpassing the institution's historical retention rates for the early stages of the program. The successful integration of complex technologies and the quality achieved in the final prototypes support the conclusion that early exposure to laboratory-based practice is an effective strategy for fostering a sense of belonging and advancing the modernization of engineering education.

5. Conclusions

The case study demonstrates that the integration of university–industry innovation infrastructure, represented by the partnership between UEA and Samsung OCEAN, and active learning methodologies constitutes an effective model for modernizing engineering education. The implementation of interactive robotics and Maker Culture enabled incoming students to overcome the initial barrier of theoretical abstraction by applying STEM concepts to the development of a functional health monitoring prototype with real-world relevance.

The peer learning structure proved to be fundamental, not only in providing technical support to first-year students but also in fostering leadership and teaching competencies among senior mentors. The findings suggest that early practical engagement, grounded in learning by doing, serves as a robust mechanism for student retention, aligning academic training with the competencies required by the contemporary labor market. For future work, it is recommended that this model be expanded to other core curriculum subjects, aiming to consolidate a culture of innovation and prototyping throughout the undergraduate experience.

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