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Enhancing Motivation and Learning in Engineering Courses: A Challenge-Based Approach to Teaching Embedded Systems

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***Abstract*—This paper addresses an approach to teaching embedded systems programming through a challenge-based competition involving robots. This pedagogical project distinguishes itself by incorporating international students from three international institutions through the Blended Intensive Program (BIP). The research findings indicate that this approach yields excellent results regarding student engagement and learning outcomes. The challenge-based program effectively promotes students' creative problem-solving abilities by combining theoretical instruction with hands-on experience in a competitive setting.**

***Index Terms*—BIP, Embedded Systems, Robotics, Project-based Learning, Control, Signal Processing, Education.**

I. Introduction

The world is currently experiencing a shortage in the numbers of engineers and, as a recommendation of the 21st-Century Required Professional Skills of UNESCO [1], governments and policymakers should take urgent actions to encourage more young people to consider engineering as a career to address the shortfall in the number of engineers. Laboratory experiments are critical in undergraduate engineering courses. As stated in Hoffenson et at. [2], this type of class is used to integrate theory methodology development and understanding of the problem. Besides, they are synchronized with lectures to maximize learning [3].

Note that there is difficulty in absorbing the rapid technological evolution of systems and equipment, and educational kits can quickly become obsolete and disposable [4]. Besides, educational modules should stimulate student development. There are several kits available in the market. However, most platforms are expensive and not available to all students. In recent years, several works have been proposed to improve the current engineering teaching process [5]. Thus, different types of methodologies have been developed to enhance learning as well as teaching models. Recently, Project-Based Learning has been an increasingly explored learning approach, where some works in the literature examined the effects of the project-based learning approach [6]. In Karpudewan et al. [7], the authors explained that this teaching scheme is built through differentiated learning activities in order to captivate the students' interest and motivation.

The use of robots as educational tools has been widely studied [8], with research consistently demonstrating their effectiveness in creating a stimulating learning environment that promotes active learning and leaves a lasting impact. Furthermore, studies emphasized the positive outcomes of students' participation in robotics competitions, like RoboCupJunior [9]. These outcomes include increased interest in STEM (science, technology, engineering, and mathematics) subjects, improved computational thinking skills, and enhanced engineering abilities.

In order to enhance teaching methods for embedded systems, numerous studies in the literature have explored diverse approaches [10]–[12]. However, this work stands out for introducing a distinctive strategy that involves a challenge-based competition utilizing robots, all within the framework of a Blended Intensive Programme (BIP). This approach incorporating BIP facilitates collaborative learning and encourages curriculum innovation and international cooperation, providing a comprehensive and holistic educational experience that transcends traditional teaching methods.

Regarding this work, in the Electrical and Computer Science undergraduate program (180 European Credit Transfer Scale - ECTS) of the Polytechnic Institute of Bragança (IPB), where this study was held, there is a curricular unit of Embedded Systems, with 6 ECTS. At Bremen, the study can be accounted for a 6 ECTS elective module in nearly all Computer Science programs. Finally, at the Hanze University of Applied Sciences, there is a course called Embedded Programming (5 ECTS) and another called Robotics (4 ECTS), both part of the undergraduate program on Electrical and Electronics Engineering. In the academic year of 2022/2023, just after the decline in restrictions due to the COVID-19 pandemic, we decided to offer a curricular unit on Embedded Systems Applications (6 ECTS) in an experimental way in the form of a BIP, using a KA131-HED - Mobility of higher education stu-

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dents and staff scholarship funded by the ERASMUS program. BIP are short, intensive programs that use innovative learning, teaching, and training methods for students and staff, including online cooperation. They are developed and implemented by at least three higher education institutions from at least three EU Member States, and third countries associated with the Programme [13]. The action aims to foster employability, social inclusion, civic engagement, innovation, and environmental sustainability in Europe and beyond by enabling students from all study fields and at all study cycles to have the opportunity to study or train abroad as part of their studies [14]. During BIP, groups of students and/or staff undertake a short-term physical mobility abroad combined with a compulsory virtual component facilitating collaborative online learning exchange and teamwork [13]. The implemented physical component lasted five days in Bragança, Portugal.

It is a very interesting way for students to go abroad at a partner higher education institution, and share students' expertise while experiencing new teaching environments. It also benefits acquiring new innovative pedagogical and curriculum design skills and digital skills to exchange good practices, enhance cooperation between higher education institutions, and better prepare students for the world of work [14]. The BIP methodology has the following objectives [14]:

- expose students to different views, knowledge, teaching, and research methods as well as work practices in their study field in the European and international context;
- develop their transversal skills such as communication skills, language skills, critical thinking, problem-solving, inter-cultural skills, and research skills;
- develop their forward-looking skills, such as digital and green skills, that will enable them to tackle the challenges of today and tomorrow;
- facilitates personal development, such as the ability to adapt to new situations and self-confidence.

In addition, the objective is to foster the development of transnational and transdisciplinary curricula and innovative ways of learning and teaching, including online collaboration, research-based learning, and challenge-based approaches to tackle societal challenges [14]. In the presented case, the BIP was implemented with students and lecturers from three EU-member institutions: Hanze UAS, Bremen UAS, and IPB. It consisted of 36 hours of online lessons delivered to the students, and a week of physical work in Bragança, carried out using hardware, experiments, and robotics challenges. A questionnaire was applied at the end of the physical week to evaluate its effectiveness and student satisfaction to allow improvement for the next edition. Therefore, this article aims to provide an insightful account of an educational initiative that addresses the potential of BIPs in fostering transversal skills, forward-looking competencies, and personal growth among students, while simultaneously facilitating collaboration, curriculum innovation, and international cooperation.

II. BIP STRUCTURE

The presented BIP, is a joint course between the Polytechnic Institute of Bragança from Portugal, the Hanze University of Applied Sciences from the Netherlands, and the Bremen City University of Applied Sciences from Germany. The BIP was structured using four teachers handling all 16 online lessons and the practical week, as presented in Table I. This table helps to understand the course structure. The first lesson presents an introduction describing the course summary and some prototyping topics. Then, three lessons on microcontroller programming are given, where basic topics on low-level programming are addressed. Lesson #5, about Sensors, Actuators, and I/O, presents some examples to teach concepts of input and output, including Interruptions, Timers, Pulse width modulation (PWM), debouncing, Infinite impulse response (IIR) filtering, and analog to digital conversion. In lesson #6 typical sensors applied in robotics are detailed. Then, concepts of robot kinematics are presented in lessons #7 and #8, focusing on the mobile and manipulator robots. Lessons #9 and #10 are dedicated to the Hardware-in-the-loop SImulation approach by using a simulation environment controlled by a real microcontroller, enhancing all its limitations (further detailed in this paper). In this lesson, a simulated differential robot equipped with 5-floor line sensors is controlled by an ESP32-based microcontroller board. Lesson #11 addresses the control architectures and behaviors for a mobile robot, and Lesson #12 deals with finite-state machines to decide the robot states depending on operating conditions. In Lesson #13, odometry-based localization applied to a differential-drive robot is presented, whereas Lesson #14 is dedicated to applying a PID controller to implement moving controllers for a robot. The last two online lessons (#15 and #16) are used to start the project development that will be finished on the physical week, as further detailed.

TABLE I: Sylabus of the BIP course on Embedded Systems Applications.

Lesson #	Type	Topic
1	on-line	Prototyping
2	on-line	Microcontroller Programming
3	on-line	Microcontroller Programming
4	on-line	Microcontroller Programming
5	on-line	Sensors, Actuators, I/O
6	on-line	Sensors in Robotics
7	on-line	Robot Kinematics
8	on-line	Robot Kinematics
9	on-line	Hardware-in-the-loop Simulation
10	on-line	Hardware-in-the-loop Simulation
11	on-line	Control architectures and Behaviors
12	on-line	Finite-state Machines for robot control
13	on-line	Odometry-based localization
14	on-line	Position controller with PID
15	on-line	Project Development
16	on-line	Project Development
WEEK	Physical	Competition and assessment

At the end of the online lessons, a face-to-face week in Bragança was mandatory. Of the 38 hours composing the practical week, four were dedicated to theoretical presentations and three to the challenge demonstrations and competitions. There were also social events and an invited talk on Robotics by an international speaker.

III. CHALLENGES

STEM education is a popular pedagogical approach for enhancing the students' creativity and problem-solving skills, increasing the interest in these areas [15]. Since robotics addresses multidisciplinary areas, it plays an essential role in the STEM concept. Competitions also bring together multiple research groups working on the same problem. This fosters the exchange of ideas [16]. A challenge-based learning (CBL) experience is a learning experience that takes place through the identification, analysis, and design of a solution to a sociotechnical problem [17]. CBL provides an efficient and effective framework for learning while solving real-world Challenges and sharing their thoughts with the world. [18].

Students were divided into teams of 3 or 4 members, preferably with students from different institutions. The scenarios were given to the students during the online lessons #15 and #16 using the Hardware-in-the-loop (HIL) approach so that students could develop the coding procedure without hardware. HIL provides a feature to test the hardware responsible for controlling all actions of the real robot but controlling the virtual robot through Serial (USB) communication established with SimTwo in real-time. In summary, there were two scenarios that students could select: a mobile robot (based on the RobotAtFactory competition [19]) and a small manipulator (based on a Dobot, arm built with Dynamixel servomotors or an EEZYbotARM MK2).

A. *RobotAtFactory Lite*

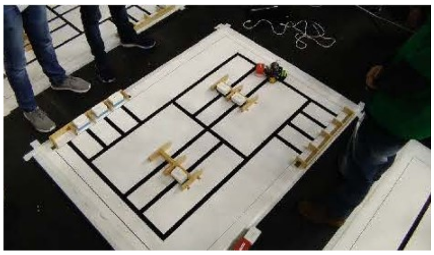
This challenge aims to present a problem inspired by deploying autonomous mobile robots on a factory shop floor. More competition details can be found on [19]. One robot developed by the team) should transport materials between warehouses, picking the material with an electromagnet and detecting it with a switch. Motors have encoders coupled to implement the odometry and a speed controller. Two H-bridges from the L9110S-based module drive the DC motors, and an ESP32 Wemos D1 R32 controls the robot. Connections can be changed, but an example is given to the students, according to Table II. The final mobile robot was built with 3D-printed parts. The maze, real, and the simulated are presented in Figure 3.

TABLE II: Sensors and actuators connections of ESP32

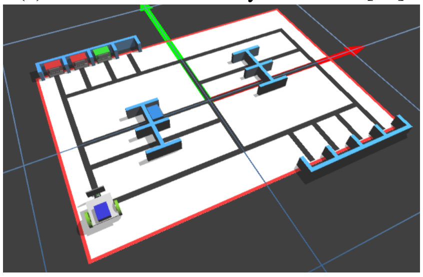
Variable	Description	ESP32 PIN GPIO	Wire color	I/O (ESP32)
ENC1_A	Right motor encoder	27	Green	I
ENC1_B	Right motor encoder	14	Blue	I
ENC2_A	Left motor encoder	19	Green	
ENC2_B	Left motor encoder	23	Blue	
ML_A	A-1A Left motor +	26		O
ML_B	A-1B Left Motor -	25		O
MR_A	B-1B Right Motor -	16		O
MR_B	B-1A Right Motor +	17		O
SOLENOID_PIN	Eletromagnet control	13		O
TOUCHSW_pin	Switch of part detector	12		I
IR line 1	Line sensor	33	Blue	I
IR line 2		32	Yellow	I
IR line 3		39	Orange	I
IR line 4		36	Green	I
IR line 5		34	White	I

B. *Arm Manipulator*

1) EEZYbotARM MK2: An EEZYbotARM MK2 model was printed and assembled to be used by students [21]. Some modifications were made to the original version. The first joint was mainly replaced by a speed servomotor (continuous movement), and an absolute magnetic encoder was attached to the shaft. The AS5600 Position Sensor allows us to measure the angle. A proportional controller was implemented in the microcontroller (Arduino UNO) that controls all the servomotors. The robot is shown in Figure 2.

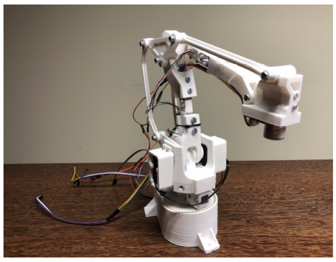


(a) Real RobotAtFactory Lite field [20]

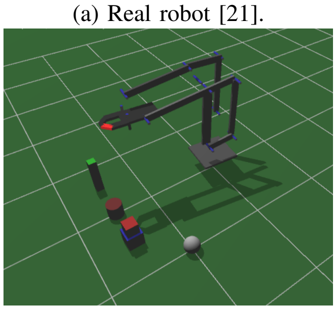


(b) Simulated RobotAtFactory Lite field

Fig. 1: RobotAtFactory Lite environments



(a) Real robot [21].



(b) Simulation environment

Fig. 2: EEZYbotARM MK2 challenge

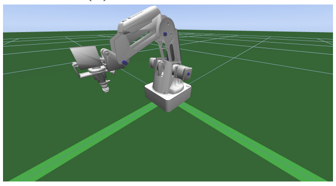
2) Dobot manupulator: The Dobot robot is shown in Figure 3. This robot can achieve the same process described in the previous robot. A simulation was also used for the online classes [22].

3) Dynamixel Arm: This robot consists of multiple Dynamixel servos that are high-performance actuators. Each servo in the arm is equipped with a built-in controller, allowing for independent control and real-time feedback 4a. The arm's control test used the SimTwo software 4b.

C. *Assessment*

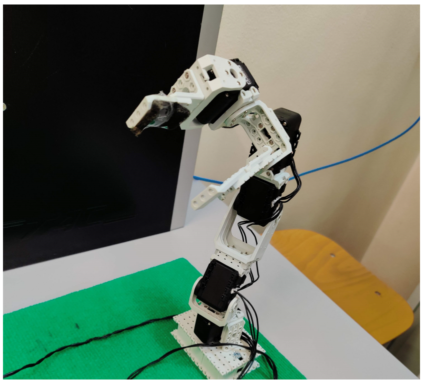
Students must be assessed accordingly with their performance. Several topics are taken into account to prepare the

(a) Real scenario

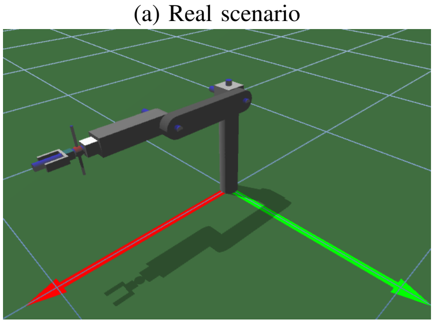


(b) Simulation environment

Fig. 3: Dobot challenge



(a) Real scenario



(b) Simulation environment

Fig. 4: Dynamixel servomotor arm challenge

final mark of the student, such as:

- Technical Report (50% of the final grade)
- Presentation (mandatory, Pass/Fail)
- Challenge (40% of the final grade, see Table III)
- Bonus/overall impression (10% of the final grade)

Since each team can choose one assignment to work on, namely the RobotAtFactory (mobile robot) and the manipulator's arm, the assessment of each team depends on their choice. The main objectives of each assignment are:

- RobotAtFactory (Mobile Robot): Transport parts on a shop floor (real robot). The team should assemble and program a differential-drive robot, using the ESP32 board, to transport (pick and place) boxes from an incoming warehouse to an outgoing warehouse. There may be multiple paths available for the robot to choose from. It can happen that a path is blocked by an obstacle.
- Manipulator: Use an Embedded System to control an arm composed of servomotors. The team should connect the ESP32 microcontroller to control a robot manipulator with each joint driven by a servo motor. The objective is to pick and place an object (cylinder) in the workspace. In the final test, an obstacle with a known size will be placed in a specified position, and the robot should be programmed to avoid it.

TABLE III: Assessment criteria

	Project		
	Robot@FactoryLite HW	Dynamixel robot arm controller	Points
Tasks	Follows the line correctly.	Controls one joint	5
	Picks one box and successfully places it in the correct destination.	Controls two joints to move the end-effector to a specified position.	5
	Picks another box and successfully places it in the correct destination.	Succesfully picks an object	10
	Picks another box and successfully places it in the correct destination.	Places the object on a specified position given by its X, Y coordinates.	10
	Picks another box and successfully places it in the correct destination.	Obstacle avoidance	10

Technical Report: To foster additional competencies in scientific writing and to reduce the risk of downgrading due to a hardware failure during the challenge, 50 percent of the grade were based on a technical report submitted after the physical component.

After submission, a detailed review of the report was issued, based on the following questions:

- Are the title and abstract appropriate, and do they motivate you to read the paper?
- Research: Are proper references to related work contained?
- Technical correctness: Are the descriptions complete and free of errors?
- Reproducibility: Is it possible to reproduce the results from the information given?
- Contribution: Does the paper contain authentic examples and evaluations?
- Readability: Is the paper well-written and easy to understand?
- Length: Is the length justified by the technical contribution?
- Overall Impression
- Typos and Further Issues.

IV. Results

The BIP course on Embedded Systems Applications was attended by thirty-three students, affiliated with institutions from Portugal, Germany, the Netherlands, and Romania, as presented in Table IV. Besides the countries above, the population of students also included nationals from other countries, like Brazil, China, Vietnam, Ukraine, Spain, Egypt, and Syria. Finally, four instructors from Portugal, Brazil, Germany, and the Netherlands enhanced the international aspect of this BIP course.

The results from this BIP program were obtained during the face-to-face sessions. The week kicked off with an orientation session, where students were introduced to each other to form

TABLE IV: Institutions of origin of students.

Students affiliation	Country, city	Number
IPB	Portugal, Bragança	10
Bremen UAS	Germany, Bremen	13
Hanze UAS	the Netherlands, Groningen	8
UOradea	Romania, Oradea	2

teams with the aim to foster collaboration. Then, the students engaged in coding exercises and spent the week working on their strategies and ensuring their robots were calibrated and optimized for optimal performance. Finally, the last day was dedicated to evaluating the robots in the tasks. At the end of the robotic challenge, the students were invited to answer a questionnaire about their experience. A questionnaire was addressed to the participating students with the following questions:

- ***Personal Questions***
  1) *What is your gender?*
  2) *How old are you?*
  3) *In which institution are you enrolled?*
  4) *What is the level of your program?*
  5) *In what year are you currently enrolled?*
  6) *What is the level of your prior knowledge and experience in the topics below before you took this course? (none to excellent)*
     Programming
     Microcontrollers
     Electronics
     Robotics
- ***About the BIP course***
  1) *Course content (Strongly disagree to Strongly agree)*
     Learning objectives were clear
     Course content was organized and well planned
     Course workload was appropriate
     Course organized to allow all students to participate fully
  2) *About the period of online sessions (Poor to Excellent)*
     Level of effort you put into the course
     Your attendance
     Your interaction/participation
     Contribution to your skill/knowledge
     Material (documents, slides...)
     Your overall opinion
  3) *About the physical component in Bragança (Poor to Excellent)*
     Your attendance
     Level of effort you put in
     Contribution of your group mates
     Contribution to your skill/knowledge
     General organization
     Schedule
     Material and infrastructure
     Your overall opinion
- *About the Instructors*
  1) *Skill and responsiveness of the instructors (Strongly disagree to Strongly agree)*
     Instructors were effective
     Lessons were clear and organized
     Instructors stimulated student interest
     Instructors effectively used time during on-line lessons
     Instructors were available and helpful during the practical sessions
  2) *General aspects*
  3) *What aspects of this course were most useful or valuable?*
  4) *How would you improve this course?*
  5) *Feel free to write other comments and suggestions.*
  6) *Why did you choose this course?*
     It was mandatory
     I like the topic
     Opportunity to work within an international group and travel abroad
     To get credits

As feedback from the students regarding the personal questions and BIP course:

- About 40% of the students declared themselves as female.
- Most (more than half) are between 21 and 23 years old.
- Most students appreciated that the course was organized to allow them to participate fully.
- Appreciation for the online part was mixed, with about a third of the students assessing it as satisfactory and the rest being divided between having a good and a bad impression of it.
- On the other hand, 86% of the students were satisfied with the physical component, with 28% assessing it as ”very good” and 36% as ”excellent”.
- 64% of the students agree that instructors were available and helpful during the practical sessions.

Based on their answers to ”What aspects of this course were most useful or valuable?”, it is possible to conclude that students valued the multicultural aspects of the program and the fact that they could work on a hands-on practical project for an entire week, with no other obligations. Creativity and collaboration between teams were also mentioned. Some of their answers are listed below (not edited):

- *”Working with actual hardware and having 1 intensive workweek in a room with a bunch of other interested and committed people.”*
- *”Visiting a different university and coming into contact with new students, culture and challenges.”*
- *”Actually working on a small robot in a closed environment and with no other obligations.”*
- *”Hands on experience.”*
- *”Working with people not from our Uni.”*
- *”Building and testing a robot, working in a international team.”*
- *”The practical aspect was very useful, because it allowed us to see real life problems with robotics and taught us ways to solve them.”*
- *”we had full freedom to do our work, and that means we should be creative.”*
- *”I really learned a lot about building a robot and working in a international team.”*
- *”Work together with students from another university who spoke another language.”*

- *"Honestly all of them but for me - working physically with the robot is the best thing, because it helps you to understand that not always the ideal code is the greatest option and see how the electronics interacts with the world."*
- *"The help we received from our colleagues since none of us knew how to do anything and we helped each other."*
- *"interaction with other colleagues, share ideals in order to learn more."*
- *"The help of other students has been very valuable, I have learned a lot with them. No matter how difficult the project is, we have felt very supported by them."*
- *"To participate with the different students and teacher from different background and cultures Knowledge in arduino and microcontrolers."*

V. Conclusions

This research reflects on the learning outcomes of a different pedagogical project based on a blended Intensive Programme to solve a robotic challenge. It discussed the impact of the hands-on experience on students' understanding of embedded systems and their coding skills. The blended nature of the program, combining online sessions with a physical week, allowed for a comprehensive learning experience. The online sessions provided the theoretical foundation, while the physical week provided the opportunity for practical application and hands-on learning, and the physical week of the blended Intensive Programme brought together students from different universities, fostering collaboration and allowing them to apply their knowledge in a practical setting. The RobotAtFactory Competition was the ultimate test of their coding skills, problem-solving abilities, and teamwork. It strengthened their technical competencies and cultivated invaluable personal and professional connections, leaving a lasting impact on their educational journey.

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