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RESEARCH ARTICLE

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Applying active learning by contextualizing robotic applications to historical heritage

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Abstract

Optional university courses are designed to allow undergraduate students to specialize in relevant fields to enhance their skills and knowledge for their future careers. However, there are some cases in which students prioritize enrolling in courses that are easy to pass. This choice results in having students with low motivation and commitment, who mainly focus on doing just enough to pass the course, missing the opportunity to boost their skills. In this study, an eclectic approach is proposed, applying a mixture of active learning methods together with the theory of multiple intelligences to improve students' performance, motivation, and commitment throughout the course. The study was applied to the 56 students enrolled in the optional Micro-Robotics Application spring course in the year 2021 at the University of Cádiz (Spain). Results demonstrate that this combination of active learning methodologies increased students' motivation, prompting them to give their best in terms of commitment, performance, and creativity. Furthermore, they were convinced that during the course they not only learned relevant robotic knowledge but also acquired essential skills needed for their future. Finally, this study highlights the benefits and future directions for implementing active learning methodologies in science, technology, engineering, and mathematics courses.

KEYWORDS

active learning, historical heritage, multiple intelligences, robotics, undergraduate engineering

1 | INTRODUCTION

In the Spanish university system, undergraduate students are required to take various kinds of courses:

(i) *Core*, common courses within the curriculum for all universities that offer a specific degree. The Ministry of Education and Science determines these courses and they represent the common content for a

Abbreviations: MRA, micro-robotics applications; PBL, project-based learning; STEM, science, technology, engineering, and mathematics.

degree, regardless of the faculty where they are studied.

(ii) *Compulsory*, are courses that the university itself establishes as mandatory within its curriculum for all students pursuing a specific degree.

(iii) *Optional*, courses that the university offers as optional to its students within a specific degree. These are usually concentrated in the later years of each degree and are intended to allow for a certain specialization within the field of study.

Although the main objective of optional courses is to provide students with a certain degree of specialization that will make them stand out from the crowd in the job market, there are many cases in which students focus more on choosing easy-to-pass courses rather than considering the knowledge they can acquire. This results in the students' primary motivation being to study to pass courses [4, 43, 92], which is a serious issue because concentrating on the short-term most of students study for the exam rather than to learn, carrying out rote learning [103]. Indeed, with this kind of learning, students tend to forget most of the concepts shortly after the exam [2, 28]. Another aspect to consider is the feeling which many students have that the study content is far removed from society's current challenges [102]. They consider that most content is too theoretical and less applicable. Thus, all the exercises that they do in a given course are only useful for passing that course. This results in a loss of motivation, entailing low student performance [94]. As a result of the aforementioned issues, it is common that teachers perceive a general lack of commitment and creativity among their students.

In the literature, various studies have aimed to improve students' motivation through the application of different techniques [34, 71, 105], including active learning methodologies [50, 92, 99]. Active learning involves proactive student engagement, leading to meaningful learning experiences that enhance knowledge, skills, values, and attitudes [77].

Apart from improving students' motivation, active learning methodologies are also suitable for skill training [18, 30, 108], enhancing their performance [8, 26, 33], and improving retention [20]. Furthermore, many studies emphasize the importance of engaging students in science, technology, engineering, and mathematics (STEM) courses through active learning, which increases conceptual knowledge and positive attitudes toward learning, while also reducing attrition rates [20, 33].

Despite the numerous benefits of active methodologies, the vast majority of these methods are currently applied in primary and secondary schools [31]. There are some cases where active methodologies are implemented in university studies [16, 32, 61, 81, 86, 112]. However, it should be noted that applying a single active learning method (e.g., only project-based learning), may not be sufficient to achieve high levels of student motivation and commitment.

Managing diversity among students enrolled in a course is another crucial aspect to be considered [9]. Following the theory of multiple intelligences [38], each individual possesses different abilities and motivations. Hence, it is advisable to implement learning strategies that cater to the development of each intelligence, fostering students' motivation and engagement in the course.

In addition to the aforementioned challenges, the suspension of in-person lessons and social distancing due to COVID-19 have resulted in various deficiencies in interpersonal face-to-face relationships between students [42, 49]. Addressing these challenges becomes even more critical in courses with students close to graduation, as these skills are essential in the job market.

Our hypothesis is that *applying active methodologies to university students' learning by contextualizing robotics applications in real scenarios enhances students' performance, motivation, and commitment*.

In particular, the study is focused on the cross-cutting theme: *Cádiz's historical heritage*.

From this hypothesis, the following objectives were established: (i) improving students' motivation, (ii) fostering meaningful learning, (iii) promoting multidisciplinary collaboration, (iv) encouraging students' commitment and creative problem-solving, and (v) motivating the learning of general knowledge about Cádiz's historical heritage.

The main novelty of this approach lies in the application of several active methodologies in combination with the theory of multiple intelligences [38] to teaching university students.

The paper is organized as follows. Section 2 describes the pedagogical framework followed in the educational project. Section 3 outlines the course in which the educational project was applied. In Section 4, the methods used are described, focusing on the description of the educational project, the participants, how data were collected and the application of the pedagogical methodology. Section 5 contains the obtained results in terms of academic performance, student feedback, and surveys about Cádiz's monuments. The Discussion is introduced in Section 6, highlighting the lessons learned and the pitfalls found. The paper finishes with the Conclusion section.

2 | PEDAGOGICAL FRAMEWORK

In this study, an eclectic approach was followed. This approach benefits from the following pedagogical methodologies (see Figure 1):

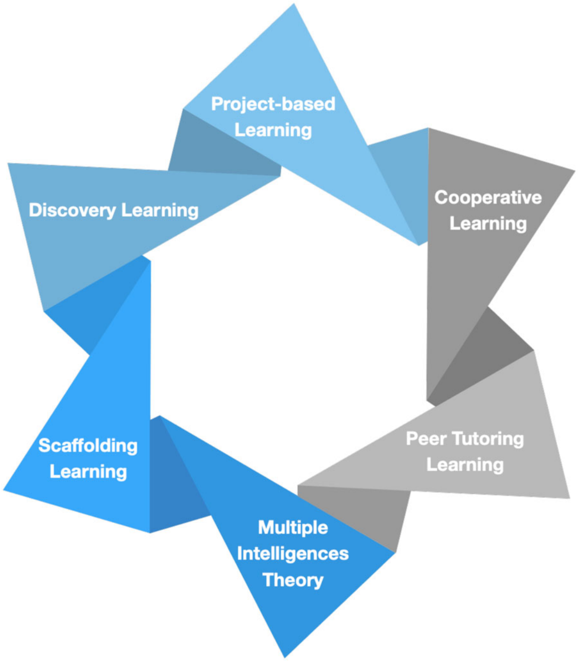

FIGURE 1 Combination of the pedagogical frameworks utilized.

- *Project-based learning (PBL)* is an approach that has been used for decades [59, 60]. Within this approach, curriculum concepts and objectives are adapted through a project to drive students to think and learn independently [18]. Experiences in PBL show that students not only acquire the instrumental and systemic competences suggested in the curriculum, but also relevant skills such as collaborative work [36, 37]. Working on a project gives students the opportunity to learn by doing [84] and experience the utility of the concepts learned, resulting in increased motivation and creativity [50, 62, 108]. Examples can be found in engineering education [68, 82].
- *Cooperative learning* is based on the idea that teamwork is more effective than competition and fosters an environment where students can enhance their interpersonal skills [47, 77]. Thus, by working in small groups or teams [67] students can help each other to understand the theoretical concepts [54, 88, 90]. The five components of cooperative learning are: positive cooperation, interaction tendency, individual responsibility, developing interpersonal and social skills, and quality of group performance [53]. Cooperative learning enhances students' academic outcomes, relational skills, and mindsets when working collaboratively with other members of the group [21, 51, 52, 97]. Additionally, this learning method increases students' motivation [51, 89, 99]. Its application in universities not only endorses these improvements [24, 65, 109] but also fosters a context of respect and collaboration in terms of gender experience [13].
- *Discovery learning* is a process based on constructivism [3, 48] which focuses on figuring out concepts through a series of data or information obtained through observation or experimentation [35, 44]. As the learning material is not given to students in its final form, they have to organize themselves to find answers and complete their learning process [14]. There are two ways of performing discovery learning: (i) *pure discovery*, learning without instructions or direction; and (ii) *guided discovery*, whereby the teacher acts as a facilitator in the learning process. This manner of learning has a positive impact on students for developing their critical thinking and problem-solving skills [30, 74, 87]. There are plenty of examples in which discovery learning can be applied in universities, such as in calculus [110] or nursing [63] courses. Furthermore, discovery learning can be applied in simulation environments [78], or in serious games [22, 27, 93].
- *Peer Tutoring Learning* is a very old practice, which started in ancient Greece. It is a process in which nonteachers from similar social groups help each other to learn, and learn themselves through teaching [41]. Depending on the situation, roles can be exchanged or not [98]. For example, when students with different expertise have to collaborate, they can exchange the roles of tutor and tutee. Peer tutoring positively affects students' academic performance [8, 70, 72] while developing social skills [6, 23]. This methodology has great relevance in university studies [56, 111], with a special impact during the COVID-19 pandemic [7, 57].
- *Scaffolding Learning* was defined by Vygotsky [19] and used as a teaching strategy [100]. The notion of *scaffolding* reflects the way in which adult support is adjusted as the child learns, and is ultimately removed when the learner can *stand alone* [106]. This suitable learning method allows students to assimilate knowledge progressively, developing skills such as reasoning or critical thinking [5]. Scaffolding learning is not only recommended to be applied in schools [39, 64], but also in higher education [5, 15, 79].
- The *Multiple Intelligences Theory* was introduced by Howard Gardner, who claims that every human possesses eight intelligences that are closely linked [38, 83]. Thus, each person learns differently due to their different degree of development of each intelligence. Therefore, teaching individual's intelligence strengths will provide a more productive learning environment and produce a more receptive student. The eight intelligences are described as follows [91]:

- *Linguistic* involves the ability to learn languages, sensitivity to spoken and written language, and the capacity to use language effectively to express oneself either rhetorically or poetically [29, 76, 107].
- *Logical-mathematical* consists of the capacity to carry out scientific research, mathematical operations, as well as to analyze problems logically [10, 12].
- *Musical* involves skills in the appreciation of musical patterns, composition, and performance, encompassing the capacity to recognize and compose musical rhythms, pitches, and tones [45, 104].
- *Spatial* involves the potential to recognize and use the patterns of areas and space [11, 101].
- *Bodily kinesthetic* entails the ability to use mental skills to coordinate bodily movements and the potential to use one's whole body or parts of the body to solve problems [58, 85].
- *Naturalistic* involves the ability to classify, identify, and manipulate elements of the environment, plants, animals, or objects [66, 101].
- *Interpersonal* is concerned with the capacity to understand the desires, motivations, or intentions of other people, allowing people to work effectively with others [25, 69].
- *Intrapersonal* entails the capacity to understand oneself, to appreciate one's motivations, fears, and feelings [40, 75].

Experiences show that the application of multiple intelligence theory is beneficial to students [17], helping them improve their performance, increase their motivation, and enhance their commitment throughout the course [55]. For example, in a Math course for primary school [95], the teacher might teach fractions considering the multiple intelligences theory as follows. *Linguistic intelligence* is developed by readings and explanations on fractions, as well as discussing questions for students to analyze and debate [29]. *Logical-mathematical intelligence* is stimulated, challenging students to solve complex fraction problems and to use critical thinking and problem-solving skills to come up with creative solutions [12]. Rhythm and music are used to help students remember key fraction concepts and principles, while boosting their *musical intelligence* [46]. *Spatial intelligence* is strengthened using visual aids like diagrams and illustrations to help students to understand the concepts of fractions and how they relate to one another [73]. Hands-on activities and games where students can practice fractions by manipulating objects and materials are carried out to enhance their *bodily-kinesthetic intelligence* [1]. Items from nature, such as plants, stones, or seeds, are used to stimulate naturalistic intelligence. Finally, *interpersonal intelligence* is developed by group activities and cooperative learning exercises where students can work collaboratively and develop their communication and teamwork skills while solving fraction problems together [73], whereas *intrapersonal intelligence* is strengthened by encouraging self-reflection and goal-setting, helping students to identify their strengths and areas for improvement in fractions [1].

This paper proposes the combination of these pedagogical frameworks in a way that promotes student motivation and engagement while facilitating meaningful learning.

PBL allows students to work in groups on a specific project. This approach combines cooperative learning and peer tutoring. Additionally, the use of generative questions will facilitate discovery-based learning as students engage with their projects. The organization of the teaching will be designed to introduce concepts incrementally, allowing students to validate acquired concepts through discovery learning. This will result in the application of scaffolding in the learning process.

Finally, the theory of multiple intelligences will be taken into account in all activities throughout the course. Its application will enable students to develop each of the intelligences described by Howard Gardner. Section 4.4 describes the tasks carried out to implement each of these pedagogical frameworks.

3 | COURSE OVERVIEW

Micro-robotics applications (MRA) is an optional course with six ECTS credits, offered during the spring semester to undergraduate students from the different degrees at the School of Engineering[1] of the University of Cádiz,[2] typically taken in Year 4. On average, MRA is annually taken by 25–30 students.

The course objective is to provide students with the key foundations and skills for developing and managing robotic projects in the future. Being an introductory-level course, no prior knowledge or experience in robotics is assumed. However, it is recommended to have some prior knowledge of electronics and programming.[3] Due to the fact that this course is eminently practical, students spend 42 h in lab sessions and 18 h in theoretical sessions. Lab sessions are carried out in the "*Applied*

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[1] https://esingenieria.uca.es

[2] https://www.uca.es

[3] Courses in Electronics and Programming are scheduled to be taken in Year 1 of every degree at the School of Engineering, so at this stage, it is assumed that all the students have enough expertise to successfully complete the MRA course.

Robotic Laboratory" (see Figure 2), which has a capacity of 20 students.

Table 1 contains the two main course themes. More emphasis is placed on the second theme because it contains more complex concepts, and it is beneficial to reinforce them for their application in lab sessions.

The evaluation is based on three summative assessments: two midterm exams and a final project. The first midterm exam covers the introduction to Robotics and Arduino, whereas the second midterm exam focuses on solving problems by applying direct and inverse kinematics or computation related to trajectories. The final project covers all course themes and requires solving a given problem using a robotic arm controlled by an Arduino board.

The pedagogical design of the course is focused on providing students with practical, hands-on experience working with Arduino and a robotic arm to solve a given problem.

FIGURE 2 Applied Robotic Laboratory—School of Engineering (University of Cádiz).

4 | METHODS

4.1 | Educational project description

All materials and sessions were adapted to the cross-cutting theme "*Cádiz's Historical Heritage*." Thus, all exercises designed to assess the robotic concepts included in the syllabus of the MRA course that were contextualized to that theme.

At the beginning of the course, students had to complete an initial survey about general knowledge of Cádiz's monuments.

In the first lab sessions, students learnt the basics of Arduino. Each student was given an Arduino initial kit that included an *Arduino One* microcontroller and several electronic components (LEDs, resistors, buttons, wires, etc.) to complete the sessions.

While some exercises required collaboration between students, most of these sessions were conducted individually.

For the remaining sessions, students worked in groups of four members, with each group focusing on one

TABLE 1 Topics covered in the micro-robotics applications course (theory sessions).

Course theme	Topics covered	Duration
Introduction to Robotics and Arduino	• Introduction to robotics · History · Evolution • Microcontrollers (Arduino) • Sensors • Actuators	6 teaching units
Introduction to robot manipulators and trajectory calculation	• Introduction to robot manipulators · Mathematical transformations · Direct kinematics · Inverse kinematics · Denavit-Hartenberg · Theoretical application to a microcontroller • Trajectory calculation with a robotic arm	6 teaching units

TABLE 2 Cádiz's monuments selected for the educational project.

Monument
Santa Catalina's castle
House of the 4 towers
Cádiz city council
Cádiz cathedral
Royal Prison
San Lorenzo del Puntal castle
House of the 5 towers
Church of La Merced
Cádiz Conference Center
Church of Santo Tomás
Castle of La Villa
Oviedo House
Church of San José
Roman Theater of Cádiz

randomly assigned monument from Cádiz. Table 2 contains the 14 monuments chosen for this educational project.

A 3D mockup of each monument was printed at a small scale[4] from https://3dwarehouse.sketchup.com/, allowing students to carry out various tasks using the *Braccio*[5] robotic arm (anthropomorphic robot with four degrees of freedom plus an end-effector) controlled by an *Arduino One* board. The 3D printing was performed using a 3D Makerbot Z18 3D printer, and more than 2 kg of polylactic acid (PLA) 850 filaments were used. Figure 3 depicts the 14 printed mockups.

For the final project, students were asked to place a 3D cube (3 × 3 cm) in different locations of the mockup[6] on the shape of each monument, being proportional to a maximum width of 15 cm. The size was limited by the printer and the robotic arm. Additionally, the final project included a second exercise where each group had to solve a jigsaw puzzle using the *Braccio* robotic arm controlled with an Arduino One. The jigsaw puzzle consisted of nine 3D-cubes, with each cube having a part of a picture of a monument on one face and a stick with a specific color on the adjacent face. Thus, each cube contained a part of the whole picture and a unique color that was used to clearly identify the cube. The *TCS3200 Color* sensor was used to recognize colors with Arduino. There were six *Braccio* robotic arms and six *TCS3200 Color* sensors available for the groups to use during their lab sessions. Figure 4 depicts examples of the two exercises carried out in the final project.

Before starting the final project, students were encouraged to research their assigned monument to gain some knowledge about it including its history, surroundings, architectonic elements, and so on. This task helped them become familiar with the monument and to learn technical terms used in the heritage domain. Although learning general knowledge about the monument was interesting, the key point of this task was that students identified possible problems that might occur while working with the mockup (e.g., where should we locate the robotic arm to reach the largest number of places? What obstacles could we find in reaching this particular place?).

Midway through the semester, each group gave a presentation about their assigned monument, allowing all students to learn about each monument and benefit from the research carried out by other classmates.

During the sessions scheduled for developing the final project, each group worked autonomously to resolve both exercises: monument mockup and jigsaw puzzle. These sessions involved programming, calibrating the robotic arm, saving locations, and taking measurements, among other tasks.

Final projects were evaluated through demonstrations, with each group required to correctly resolve the proposed exercises. A rubric, previously shared with the students, was followed to assess each exercise (see Appendix B).

At the end of the course, the students completed two more surveys: one about the monuments, similar to the initial one, and a general questionnaire to provide feedback about the approach followed at the MRA course.

4.2 | Participants

The teaching and learning experience discussed in this paper was conducted at the School of Engineering at the University of Cádiz. The participants were all the students enrolled in the MRA course in the 2020/2021 academic year, totaling 56 students, with 85.17% male and 14.28% female participants. Due to the capacity of the lab (20 people), students were divided, for lab sessions, into three groups of 20, 20, and 16, respectively.[7] The students came

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[4] The files with the monuments in 3D were obtained.

[5] https://store.arduino.cc/products/tinkerkit-braccio-robot

[6] The size of each mockup depended.

[7] The restrictions caused by the COVID-19 pandemic resulted in a reduction of the laboratory's maximum capacity from 20 to 12 students. This measure was taken to ensure that students could maintain the social distancing recommended by health authorities. As a consequence, there was a need for logistical restructuring, involving an increase in the number of groups and more efficient use of the laboratory space.

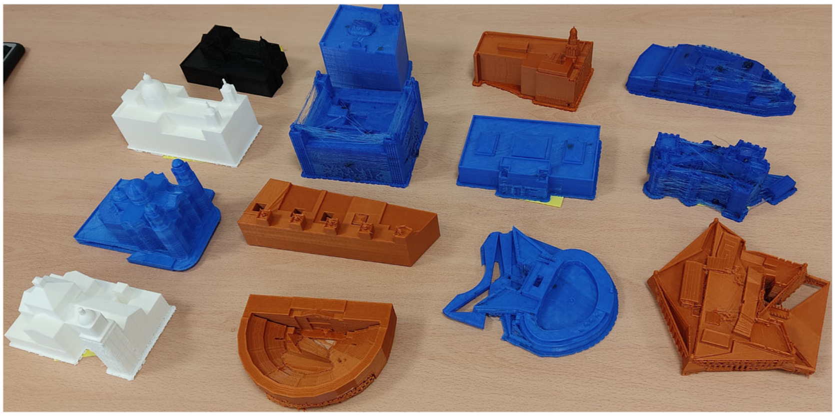
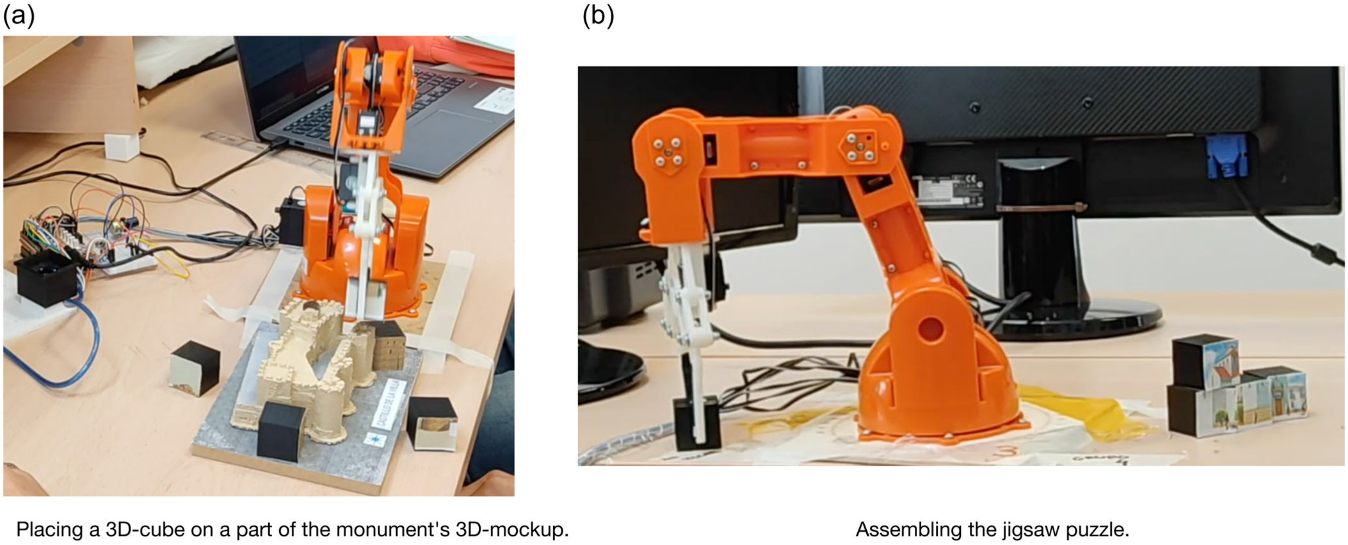


FIGURE 3 Mockups of Cádiz's monuments printed in 3D.



(a) Placing a 3D-cube on a part of the monument's 3D-mockup.

(b) Assembling the jigsaw puzzle.

FIGURE 4 Examples of final project exercises.

from different disciplines (see Table 3).[8] The average age of participants was 22.3 years old.

Four lecturers were in charge of developing the experience (one for theoretical sessions and three for lab sessions). Each session was conducted by the same lecturer for all groups to minimize the effect of "*unobserved teacher characteristic in the student's academic performance*" [80].

4.3 | Data collection

The data of this course were collected from the surveys published on the virtual campus of the University of Cádiz.

First, students completed an initial survey about Cádiz's monuments. The objective was double. On the one hand, this provided us with information about the students' initial knowledge of Cádiz's heritage. On the other hand, the survey also introduced domain-specific terms about monuments to prompt students to familiarize themselves with them, fostering discovery learning.

Second, students completed another survey about Cádiz's monuments, similar to the initial one, to check their progress in Cádiz's heritage knowledge. The repetition of some questions and domain-specific terms helped students identify and consolidate important concepts.

Third, students completed a final survey to provide feedback about different elements of the course, such as their favorite sessions, the skills they developed, and whether they recommend repeating this kind of learning in future years.

The assessment of the final projects followed two rubrics that were shared with the students during the final sessions (see Appendix B1 and B2).

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[8] Students worked in multidisciplinary groups of four members for their projects, as is detailed in Section 4.1.

TABLE 3 Number of participants by discipline.

Degree	Number	Percentage
Degree in Industrial Electronic Engineering	30	54
Degree in Industrial Technologies Engineering	7	13
Degree in Mechanical Engineering	7	13
Degree in Electrical Engineering	4	7
Degree in Aerospace Engineering	3	5
Degree in Industrial Design and Product Development Engineering	2	4
Double Degree in Mechanical and Electric Engineering	1	2
Double Degree Mechanical - Industrial Design and Product Design Engineering	1	2
Double Degree Electrical Engineering - Industrial Electronics Engineering	1	2

4.4 | Application of the pedagogical methodology

The methodologies described in the pedagogical framework section were applied to some extent in theoretical sessions and completely in practical sessions (see Appendix "*Lab sessions*"). The strategies followed are described below:

- *Project-based learning*. The course was contextualized to the historical heritage of Cádiz, focusing on its customs and most relevant monuments. This cross-cutting theme provided students with general knowledge about the city and also offered continuous reinforcement of their learning every time they passed through the places they were working on during the course. PBL was applied from the beginning of the course, with all students divided into groups and working on a final project, centered around a particular monument. This approach allowed each group find different solutions based on the unique aspects of their assigned monument.
- *Cooperative learning*. As MRA is offered to all students of the School of Engineering, in 2020/2021, the course had students with different backgrounds (see Table 3). All of them were encouraged to work in multidisciplinary groups. In fact, working in such an environment helped them benefit from different expertise, providing a helpful experience in teamwork. In the middle of the semester, all groups gave a presentation about their assigned monument. Thus, all students could learn about all of the monuments and how other classmates planned to face potential issues that might be experienced while working with their mockups for the final project.
- *Discovery learning*. This was promoted by the initial questionnaire that included terminology regarding the selected monuments of Cádiz (see Table 2). As most students were not familiar with this domain of knowledge these terms acted as generative questions, promoting each group to find the meanings of the concepts related to their project. Once each group had been assigned a monument to work on the students carried out a study to find information about it, reinforcing the new knowledge discovered after the initial questionnaire. During the presentations, lecturers asked questions and gave feedback to clarify concepts and to double-check that each group had the necessary knowledge to successfully complete the final project. This was the method chosen to validate the discovery learning process.
- *Peer tutoring*. This was fostered with both multidisciplinary groups and the mid-semester presentations. The former meant that students with different expertise could teach each other. Similarly, with the latter all students could benefit from the explanations about each monument, focusing on their history, features, and the decisions made by each group to solve the robotic problem. Moreover, this methodology also promoted autonomous work.
- *Scaffolding*. All concepts were taught incrementally. Thus, each theoretical and practical session contained the concepts of the previous session, and added new ones. This was a way to reinforce learning while adding new knowledge step by step. The final project required students to apply all of the concepts taught during the course.
- *Theory of multiple intelligences* The application of multiple intelligences aimed to foster the skills of each student.
  - *Linguistic*. Students had to give two presentations over the course (mid-semester and during the final project). Moreover, they used this intelligence to communicate during every session.
  - *Logical-mathematical*. In all sessions, students had to solve problems that required the use of mathematical logic.
  - *Musical*. This intelligence was fostered by the inclusion of the "*buzzer*." Nonetheless, session 3 was designed to focus mostly on the musical intelligence. In that session, students had to identify

TABLE 4 Comparison of academic performance.

	2016/2017	2017/2018	2018/2019	2019/2020	2020/2021
Performance rate	95.74% (45/47)	100% (35/35)	89.2% (25/28)	92.3% (24/26)	**100% (56/56)**
Success rate	93.33% (42/45)	77.14% (27/35)	100% (25/25)	100% (24/24)	**100% (56/56)**
Average mark	6.62/10	6.96/10	7.2/10	7.1/10	**7.9/10**

messages in Morse code, and be synchronized with each other when playing songs with Arduino.

- *Spatial*. Exercises that involved trajectory calculations and solving problems that required the movement of elements (e.g., robotic arm, 3D-cubes, etc.) contributed to developing this intelligence.
- *Bodily kinesthetic*. Students trained this intelligence mainly by improving their nonverbal communication and body language for the presentations and during lab sessions (e.g., assembling and repairing the robotic arm, improving the mockups, coordinating with other students, etc.).
- *Naturalistic*. COVID-19 restrictions clearly limited the ways to interact with the natural environment. However, restrictions were softened over the course and students were able to visit the monuments in person to familiarize themselves with their environments. This helped train, to some extent, naturalistic intelligence.
- *Interpersonal*. The teamwork carried out during the execution of the projects prompted students to develop this intelligence.
- *Intrapersonal*. In all theoretical sessions and during the first lab sessions students worked individually, fostering their autonomy and individual decision-making skills.

5 | RESULTS

The main findings are presented in three parts: (i) students' academic performance compared with respect to previous years, (ii) their feedback about the course, and (iii) the progress of their knowledge about Cádiz's monuments throughout the course.

5.1 | Academic performance

Academic performance is measured using three metrics: (i) *performance rate*, which shows the proportion of students who finish the course, (ii) *success rate*,[9] which indicates the proportion of students who pass the course, and (iii) *average mark*. Table 4 shows the comparison of academic performance attending to these metrics.

According to Table 4,[10] during the course 2020/2021, which is when the pedagogical approach presented here implemented, the success rate was the highest (100%), maintaining the trend of previous years even though the number of students had doubled. The COVID-19 pandemic restrictions possibly affected the number of students enrolled in the course. The travel limitations also prevented students from obtaining Erasmus fellowships. Thus, these students had to enroll in courses at their home universities. Enrollment was around 125% higher than the previous year (from 25 to 56 students). Similarly, the performance rate was 100%, increasing around 10% compared to the rate of the previous year. This is extremely important since it shows that students were engaged and finished the course. Thus, the learning method used was shown to prevent students leaving the course and keep students' interest over the course. The average mark improved considerably, increasing by 0.8 points compared with other years. This is clear evidence of how students did their best during the course.

5.2 | Students' feedback

Figure 5 depicts students' opinions about the 15 lab sessions. The first 8 sessions were conducted weekly, while in sessions 9–15 students worked on the exercises for the final project: puzzle solving and scenarios using the monument mockup. (see Appendix "*Lab sessions*"). The reason for asking "like vs. dislike" for each session was to understand the students' experience and to infer the impact of each session on their motivation. Additionally, this information was relevant for refining the teaching program for future years.

Generally, students liked the Arduino sessions (sessions 1–4), highlighting session 3 where they worked with the buzzer.

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[9] Success rate only considers the students who did not drop the course.

[10] In the 2019/2020 course, teaching was mostly virtual because of the COVID-19 outbreak. Thus, students used Tinkercad (http://tinkercad.com/) to do the exercises scheduled for lab sessions. Despite the teaching process not being the same as in previous years the 2019/2020 course students' performance is worth including, considering the impact of COVID-19 on students' marks [96].

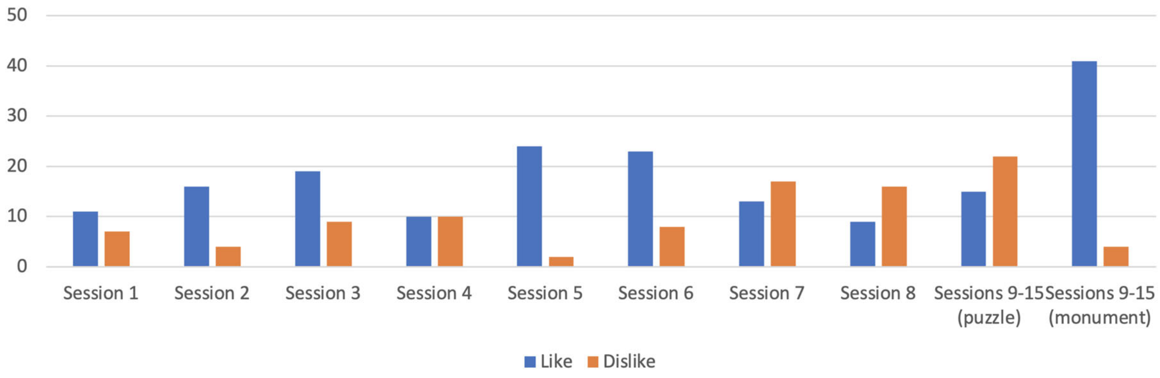

FIGURE 5 Students' opinions about sessions.

TABLE 5 Students' opinions about the course.

	1	2	3	4	5
What kind of teaching do you prefer, traditional (1) or project based (5)?	1.75%	1.75%	3.51%	26.32%	66.67%
To what degree do you consider that the contextualization to Cádiz's monuments has contributed to improving your motivation?	14.04%	12.81%	16.05%	32.81%	24.30%
Which degree of motivation do you consider that you have had over the course?	0%	3.51%	35.09%	43.86%	17.54%
To what degree do you consider that the contextualization to Cádiz's monuments has contributed to consolidating the knowledge of the course for you?	5.26%	26.32%	21.58%	27.81%	19.04%
To what degree do you think that the course has been useful for learning about Cádiz's monuments?	1.75%	17.54%	26.32%	26.32%	28.07%
To what degree do you think that the knowledge and the skills you have learned and developed along the course will be useful for you in the future?	1.75%	5.26%	24.56%	45.61%	22.81%
To what degree do you recommend repeating PBL (e.g., contextualized to monuments) in other courses/years?	3.51%	3.51%	28.07%	26.32%	38.60%

The most popular sessions were the ones in which students had to work with the 3D-mockups of the monuments. This shows the importance of applying the learned theoretical concepts to real scenarios for both capturing students' attention and helping them to consolidate knowledge. After that, the two most liked sessions were the ones in which students had to apply kinematics, direct and inverse, using the robotic arm.

Regarding the less popular sessions, students highlighted those sessions in which they had to use the color sensor (sessions 7–8 and puzzle). The main reason was its nondeterministic and imprecise behavior, forcing students to be continuously taking measures and recalibrating the sensor to identify the colors needed to solve the jigsaw puzzle.[11]

Considering students' opinions about the course in general (see Table 5), more than 92% prefer PBL to traditional teaching. Around 60% think that the contextualization of the course to the cross-cutting theme contributed to improving their motivation. The same percentage of students agree that they had a high degree of motivation over the course.

More than 46% consider that the contextualization to the cross-cutting theme helped to consolidate the knowledge of the course, while around 31% disagree with this statement. In addition, over 55% think that the course helped them to learn about Cádiz's monuments.

Around 70% of students think that the skills developed during the course will be useful in the future. In fact, one of the questions in the final survey asked students to select the skill or skills they believed they had developed during the course. Figure 6 illustrates the students' perception of the skills developed. Thus, for each skill, it can be observed the number of students who believe they have developed it. It is remarkable how students consider that they have worked at some point on all of the skills surveyed. In particular, they highlight

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[11] The sensor used is a low-cost sensor, easy to integrate with an Arduino board.

teamwork, problem resolution, reasoning, and adaptation to change as the more developed skills.

Finally, around 65% of students recommend repeating PBL in future years, while only 7% do not recommend it.

5.3 | Surveys about Cádiz's monuments

Figure 7 depicts the results of the student surveys about Cádiz's monuments conducted at the beginning and at the end of the course. In the former, around 60% of students obtained less than 5 out of 10, with an average mark of 4.35 out of 10. On the contrary, the average mark considerably increased in the latter, being 6.38 out of 10. In addition, more than 75% of students obtained more than 5 out of 10.

6 | DISCUSSION

6.1 | Lessons learnt

Considering the results described in the previous section, several conclusions regarding different perspectives can be extracted.

The performance of students substantially improved compared to previous years. All students passed the course, and the average grade increased by around one point compared with other years (see Table 4). It is remarkable that even though the number of students increased by around 125% compared to previous years, the attrition rate of the course was zero.

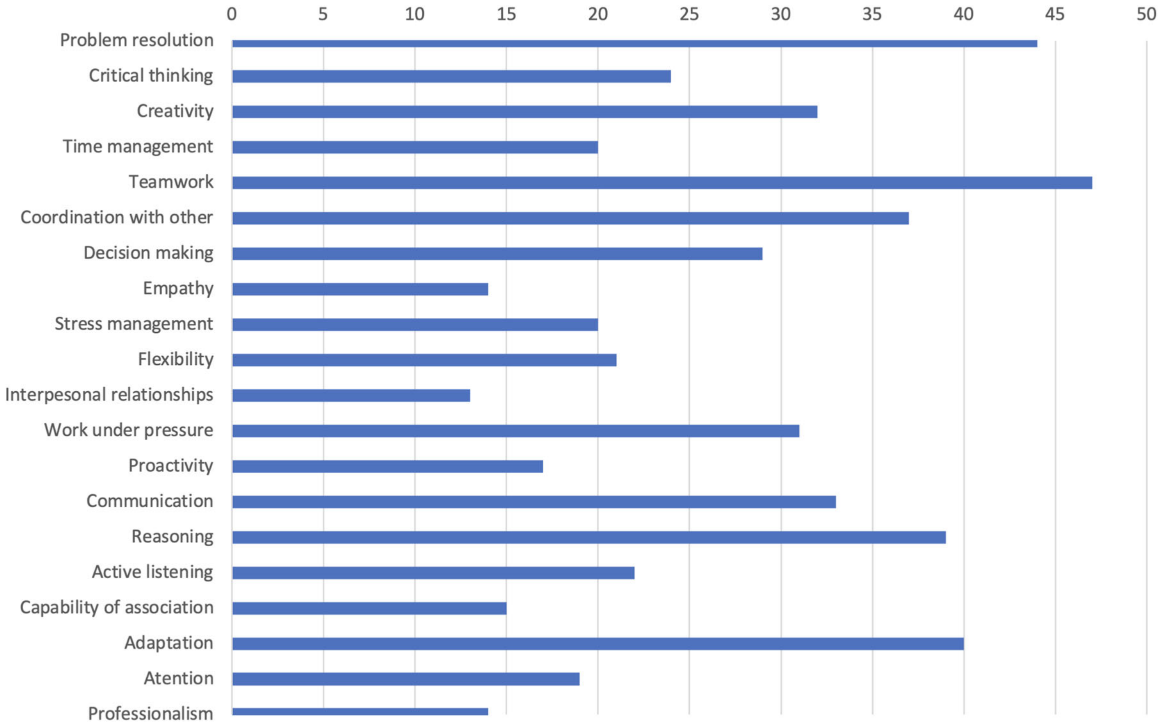

FIGURE 6 Students' perception of the skills developed throughout the course.

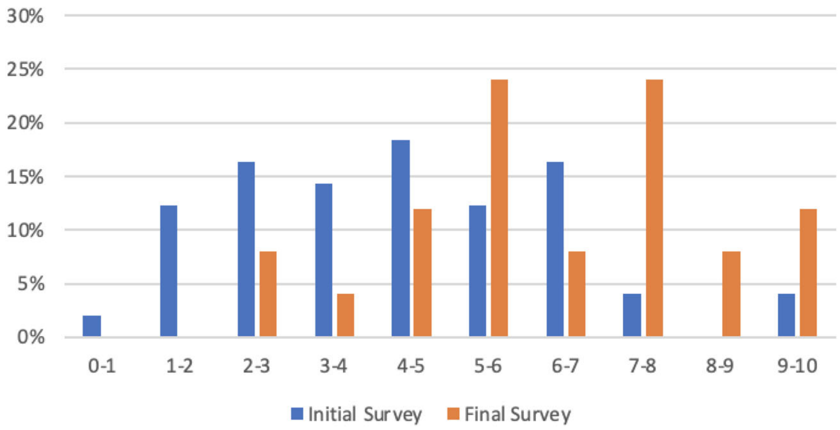

FIGURE 7 Results of the initial and final surveys about Cádiz's monuments.

Regarding motivation and commitment, the students improved considerably with respect to other years. The final survey (see Table 5) pointed out the feeling that students had about the greater motivation that they experienced during the course. Nonetheless, there were multiple examples that illustrate such high standards of motivation and commitment. A remarkable example was the participation of several students in guided visits to learn about the monument that they were working with. Another example was the number of extra hours that students spent in the lab to do their best in the final project. The total number of extra hours were 108, which averages almost 8 extra hours per group. In principle, the plan was for students to use the mockups of the monuments as they were 3D printed. However, they decided to improve the mockups, making them as similar to the real monuments as possible. Apart from enhancing appearance, the improvement also consisted of adding products that provided a better adhesion to the mockup, which was key for the performance of the final project (see Figure 8).

Finally, the demonstrations of the final project confirmed that students had pushed themselves to do their best. For example, all groups used direct and inverse kinematics to place 3D pieces in the most complex locations of their mockups. In addition, two groups developed graphical interfaces (an item not included within the scope of the course) to control the robotic arm and run the demonstrations.

Apart from learning the robotic concepts specified in the syllabus of this course, students also acquired knowledge about the monuments of Cádiz. Learning general knowledge about Cádiz's historical heritage is not a goal established in the scope of this course. However, this is an additional advantage of this educational project. Figure 7 depicts to what extent students improved their knowledge about the cross-cutting theme throughout the semester. Far from intending that they become experts in Art history, the requirement for students to carry out research on Cádiz's monuments and learn heritage domain terms aimed at simulating scenarios they will face in their workplaces where they have to interact with people with different expertise. Thus, the Cádiz monuments survey (see Figure 7), apart from showing that students notably improved their knowledge about Cádiz's heritage, is also a reliable indicator of the adaptability that students have to new contexts or environments, as well as the impact that this kind of project has on learning about fields of which students have scarce previous knowledge. Furthermore, by contextualizing robotics applications to Cádiz's monuments it was possible to "*anchor*" robotics concepts to the monuments. For example, the students who, applying direct kinematics, struggled to place a 3D-piece next to the Cathedral's west tower are likely to recall the decisions made and the concepts applied every time that they pass by the Cathedral. Thus, they experienced meaningful learning in both robotics and general knowledge regarding Cádiz's historical heritage.

One of the most remarkable aspects was the perception that students had about the skills developed throughout the course (see Figure 6). According to students, problem resolution, adaptation to change, reasoning, creativity, teamwork communication, and coordination with others were the most developed skills. Moreover, the vast majority of students thought that the

FIGURE 8 Mockups of Cádiz's monuments: Cádiz Cathedral, Church of San José, Cádiz Council, Church of Santo Tomás, Roman Theater of Cádiz.

skills developed over the course will be useful in their future. This denotes the students' feeling of worthiness of the work carried out in the course.

The application of this project to other STEM courses is not direct, because there might be cases (e.g., in the topography field) in which printing 3D monuments may not make sense. However, the eclectic use of active learning methodologies, adapting materials to a cross-cutting theme and designing activities attending to the multiple intelligences theory [38] are definitely applicable.

6.2 | Pitfalls

There are some pitfalls to this study, some of which have already been suggested.

The COVID-19 pandemic affected the development of the project, partially. Although in the 2020/2021 course, the pandemic was more controlled than in the 2019/2020 course, in-person teaching implied a number of restrictions that resulted in reducing the capacity of the lab to maintain security distance among students. This caused some logistical issues that were resolved either by increasing the groups or using an efficient distribution of the lab.

Time was the main problem. Fourteen monument mockups were 3D printed, needing around 70 h for printing. In addition, some technical issues with the 3D-printers slowed down the printing process. This forced us to reschedule sessions, giving time for students to improve their mockups while working on other parts of the final project. Thus, those students who had the mockups could work on them while the others focused on configuring the color sensor or robotic arm and coding the program for the jigsaw puzzle.

Another critical issue was the technical problems with the robotic arms and the color sensor. Students experienced failures and breakages of some pieces. This resulted in having to repair the robotic arm and to take measures several times. Similarly, the behavior of the color sensors provided to the students was not stable, so a minimum change in brightness in the lab resulted in a situation where students had to calibrate the sensor to identify the colors of the 3D cubes.

Although students got frustrated at times with having to discard previous work and to start from scratch, this also forced them to experience real scenarios where problems can happen, and to develop essential skills like problem-solving and adaptation.

Regarding the assessment of knowledge about the monuments of Cádiz, students were given an initial questionnaire at the beginning of the course (February) and a similar questionnaire after the presentations of each monument (April). Although there was a 2-month interval between each questionnaire, it is possible that some students answered certain questions correctly by memory recall rather than through meaningful learning. In the future, it could be advantageous to use a questionnaire with different questions. Additionally, it would also have been interesting to explicitly ask the students about the cognitive load they experienced while working in a domain for which no prior knowledge was assumed. This inquiry would provide a deeper understanding of the impact of these types of projects on students.

Moreover, it would be interesting to modify the questions about "like vs. dislike" for each session so that students could provide more precise feedback on why they liked or disliked a particular session.

Another pitfall could be the implementation of this project in large-sized courses. In our case, the logistics of 3D printing 14 monuments and managing around 60 students was challenging at times (e.g., when the 3D printer or robotic arms broke down). Therefore, for larger groups, it would be necessary to start the printing process of the monuments well in advance and have contingency plans in case of any setbacks.

7 | CONCLUSIONS

The findings of the study are promising and encouraging. They show that the application of the proposed combination of active learning methodologies has a considerable impact on undergraduate engineering students, helping them acquire meaningful learning and fostering their motivation and creativity.

This study highlights the benefits and future directions for implementing such active learning methodologies in other STEM university courses.

Although the findings of this study support the positive impact of active learning methodologies with undergraduate engineering students, the study was limited to 56 students. Therefore, future research projects are recommended to examine the possible application of this educational project to larger groups and consider control groups.

Future studies will consider the implementation of PBL at different levels, allowing students to start working on a selected project from the beginning of the course while engaging in active learning. This will also involve the participation of students in defining the rubrics used to assess their work. Another aspect to consider in the future is how to evaluate students without the need for exams, considering taking into account the work carried out throughout the course. Finally, further investigations are needed to assess the impact of adapting teaching activities to the multiple intelligences theory regarding university students.

AUTHOR CONTRIBUTIONS

Francisco J. Quesada-Real, Fernando Pérez-Peña, and Juan J. Ruiz-Lendínez equally contributed to the design of the study. Arturo Morgado-Estévez printed all monuments 3D mockups. Francisco J. Quesada-Real and Arturo Morgado-Estévez prepared the material needed, ran the experiments, and gathered the data. All authors contributed toward the writing of the paper. All authors have read, revised, and approved the final draft.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

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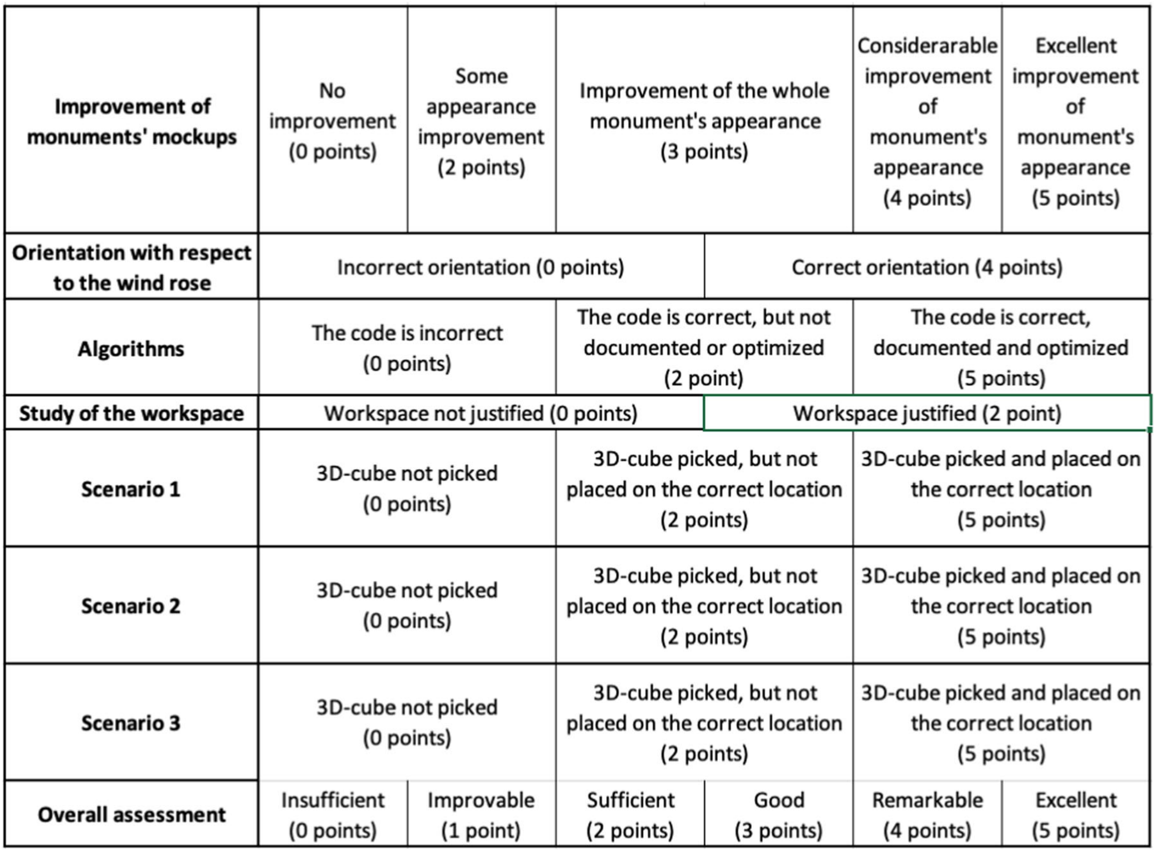
APPENDIX A: LAB SESSIONS

- *Session 1: Cádiz city of light*. Designing a circuit to switch several LEDs on and off, Arduino was introduced together with some basics of electronics. Thus, we described the route of the sun across Cádiz. The students had to simulate the route of the sun, switching their LEDs on and off going from East to West.
- *Session 2: The lighthouse*. Light-sensitive sensors were introduced. We explained how a lighthouse works, focusing on the most relevant light codes used to communicate with boats. Students had to reproduce the performance of St Sebastian's Lighthouse (Cádiz's Lighthouse) and work together to try to figure out the light codes.
- *Session 3: Cádiz's sounds*. Buzzers were used to play sounds with Arduino. We explained the use of Morse code, which has been used in Cádiz for decades. Thus, students had to assemble a circuit that integrated a buzzer and all of the electronic components explained in previous sessions. After that, they had to develop a program that, receiving a string as input, played the sounds of the equivalent Morse code. Moreover, students learned how to play melodies with Arduino. Using the same circuit, they developed the necessary code to play typical Cádiz folklore songs.
- *Session 4: Joining hearts*. Servo motors were introduced in this session. Understanding these motors was essential to moving the joints of the robotic arm. Using two servo motors, students had to simulate the functioning of Carranza's bridge that was the first bridge that connected Cádiz and Puerto Real, allowing vehicles to cross over Cádiz's Bay. This bridge can open and close its central part (e.g. to allow large vessels to go under it).
- *Session 5: Direct kinematics*. Concepts of direct kinematics were applied using as examples measures of Cádiz's monuments.
- *Session 6: Inverse kinematics*. Concepts of inverse kinematics were applied using as examples measures of Cádiz's monuments.
- *Session 7: Color sensor*. Students learned how to identify colors with Arduino using a “color sensor.” This was crucial for building the puzzle in the final project. Identifying colors was the way to identify each 3D-piece of the puzzle.
- *Session 8: 3D Monuments improvement*. Students worked on improving monuments' appearance, and adhesion. To do so, they used paint and stickers.
- *Sessions 9–15: Project development*. During the last six sessions students developed the final project that had two parts: building a jigsaw puzzle using 3D pieces and placing 3D pieces in different locations of a monument's mockup.
  - Jigsaw puzzle. Each group had a jigsaw puzzle with the picture of a monument, formed by nine 3D cubes. Each cube had a part of the picture on one face and a sticker with one color on the adjacent face. The goal was to solve the jigsaw puzzle by building a “*wall*” with the 9 cubes. First of all it was necessary to locate the base of the wall, secondly the second level and finally the third level.
  - Monument. Each group had to work with the mockup of a monument and put several 3D pieces in different locations. To do so, students needed to apply both direct and inverse kinematics. All mockups were fixed to a board with the real orientation of the monument. Thus, the four cardinal points were indicated with a wind rose pasted to the board. In the final assessment, students were asked to locate the pieces in different places, using domain-specific terms (e.g., next to the West tower, South door, in the atrium…).

APPENDIX B: FINAL PROJECT RUBRICS

Monument

Figure B1



Improvement of monuments' mockups	No improvement (0 points)	Some appearance improvement (2 points)	Improvement of the whole monument's appearance (3 points)		Considerarable improvement of monument's appearance (4 points)	Excellent improvement of monument's appearance (5 points)
Orientation with respect to the wind rose	Incorrect orientation (0 points)			Correct orientation (4 points)		
Algorithms	The code is incorrect (0 points)		The code is correct, but not documented or optimized (2 point)		The code is correct, documented and optimized (5 points)	
Study of the workspace	Workspace not justified (0 points)			Workspace justified (2 point)		
Scenario 1	3D-cube not picked (0 points)		3D-cube picked, but not placed on the correct location (2 points)		3D-cube picked and placed on the correct location (5 points)	
Scenario 2	3D-cube not picked (0 points)		3D-cube picked, but not placed on the correct location (2 points)		3D-cube picked and placed on the correct location (5 points)	
Scenario 3	3D-cube not picked (0 points)		3D-cube picked, but not placed on the correct location (2 points)		3D-cube picked and placed on the correct location (5 points)	
Overall assessment	Insufficient (0 points)	Improvable (1 point)	Sufficient (2 points)	Good (3 points)	Remarkable (4 points)	Excellent (5 points)

FIGURE B1 Rubric followed to assess exercises with monuments' 3D-mockups.

Jigsaw Puzzle

Figure B2

<table>
<tr><td>(Algorithms) Colours identification</td><td colspan="2">The code is incorrect (0 points)</td><td colspan="2">The code is correct, but not documented or optimised (3 point)</td><td colspan="2">The code is correct, documented and optimised (5 points)</td></tr>
<tr><td>(Algorithms) Pick/place 3D cube from the grid</td><td colspan="2">The code is incorrect (0 points)</td><td colspan="2">The code is correct, but not documented or optimised (3 point)</td><td colspan="2">The code is correct, documented and optimised (5 points)</td></tr>
<tr><td>(Algorithms) Pick/place 3D cube from the hopper</td><td colspan="2">The code is incorrect (0 points)</td><td colspan="2">The code is correct, but not documented or optimised (3 point)</td><td colspan="2">The code is correct, documented and optimised (5 points)</td></tr>
<tr><td>(Algorithms) Jigsaw puzzle assembly</td><td colspan="2">The code is incorrect (0 points)</td><td colspan="2">The code is correct, but not documented or optimized (3 point)</td><td colspan="2">The code is correct, documented and optimized (5 points)</td></tr>
<tr><td>Identification of 3D cubes' colour</td><td>No colour identification (0)</td><td>At least 2 colours are identified (2 point)</td><td colspan="2">At least 5 colours are identified (3 points)</td><td colspan="2">All colours are identified (5 points)</td></tr>
<tr><td>Use of inverse kinematics</td><td colspan="3">No (0 points)</td><td colspan="3">Yes (4 points)</td></tr>
<tr><td>Movement of 3D-cubes with the robotic arm</td><td>3D-cubes are not picked from the grid (0 points)</td><td>3D-cubes are picked from the grid (1 point)</td><td colspan="2">3D-cubes are picked from the grid and placed in the hopper (3 points)</td><td colspan="2">It starts assembling the jigsaw puzzle (5 points)</td></tr>
<tr><td>Jigsaw puzzle assembly</td><td>No or incomplete first row assembly (0 points)</td><td>Correct first row assembly (3 points)</td><td colspan="2">Correct two first rows assembly (6 points)</td><td colspan="2">Correct jigsaw puzzle assembly (8 points)</td></tr>
<tr><td>Overall assessment</td><td>Insufficient (0 points)</td><td>Improvable (2 points)</td><td>Sufficient (3 points)</td><td>Good (4 points)</td><td>Remarkable (5 points)</td><td>Excellent (6 points)</td></tr>
</table>

FIGURE B2 Rubric followed to assess the jigsaw puzzle assembly.

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