Embedded Systems Training: Experiences, Results, and Lessons Learned

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Abstract. *Embedded systems have become key elements in the transformation of the modern, connected world, particularly in the context of Industry 4.0, which integrates digital technologies into production processes. To meet this growing demand, the EmbarcaTech embedded systems vocational training program emerged as an educational initiative to address the increasing need for professionals in this area. This article presents an experience report of the program, which enrolled 1,000 students and graduated 491. The report presents results and lessons learned, as well as the outcomes achieved by EmbarcaTech. Feedback from 286 students indicated high levels of satisfaction and highlighted lessons learned for future editions. Despite the challenges, the 49.1% completion rate and generally positive evaluations demonstrate the educational potential of the initiative.*

1. Introduction

According to [Heath 2002], embedded systems are designed for specific functions and integrated into larger devices. They have become central to the transformation driven by Industry 4.0, fostering innovation in sectors such as automotive, aerospace, telecommunications, and medical devices [da Silva et al. 2023c]. Technological development is essential for economic and social growth, including in Brazil [Gadelha 2021]. In this context, training in embedded systems underpins emerging technologies such as robotics and the Internet of Things [Soori et al. 2023].

Remote education has expanded access to technical training at scale [Feitosa et al. 2020, de Sousa Fernandes et al. 2024]. In Brazil, it helps mitigate geographical and economic barriers, enabling access to high-demand areas such as embedded systems [Moran 2007, Feitosa et al. 2020, da Silva et al. 2023b]. By preparing qualified professionals, such courses strengthen industrial competitiveness and technological infrastructure [Schwab 2016, Maruyama et al. 2024].

The adoption of hardware-based educational technologies, such as robotics, faces challenges in Brazil, particularly in public and rural schools, mainly due to high equipment costs and limited teacher training [Ramos et al. 2022, de Souza et al. 2022, Araújo et al. 2022, Martins et al. 2024, Silva et al. 2023a]. To address these issues, low-cost educational robotics initiatives using accessible or recycled materials have emerged, expanding opportunities for hands-on learning [de Souza et al. 2022, Martins et al. 2024].

In this context, the EmbarcaTech program, promoted by iRede (Institute of Management, Technological Networks and Energy), offers a course focused on embedded systems, integrating theoretical and practical aspects of hardware and software, including architectures for Internet of Things applications. EmbarcaTech had a total of 1,000 students enrolled. Most students were undergraduates, graduates, or in training. With 491 graduates, indicating good student satisfaction and engagement, it is possible to say that the embedded systems course contributed to the training of professionals in this field. Although the program achieved significant reach and retention, the lessons learned revealed opportunities for improving course delivery and student support.

In this sense, this work presents an experience report addressing the lessons learned and results of the course, aiming to provide an overview of the challenges of a practical course involving the manipulation of hardware components, offered remotely. Thus, the aim is to demonstrate what worked and what can be improved for future applications, also showing that it is possible to combine remote teaching with active learning, involving practical activities with remote assistance.

This work is structured as follows: Section 2 presents the theoretical framework. Section 3 presents the related work. Section 4 describes the pedagogical, organizational, and structural aspects of EmbarcaTech. Section 5 presents the methods used to evaluate the students' experience in the course, as well as the results obtained. Section 6 discusses the lessons learned during the course execution. Finally, Section 7 presents the limitations, challenges, and conclusions.

2. Theoretical Background

Desktop computers and application software initiated the digital transformation, enabling organizations to integrate software into their workflows. This process expanded beyond desktop environments with the advent of ubiquitous or pervasive computing, which allows access to computational resources anytime and anywhere through computers embedded in everyday products [Camposano and Wilberg 1996, de Araujo 2003].

Ubiquitous computing is enabled by embedded systems-specialized software tightly coupled with dedicated hardware designed to perform specific functions [Camposano and Wilberg 1996, de Araujo 2003]. Typical examples include automotive microcontrollers, hospital monitoring systems, household appliances, and Internet of Things (IoT) sensors.

As noted by [Camposano and Wilberg 1996], embedded systems support applications across multiple domains, such as autonomous vehicles, traffic control, advanced-sensor robotics, and smart buildings, contributing to efficiency, comfort, energy savings, and safety. Despite their potential, embedded systems require high reliability, and key design challenges include information security, confidentiality, functional safety, reliability, maintainability, and availability [Camposano and Wilberg 1996].

Teaching and learning embedded systems can also be challenging, especially in remote settings, as it involves handling hardware components and requires pedagogical approaches that provide greater student support in their manipulation. On the other hand, the remote education has become an effective alternative for democratizing access to education, reaching students from different regions and contexts [Santos Junior 2024, Santos 2024]. With the advancement of digital technologies, virtual platforms enable courses ranging from basic education to graduate programs [Pimentel and Carvalho 2021, Santos 2021], offering flexibility and autonomy, especially for those who need to combine studies with other activities [Santos 2024].

Despite its benefits, remote education still faces challenges in areas requiring direct interaction with physical equipment, such as embedded systems education. This field of engineering and computing involves developing integrated hardware and software solutions applied to electronic devices, automation, and the Internet of Things [Magrani 2018, Moreira et al. 2020].

Learning embedded systems requires hands-on practice with boards, sensors, and actuators—resources that are not always available in remote environments [Moreira et al. 2020]. Therefore, institutions must invest in strategies such as kit lending, virtual laboratories, and continuous support to ensure effective training.

In this context, active learning [Diniz 2020, Silva et al. 2023b] becomes an essential pedagogical approach for teaching and learning embedded systems, as project-based learning methodologies [de Angelo Nascimento and da Silva 2025] enable students and teachers to work collaboratively on practical activities using hardware and implementing embedded systems to solve real-world problems.

According to [Diniz 2020], active learning encourages students to act and reflect on their actions, promoting an active intellectual stance instead of the passive role common in traditional approaches. These methodologies create creative and engaging learning environments through innovative resources and greater access to research [Lovato et al. 2018, Sabec et al. 2020], helping students connect practice with theory.

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3. Related work

The teaching of embedded systems has increasingly adopted active methodologies to enhance engagement and learning outcomes, emphasizing participation, collaboration, investigation, and hands-on practice, which are well suited to technical and interdisciplinary contexts [Sabec et al. 2020].

In [da Silva et al. 2023a], a short course developed within the PET-TI program at UFC Quixadá used Arduino to teach programming and basic electronics through active and cooperative methodologies that combined theory, Tinkercad simulations, and group activities. Over 12 sessions, students advanced toward a final project, demonstrating increased motivation, improved understanding of programming concepts, and high satisfaction, indicating Arduino as an effective introductory tool that may reduce dropout rates.

The study carried out by [Tello and Passos 2019] investigated authentic learning supported by educational robotics in a technical course in Industrial Automation. Using Arduino, Scratch, Tinkercad, and Padlet, the approach integrated theory and practice while fostering logical reasoning, creativity, and collaboration. Results from a case study involving 21 students, analyzed using ANOVA, showed high satisfaction, motivation, and improved understanding of the content.

Similarly, [Silva et al. 2022] reports an experience combining educational robotics with Cooperative Learning over four months with early undergraduate students. Activities spanning basic electronics to robotics fundamentals resulted in increased engagement, peer knowledge exchange, and the development of technical and collaborative skills. Overall, the related works confirm the effectiveness of active methodologies—such as project-based learning, cooperative learning, and educational robotics—in embedded systems education. Unlike prior studies focused on specific tools or approaches, the work proposed here integrates embedded systems and IoT within an extension course, emphasizing interdisciplinary activities and real-world applications, and addressing contemporary challenges of ubiquitous and connected systems.

Finally, the related works show strong alignment with the Embarcatech program by highlighting the use of active methodologies, hands-on learning, and a project-based approach in teaching embedded systems. Similar to experiences with Arduino and robotics, Embarcatech also integrates theory and practice with a focus on programming, electronics, and IoT, promoting collaborative learning and student engagement.

4. The Embarcatech Program

The Embarcatech is a technical professional training program aimed at higher education students in Information and Communication Technologies (ICT) and related fields, with a focus on embedded systems. Within this program, an Embedded Systems course was offered to provide professional training in the area. The course was conducted from 11/18/2024 to 02/09/2025, with a total workload of 160 hours. Its main objective was to develop participants' understanding and practical skills in embedded systems by integrating theoretical and hands-on activities related to hardware and software requirements, constraints, and functionalities, with particular emphasis on Internet of Things application architectures.

The course targeted undergraduate and graduate students in Information and Communication Technologies (ICT), Engineering, Mathematics, Physics, and Statistics, as well as students and graduates of technical programs in Control and Industrial Processes and Information and Communication, in accordance with the National Catalog of Technical Courses (CNCT). The training was also open to staff members of IFCE(Federal Institute of Education, Science and Technology of Ceará), and prior knowledge of information technology was considered desirable. Dissemination strategies included the project's institutional social media, and direct email invitations to candidates not selected in previous ICT-related selection processes, resulting in 1,800 registrations.

The course enrolled a total of 1,000 students, with 509 dropouts and 491 graduates. Registration form data revealed that most participants were undergraduate students (68%), of whom 55% had not yet completed their degree. The predominant fields of study were Systems Analysis and Development, Computer Science, and Engineering, with emphasis on knowledge in Python, Java, and JavaScript. About half of the enrolled students reported having no prior knowledge of the course topics, highlighting the need for conceptual leveling strategies at the initial stages. Regarding employment status, there was a balance between participants already in the job market (42%) and those without employment (48%), in addition to 10% working as freelancers.

4.1. Student selection and course access

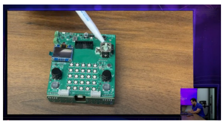
Admission to the course was conducted through published selection rules defining the criteria and procedures for candidates. Interested applicants completed a registration form and submitted proof of minimum education, while regularly enrolled students also provided an academic transcript and information about time availability. A total of 1,000 students were enrolled, with selection based on registration order, Cultural Fit criteria consisting of 45 questions, and extra points for academic titles. After enrollment, students accessed the Homero [Machado et al. 2024] platform for video lessons and an intelligent tutor, and later used the Moodle platform [Asano et al. 2022] to complete exercises and assessments.

4.2. Pedagogical approaches and student support

The embedded systems course adopted active methodologies, mainly Problem-Based Learning (PBL) [Finger et al. 2021] and gamification, to promote active learning, problem solving, and student engagement. The course was delivered remotely, with weekly synchronous classes streamed on YouTube and made available on the Homero platform, complemented by synchronous meetings with tutors and specialists. Students were organized into groups of 25 and participated in weekly online mentoring sessions via Google Meet. Asynchronous interaction and support were provided through Discord, which enabled discussions, material sharing, and communication among students, mentors, and educational support staff.

4.3. Curriculum structure and development kit

The course curriculum covered distance education, embedded systems, programming, microcontrollers, IoT, case studies, and practical projects, including topics such as C programming for embedded systems, microcontroller architecture, communication interfaces, PWM, A/D converters, and IoT applications. The practical classes were conducted individually with the support of Moodle resources. Development kits containing the necessary hardware components for practical activities were provided to students. Delivery was carried out in person in (omitted for review)), and for students living outside the region, via shipping directly to their residence. To guide initial kit handling, a video with usage instructions was made available to students across all communication channels, as shown in Figure 1.



(a) The kit being presented in a video lesson.

(b) Development kit provided for student practice.

Figure 1. Embedded systems development kits used in the course.

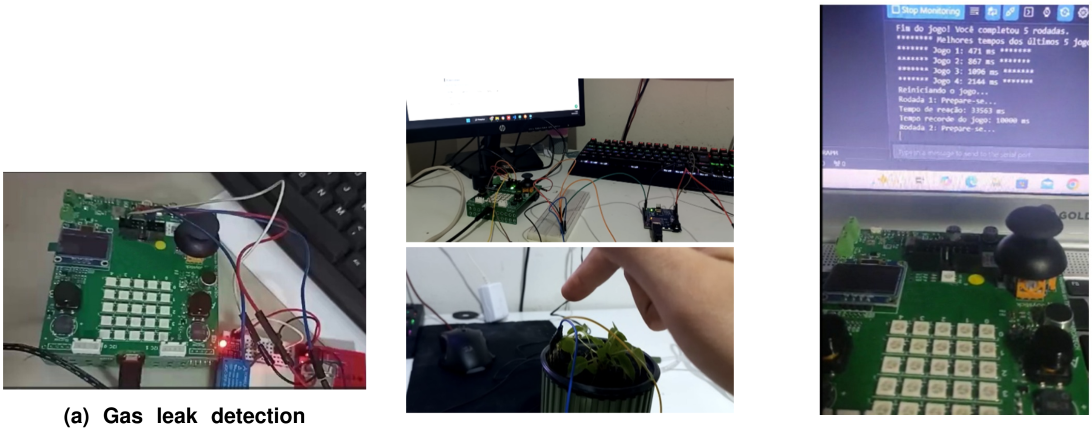
4.4. Synchronous classes and Assessment activities

These spaces for real-time interaction—live classes on YouTube and mentoring sessions via videoconferencing—enabled instructors and tutors to identify immediate signs of understanding and difficulty. Through chat logs, quick polls, and mentoring notes, it was possible to detect active learning behaviors, adjust the instructional pace, and provide timely support. To this end, participation logs (attendance reports and connection time from YouTube Analytics and Google Meet records), short post-session questionnaires with 2–3 objective questions, and an adapted version of the Online Student Engagement Scale (OSE) [Dixson 2015] were employed, as presented in the section 5.

Throughout the course, reviews were conducted in a processual and cumulative manner, including the development of practical projects involving the integration of hardware and software, aligned with embedded systems requirements and constraints. In addition, *quizzes* were applied to assess theoretical knowledge, as well as discussion forums evaluated based on the quality of contributions. Effective participation in forums and performance in practical projects were the main instruments for verifying learning. For certification, a minimum attendance of 75% and a grade equal to or greater than 6.0 were required.

4.5. Projects developed by students

Regarding the use of the boards during training, they were widely integrated into activities, being used repeatedly in live classes, mentoring sessions, and final projects, reinforcing their importance in the practical dimension of training. Below are some examples of how students used the boards in their final projects. The figure 2 shows examples of projects developed by students during the training.



(a) Gas leak detection monitoring system. (b) Automatic irrigation prototype. (c) Reaction Game interface.

Figure 2. Examples of projects developed by students during the training.

- **Gas Leak Detection Monitoring System** — Device based on the Raspberry Pi Pico with an MQ-2 gas sensor, LED, buzzer, and relay. It continuously monitors the environment and, in case of gas leakage, triggers visual and audible alerts, sends a message to the Visual Studio Code serial monitor, and activates a cooler to disperse the gas. Figure 2a shows the system.
- **Automatic Irrigation System** — Prototype for household vegetable cultivation using a soil moisture sensor and Wi-Fi communication via MQTT. Data are sent to a remote server and visualized on the MQTTX dashboard and the OLED display of the BitDogLab board, enabling real-time monitoring based on moisture thresholds. Figure 2b shows the prototype.
- **Reaction Game** — Interactive game developed for the BitDogLab board with the Raspberry Pi Pico W. Players respond to LED color signals by pressing the corresponding button, and reaction time is measured in milliseconds to track performance. Figure 2c shows the game interface.

5. Student Experience Evaluation

An anonymous experience evaluation, conducted without identifying the students, was applied in the final stages of the training. A questionnaire was used, covering aspects of the course, teaching materials, platforms used, and development kit. Additionally, student engagement was assessed, as presented below.

5.1. Course Evaluation and Student Perceptions

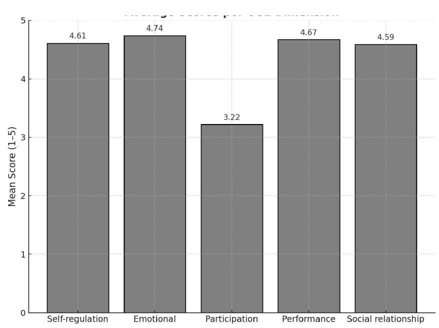
In the final stages of the embedded systems training, an anonymous and voluntary questionnaire evaluating the course, teaching materials, platforms, and development kit was answered by 286 students. Participants were predominantly young adults aged 18–34, mostly male, mainly from Fortaleza and other cities in Ceará. Most respondents were linked to higher education, including undergraduate students, graduates, postgraduates, and master's degree holders.

The evaluation revealed a predominantly positive perception of the course: 50% rated the overall experience as excellent, 42.31% as good with room for improvement, 6.29% as fair, and 1.4% as poor. Mentoring classes and mentors received an average score of 9.1, mainly due to content quality (82.52%), didactics and clarity of explanations (80.77%), and organization (57.34%). The Homero platform achieved an average score of 8.91, with content organization (76.57%), ease of navigation (66.78%), and system performance (55.24%) highlighted as strengths, while Moodle obtained an average score of 8.38. Regarding the question **"How did the embedded systems training course contribute to your learning and development, based on your personal experiences?"**, students emphasized improvements in practical knowledge, interest in technology projects, and motivation for autonomous learning, such as: *"My journey in the course was an enriching experience, where I was able to improve my knowledge in embedded systems and apply in practice what was previously only theoretical."; "The training opened new horizons for me, gave me access to an area I did not know, and sparked my interest in practical technology projects."; "It gave me ideas and knowledge, as well as motivated me to seek more learning on my own."*

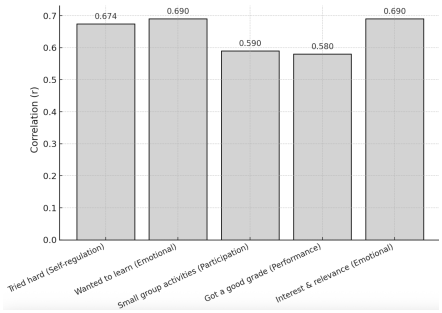
5.2. Student Engagement Analysis Using the OSE Scale

The Organizational Engagement Scale (OSE) was used to assess student engagement in virtual learning environments across five dimensions: self-regulation, emotional, participation, performance, and social relationship [Dixson 2015]. The scale conceptualizes engagement as a multifactorial construct that goes beyond attendance or task completion. In EmbarcaTech, the OSE was adapted for use by tutors as an observation and self-assessment instrument, supporting the monitoring of engagement and disengagement indicators, the identification of participation patterns, the recognition of emotional, cognitive, or motivational difficulties, and the improvement of pedagogical mediation through data-based strategies. To assess student engagement in the course, a 25-item OSE questionnaire was applied using a Likert scale (1 = "Strongly disagree" to 5 = "Strongly agree"). The generated indicators included the overall engagement mean, subscale means, percentage of students with high engagement (mean 4), response rate, and the correlation between engagement and performance.

The application of the OSE resulted in 285 responses and indicated positive engagement across all evaluated dimensions. In self-regulation, "I tried hard" obtained the highest mean score (4.61) and a strong correlation with overall engagement (0.674). In the emotional dimension, "I really wanted to learn the subject" reached the highest mean (4.74), while interest and perceived practical relevance showed the strongest correlations with engagement (up to 0.69). Participation scores were more moderate (3.22 to 3.83), with small group activities presenting the highest correlation with engagement (0.59). Regarding perceived performance, students positively evaluated their academic results, with mean scores of 4.59 for grades and 4.67 for test results. The item "I got a good grade" showed a notable correlation with engagement (0.58). Figure 3a presents the average scores per OSE dimension, while Figure 3b shows the items with the highest correlations with overall engagement.



(a) Average scores per OSE dimension.



(b) Highest correlations with overall engagement.

Figure 3. Engagement analysis based on OSE dimensions.

Finally, the social relationship dimension indicated that peer interaction and the sense of belonging had a direct impact on persistence and engagement, reinforcing the collaborative nature of the learning process. In summary, the OSE data confirm that personal effort, intrinsic motivation, and the perception of practical relevance of the content were the main drivers of engagement, whereas participation in forums and structured note-taking emerged as aspects that could be further strengthened in future editions of the course.

6. Lessons Learned

The lessons learned presented here help to understand the knowledge acquired through experience, both regarding positive aspects and challenges faced during the embedded systems course. In addition, improvements suggested by students and the pedagogical team are highlighted for future editions of the course. Student retention remains a major challenge in distance education. According to [da Silva et al. 2025], only 34% of students enrolled in distance education in 2018 remained by 2020, while 66% dropped out, and dropout rates in Brazilian corporate training courses exceed 30% [de Almeida et al. 2013]. During the course, participants reported difficulties in balancing academic, personal, and professional demands. To mitigate these issues, flexible deadlines and asynchronous classes were adopted, while dropouts motivated by external factors were monitored through specific forms and re-engagement actions, reinforcing the need for preventive and supportive strategies from the outset. Challenges related to irregular engagement and communication in large classes were addressed through mentoring, the use of the Online Student Engagement Scale (OSE) [Dixson 2015], and distributed communication across multiple channels. Additionally, prior knowledge in embedded systems was identified as a relevant factor, as participants who reported previous experience achieved significantly higher completion rates.

These initiatives were essential to achieving 491 course completions, corresponding to a 49.1% completion rate and a 50.9% dropout rate. For future editions, the expansion of flexible learning tracks with varying workloads is recommended, along with the establishment of a layered coordination structure, automated communication processes, and enhanced interactive dynamics to foster belonging, guided autonomy, and active presence in digital learning environments. It was observed during the course that the simultaneous use of multiple digital platforms (Homero, Moodle, Discord, WhatsApp) caused a sense of dispersion, leading to adjustments in content delivery. Centralizing activities in a single virtual environment was a recurring recommendation, aiming to avoid dispersion and confusion in the learning journey. Despite recognizing the potential as a Homero teaching platform, the data highlight the need for instructional design adjustments and integration with other course systems to ensure a clearer, more accessible, and effective student experience. Therefore, it is recommended to centralize resources in a single platform, with clear and continuous guidance on where to find and carry out each activity.

The heterogeneity of participants' prior knowledge levels was also a challenge, particularly among those without familiarity with embedded systems. The adoption of initial diagnostics and engagement monitoring was fundamental, and the inclusion of optional introductory modules is suggested. Although 1,000 development boards were planned for distribution, not all were actually delivered. The main reasons were the absence of signed Terms of Commitment and the lack of address confirmation by some students. During the training, there were also cases of dropout. In several on-site centers, boards remained available for pickup, awaiting students who did not attend. It is important to note that alternative times and flexibility in delivery were offered to facilitate access to the material.

From the students' perspective, overall satisfaction with the course was high; however, recurring issues were identified regarding schedule organization, clarity of the target audience profile, quality and structure of the learning materials—particularly on the platform (withheld for review)—and mentor preparation. Participants reported that the course duration and workload were insufficient for adequate content assimilation, especially for completing practical activities and the final project, suggesting the need for a longer course period to better balance theory and practice. The use of multiple digital environments (Moodle, Discord, and WhatsApp) also caused fragmentation, leading to confusion and difficulties in tracking activities, which motivated suggestions to unify platforms and improve communication. Logistical delays in delivering hardware kits, particularly for participants from other states, negatively affected practical learning, highlighting the need for earlier shipment.

7. Limitations, Challenges and Conclusion

This study presents limitations that must be considered when interpreting the results. The high dropout rate (50.9%) threatens external validity, as the findings reflect only the 49.1% of participants who completed the course, potentially introducing survival bias. Logistical issues related to the delivery of development kits—especially delays and incomplete distribution to students from other states—compromised the consistency of hands-on activities and affected construct validity. Additionally, the simultaneous use of multiple platforms (Moodle, Discord, YouTube, WhatsApp, and a proprietary system) led to fragmentation, communication difficulties, and challenges in tracking activities. Prior knowledge also played a significant role, since approximately half of the participants lacked familiarity with the subject, influencing completion rates and limiting generalizability. Finally, the voluntary nature of the final evaluation, answered by 286 of the 491 completers, may have biased the results toward more motivated or satisfied students, potentially inflating engagement and satisfaction indicators.

This work advances the state of the art by integrating embedded systems and the Internet of Things (IoT) within an extension course. While related studies emphasize specific dimensions—such as Project-Based Learning, cooperative practices with Arduino, or authentic learning through educational robotics [Sabec et al. 2020, da Silva et al. 2023a, Tello and Passos 2019, Silva et al. 2022, Silva et al. 2023a]—the proposed approach combines interdisciplinary activities with broader applicability and reach, extending active methodologies to contemporary, connected technological contexts. The main contributions of this study are summarized as follows: **Scale and scope:** The program reached more than 1,000 participants, exceeding the scale of typical class-based or short-term initiatives. **Technology convergence:** The integration of embedded systems and IoT prepares participants for challenges associated with ubiquitous and connected systems. **Diverse audience:** The course engaged undergraduate and graduate students from multiple fields, technical students, and institutional staff, raising relevant challenges related to leveling and engagement. **Active and inclusive methodologies:** The combination of Project-Based Learning, cooperative practices with Arduino, and authentic learning through robotics fostered motivation, teamwork, creativity, and autonomy, while promoting inclusion and alignment with real-world demands. The EmbarcaTech training program, supported by an innovative online structure, enabled 491 participants to complete the course and develop original projects through intensive, practice-oriented activities. Despite a dropout rate of 50.9%, the initiative proved effective, demonstrating significant transformative potential.

Future work will focus on expanding the course to new regions and institutions in order to broaden participation and impact, incorporating emerging technologies such as artificial intelligence, cloud computing, and cyber-physical systems, and conducting longitudinal assessments to evaluate skill retention, professional insertion, and long-term outcomes.

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9. Declaration of AI Use

The authors used large language models (LLMs) for textual revision and language correction.

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