Project-Based Learning in Robotics Subject of a Master's Degree

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Abstract

The work presented here is part of the development and implementation of methodologies that promote a more reflective, autonomous, collaborative, participatory and meaningful learning, based on entrepreneurship and learning to learn. It is about introducing project-based learning in the Robotics subject of the master's degree in Automation and Robotics. This subject has been taught for the previous 10 courses in a traditional way, that is, with theoretical classes in a lecture format, where the teacher taught the theoretical contents within the framework of an oral presentation with questions from the students during the presentation or at the end of it. In addition, a series of guided practice exercises were taught, where students consolidated the theoretical contents and acquired the practical skills of the subject. Upon the proposal of the use of projects to manage student learning, it is intended that they are the ones who acquire the necessary knowledge to solve the projects. The teacher becomes a director in the learning process, providing the necessary material so that the student may continue with the development of their real project, understanding each theoretical concept involved in it. One of the main problems that teachers of the subject have encountered over the last 10 years in this subject is that students possess different Engineering profiles. Project-based learning allows teachers to assess the depth in learning specific concepts, so that the subject can add value to all students. In order to know information, an anonymous survey has been carried out that allows for knowing various aspects of the proposed methodology. As students worked in groups, we also consulted about the operation of the group. An individual report of the work carried out was also requested, as well as a group report. All these documents allow teachers to discover the strengths and weaknesses of the proposed methodology.

Keywords: Project-Based Learning; Robotics Education; Engineering Teaching.

1 Introduction

This document describes the experience acquired when introducing Project-Based Learning (PBL) in the teaching of the Robotics subject of the Master's Degree in Automation and Robotics at the University of Alicante. This compulsory 60-hour course is taught intensively in 12 sessions of 5 hours separated in three weeks. This is an important factor when it comes to understanding the operation of the subject and how an active learning methodology such as PBL will affect the acquisition of the different competences.

It is also important to highlight the entry profile of the students who regularly study this master. Although mostly this profile corresponds to mechanical, industrial, automatic, or electronic engineering, it is also very common for students with a degree in computer engineering to study it. Any engineering will give access to study this Master. Robotics is a very transversal subject, requiring knowledge from many important engineering subjects, such as mechanical design, kinematics, sensors, automatic control, microcontrollers, programming languages, and software algorithms development. These subjects are not taught in the same way in the different engineering degrees. Thus, computer engineers have a great knowledge of programming languages, algorithm, and software development, or even microcontrollers, but not so much in automatic control, sensors, kinematics, or mechanical design. Just the opposite happens with an industrial engineer. Hence, the teachers of this subject have encountered year after year with serious difficulties in homogenizing knowledge while explaining the matter.

In order to design an active learning strategy in this subject, it is important to review the learning outcomes required in the verified memory of the title:

- Develop reports with proposals for robotic systems that meet the necessary requirements for their application.
- Identify the equipment that different companies can offer and deduce the most appropriate according to the application to be carried out.
- Develop robot programming projects according to their specific language.
- Discriminate the advantages of using object-oriented programming languages for the implementation of programs for robotic systems.
- Compare the most widely used software schemes for the design and development of robotic system controllers.
- Implement the motion controllers of any robotic system to generate complex programs that solve any task.
- Determine the most used artificial intelligence schemes in applications with robotic systems.

This subject has been taught for the previous 10 courses in a traditional way. The teachers made available to the students a series of documents with the slides that they later explained in class. They were classes of 2.5 hours in which the student was unable to follow the common thread beyond the first hour. These theoretical classes were complemented with practical classes, also lasting 2.5 hours, where practical exercises were proposed for programming the different robots available in the robotics laboratory of the University of Alicante (see Fig. 1).

Figure 1. Robotics Laboratory of the University of Alicante.

In order to provide the student with active learning, PBL has been chosen because it is a teaching method in which teaching and learning activities are organized around a project to achieve the desired learning outcomes of the course (Sanchez-Romero, 2019). The teacher assumes a client role in which the students form a small company that will provide the service demanded by the teacher. Students, as a team, work together to solve complex robotic engineering problems, participate in decision making, and demonstrate leadership on a variety of tasks over a period of time to achieve project-specific deliverables. PBL can be used to improve student learning, as well as to improve student participation in the teaching/learning process and achieve higher levels of involvement (Lacuesta, 2009). PBL has also made it possible to further customize the level of entry-level learning outcomes for different entry-level engineering profiles.

2 PBL & Robotics

PBL is not a new teaching methodology. In (Postman, 1969) a teaching model was proposed in which lectures were abandoned and students developed their creative abilities through open questions and problems. These ideas were applied for the first time at the Mc Master University (Canada) and at the Case Western Reserve University School of Medicine (USA), when the name of problem-based learning methodology appeared for the first time. This method quickly spread to European Universities in the 1970s. It is in this decade that the Danish University of Aalborg developed a new method derived from problem-based learning: project-based learning (PBL). Currently, the PBL is considered one of the most suitable methods for the new higher education models based on active learning (Guo, 2020; Bittencourt, 2018; Guerra, 2017). With this methodology, students must assume greater responsibility and freedom of action. They will go through an active learning process that is necessary to solve the projects proposed by the teacher. PBL-based teaching is based on the development of a project that sets goals such as the development of the final product. Its achievement will require the learning of technical concepts and attitudes. The PBL methodology will only be in tune with the objectives of the European Higher Education Area (EHEA) if the student takes an active role in their learning process.

One of the main advantages of the PBL methodology is that it is developed in a real and experimental environment. This characteristic helps students to relate the theoretical contents with the real world, thus improving the acquisition of theoretical concepts. At the same time, the student takes an active role in the project and sets the pace and depth of their own learning, which makes this methodology perfectly applicable to groups with disparate base knowledge. The PBL motivates students, therefore, it can be considered as an instrument to improve academic performance and persistence in studies. Furthermore, the PBL creates an ideal framework to develop various transversal competences such as teamwork, planning, communication, and creativity.

Robotics is a field where it is relatively easy to propose didactic projects. It is a subject in which many topics take part, such as mechanical design, kinematics, dynamics, sensors, automatic control, microcontrollers, programming languages or frameworks for advanced software development. The interconnection of many of the issues listed in any robotics project makes a robotics subject ideal for the implementation of a PBL methodology (Hung, 2002). Indeed, in the literature, there are several works such as (Ghaleb, 2020; Qidway, 2011; Piguet, 2002), where experiences related to the use of robots within the framework of PBL are presented.

It is easy to find works related to PBL that describe projects that students carry out to learn concepts other than robotics, but using a robot (Carbonaro, 2004; Hamblen, 2004). In (SantClair, 2021) it is possible to find cases in elementary schools for which the construction and programming of a robot is used with the aim of teaching concepts of electronics, mechanics, or programming (Zadok, 2018). At the University, the use of the robot in the project is already focusing more on the acquisition of concepts of robotics (Havenga, 2020; Montagner, 2018). Although they are very directed projects, they leave little chance for the student to decide which path to take and how to develop it from scratch. The most common is to find jobs that focus on another subject related to robotics, such as industrial computing, which is taught through the construction and programming of a 2-degree-of-freedom robot with the LEGO Mindstorm platform in (Calvo, 2018), or by building and controlling a prototype of a low-cost robot controlled by a joystick in (Hassan, 2015).

3 Methodology

This section describes the methodology used to introduce the PBL in the teaching of this course of the robotics subject. In the first place, the participating students will be described, then the projects offered are summarized, emphasizing the theoretical and practical concepts where the subject is most affected. To ensure that theoretical concepts are acquired, two gamification experiments are performed using Kahoot! The section ends by briefly explaining this approach that complements the use of PBL in the subject.

3.1 Participants

Students enrolled during the course in which the PBL methodology is tested enter the Master's degree through very different degrees. 23 students participated in the subject in this last course. Table 1 shows the access profile grouped according to degree studied.

As indicated above, the entry profile is relevant, since not all degrees provide the same basic competencies for a subject as multidisciplinary as robotics. Thus, Robotic Engineers have a great knowledge of the kinematics and dynamics of robots, their programming, as well as their control. However, mechanical engineers, to take another example, do not have a large programming base, but they have a greater knowledge of the mechanical design of robots.

On this basis and based on the learning results to be achieved in the subject, the teaching staff defined 6 projects. To divide the group of 23 students and assign one of the 6 projects to each subgroup, an initial survey was carried out at the beginning of the course. The survey consisted of 3 questions. The first one asked about the knowledge of robotics they had at that time: robot structure, typology, kinematics, dynamics, programming environments (which ones), etc. In the second question they were asked about programming knowledge and the programming languages in which they had programmed. Finally, they were asked about their preference of working with an industrial robotics project or with a service robotics project.

Table 1. Entry profile of students enrolled in the 2020-21 academic year in the Robotics subject.

Degree	**Number of students**
Robotic Engineering	8
Electronic Engineering and Industrial Automation	6
Industrial Electronic Engineering	4
Mechanical Engineering	2
Industrial Engineering	1
Mechatronics Engineering	1

3.2 Robotic projects offered

Once the different groups had been created and the projects were assigned to each one of them, they began to work on the project. Due to COVID-19, teaching strategy was organized in a dual way. For this, the class was divided into 2 large groups. Thus, working groups 1, 3 and 5 attended together in person (3 groups can be seen working with the robots in Fig. 2). This allowed each group to work with the robots more easily. At the same time, the other groups were assigned a Google Meet room for each one of them. So, if any group needed to consult something, they indicated it in a WhatsApp group and the teacher immediately answered their questions. The presence alternated daily, so the operation was quite fluid.

Figure 2. Students working on the different projects during the classes of the subject.

The projects that were offered to the students are described below.

3.2.1 Project 1. Simulation of a robotic cell in CoppeliaSim with a UR3 and control of the real robot.

In this project it is proposed to work with the UR3 collaborative robot from Universal Robots to carry out a simulation of an industrial task. First of all, to simulate the process, the CoppeliaSim simulator is used. It uses a vision system integrated in the program that recognizes the objects, and the inverse kinematics module for the calculation and programming of trajectories. The objective of the project is to synchronize the trajectories generated in the simulator with those of the real robot, so a Python program is in charge of implementing the real robot controller and establishing the connection between the simulated robot and the real one by using TCP/IP protocol sockets. In this project different strategies for the control of the real robot are tackled. In this way, concepts of path planning, concepts of direct and inverse kinematics of the robot, aspects of sending trajectories to the real robot, communications, etc. are worked on.

3.2.2 Project 2. Simulation of a robotic cell in RobotStudio with two ABB IRB120 controlled by Matlab and synchronization with the real robots.

In this project, two ABB IRB120 robots are used to simulate an industrial task. It makes use of a vision system integrated in the program itself that recognizes the objects and the inverse kinematics module for the calculation and programming of trajectories. Concepts of path planning, concepts of direct and inverse kinematics of the robot, aspects of sending trajectories to the real robot and communications are worked on. Matlab is used for performing the control computation and connected to a RobotStudio server to perform the simulation.

3.2.3 Project 3. Teleoperation of a collaborative robot Kinova Mico 2 through keyboard commands: Cartesian and articular movements.

In this project, it is proposed to carry out the remote control of a Kinova MICO2 robotic arm operated through the keyboard. The most effective control method should be studied in accordance with the system requirements, having control options in Cartesian and articular space and these, in turn, by position or speed. Concepts of direct and inverse kinematics, aspects of control by position or speed, as well as real robot programming are developed. It is programmed with the robot's own API, on C++.

3.2.4 Project 4. Guidance of a UR3 collaborative robotic arm through image-based visual servoing.

Image-based visual servoing is a control technique that allows for a robot to be guided only through successive images captured by a camera. In this project, a visual servoing system is developed that allows guiding the robot, a UR3 collaborative robot, from any position to a desired final position. A pattern of characteristics is used for guidance. Concepts of transformation of coordinates between the different reference systems, concepts of inverse kinematics of the robot, aspects of sending trajectories to the real robot and synchronization with external signals are worked on to activate the camera and obtain each one of the frames. Everything programmed over Matlab, ROS, or through any application developed in C ++, .NET or Python.

3.2.5 Project 5. Construction of a tower using an ABB IRB120 through ROS.

In this project, a tower is built with wooden parts using an ABB IRB120 robot. For this, the necessary movements of the robot are programmed from ROS. Concepts of trajectory planning, inverse kinematics of the robot, and aspects of sending trajectories to the real robot, communications are worked on. Aspects of ROS are developed at a basic level and work is done on a RobotStudio server that allows it to be connected to ROS.

3.2.6 Project 6. Automated stop motion with an ABB IRB120 robot.

In this project, one of the ABB IRB120 is used to automatically generate each of the frames of a stop motion video. The objective is to be able to create this video through the positioning of the objects that appear in the scene by means of the industrial robotic arm. More complex concepts of trajectory planning, concepts of inverse kinematics of the robot, aspects of sending trajectories to the real robot and synchronization with external signals are worked on to activate the camera and obtain each one of the frames. All programmed over RobotStudio and RAPID.

3.3 Gamification and M-Learning

The theoretical content of the subject was taught through 1 hour master classes, where the teachers explain the subject based on slides with audiovisual content. To complement the acquisition of the theoretical content, two competitions were held through Kahoot! with online questionnaires. The questions that appeared in the questionnaires were mainly of two types: true/false questions and multiple-choice questions (4 possible answers). Each question is asked at the same time to all the students, so that the sooner it is answered, the more points are obtained. When the time for the question runs out (or all the students have answered), a summary is shown with the position up to that moment of the 5 best global scores. The three best students in each competition received an award in the form of an extra score for the final grade for the course. The most interesting thing about the two competitions held, however, is that the teachers were able to use this questionnaire to, once finished, go over the questions one by one and explain each of the correct answers. This helped a lot to consolidate specific theoretical concepts that were difficult to clarify within the framework of their projects.

4 Results

A study has been carried out on how PBL methodology has affected the final grades. It is important to emphasize that the grades have improved, but they did not start from bad results that had to be improved. The main objective of the methodology was to achieve a better integration of the different access profiles to the master. Therefore, in this section we will also show a summary of the final survey carried out, where the students, freely and anonymously, described their main opinions about the methodology used in the subject.

We begin the analysis of the results of the implementation of the PBL methodology by talking about the students' grades. In Fig. 3 the improvement obtained in the final grade during this course compared to previous courses can be seen. The normal distribution has shifted towards 9/10. It is also important to analyze the data related to the students' marks in the final theory exam. This exam is composed of 20 multiple-choice questions with theoretical concepts. The grades this year have improved a lot (see Fig. 3). In part, we understand that because the project encouraged them to understand these theoretical concepts to continue moving forward, and in part because of those two questionnaires carried out in Kahoot! The result is very promising and should be ratified in subsequent courses, but it is observed that the PBL not only improves the acquisition of the practical skills of the subject (something that was to be expected), but it has also considerably improved the acquisition of theory skills of the subject.

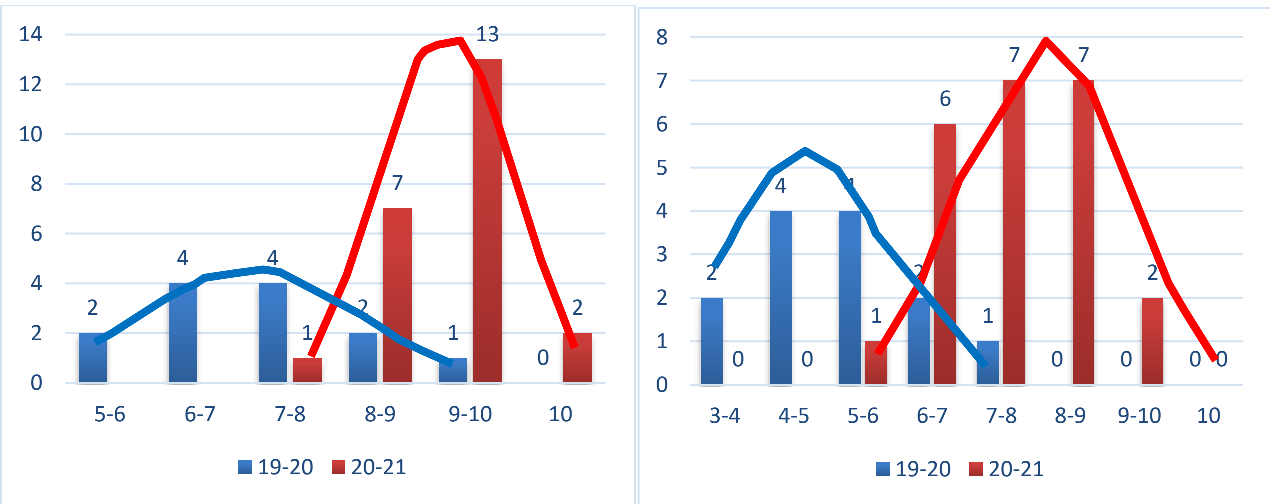

Figure 3. Left: Final grades of the subject in the last two courses; Right: Theory exam grades of the subject in the last two courses.

The other aspect to be analyzed is related with the opinion of the students regarding the PBL methodology. The survey carried out can be seen in Table 2. Although not all the questions are closely related to the methodology, they are indirectly. The first three are specific questions about the PBL methodology. The free response mode has worked very well so as not to restrict the student's thinking by anchoring it to a discrete structure of the typical surveys with responses from 1 to 5. In these first three questions we wanted to know if the student liked the PBL methodology, if it has seemed more difficult than a traditional methodology, and if they have aroused more interest in the subject learning from a very specific project. The responses are very positive towards the proposed methodology. 95% indicate that they like the teaching format, 90% affirm that it has not seemed more difficult than a classical methodology, while 100% affirm that the use of this methodology has aroused more interest in the subject.

In questions Q4, Q5 and Q6, it is intended to obtain the opinion regarding group work. Aspects such as if they have had a conflict and how they have solved it, or how the work has been divided and if they have detected any imbalance in the workload towards a member of the specific group were asked here. In this regard, no problem has been indicated, 100% are happy with how the work has been divided and they consider that there has not been much imbalance in the workload of the different members of the group.

In the block of questions from Q7 to Q11, the subject is asked in general, if they think the subject contributes what they expected for their professional future, how they would improve it, as well as what opinion those who already knew basic concepts of robotics and those who had no prior knowledge have. Regarding question Q7, the students answered affirmatively in a general way (85%). However, it is important to emphasize a comment that the remaining 15% agreed, and it is that they think that they would have liked to know more details of the projects carried out by the other groups, since each group was focused on its own project and had not time to see what the rest did. In this regard, it is important to write it down in order to improve it in future editions of the course. Perhaps a simple solution would be a presentation session on the last day of class where each group tells how their project has been carried out. In the question about how they would improve the teaching of the subject, interesting advice were obtained. The most recurrent was to make short videos with specific theory topics so that those who need to expand these concepts can do so at their own pace. From the answers to questions Q10 and Q11 we can conclude that the subject has contributed to students who already knew about robotics, and that students who had no previous knowledge are now able to face a robotics project. However, they highlight the need to better consolidate theoretical knowledge, an aspect that could be solved with those videos that they themselves indicated in question Q9.

Question Q12 asks about the work of teachers. 100% affirm that teachers have been able to motivate them to improve their knowledge of the subject. As for whether they have been able to guide them with the project, 10% indicate that they would have liked a little more guidance at the beginning of the project.

Finally, in the last question, they are asked to give themselves a global grade to know how they value their own work in the subject. We can see grades from 6/10 to 10/10 in this self-assessment. But it is true that they themselves were much more demanding than the final grades obtained.

Table 2. Final survey of the subject.

Q1	Did you like the teaching format of the subject using PBL?
Q2	Has it seemed more difficult than a classical methodology?
Q3	Has it caused more/less interest in the subject?
Q4	How has the experience of working in a group been? Have there been any conflicts? If so, how have you solved them?
Q5	Are you happy with how the work has been divided between the members of the group?
Q6	Do you think there has been a lot of imbalance when it comes to the work done by each other?
Q7	Do you think that this subject has given you what you expected of it for your professional future?
Q8	If the subject was not compulsory to obtain the master, would you recommend to a friend of yours to take it?
Q9	How would you improve the teaching of the subject?
Q10	If you already knew about robotics, what has the subject given you? What have you missed?
Q11	If you did not know about robotics, do you think that now you would know how to start a robotics project? What have you missed?
Q12	Have the teachers been able to motivate you to improve your knowledge of robotics? Have they been able to guide you in the project?
Q13	What overall grade would you give yourself in the subject?

5 Conclusion

In general, the students expressed their satisfaction with the training received through the project, they consider that they have learned independently, and that they have acquired research experience. They especially value the fact of working with real robots and with objectives like those that can be asked in the professional world. Most consider that the chosen project has been adequate, and the motivation and stimulation that it has produced has been positively valued. Regarding competencies, the students say that the project has allowed them to gain valuable experience of teamwork, that it has allowed them to put their own initiatives into practice and that they have not had to follow any scripts. For their part, the teachers consider that the PBL methodology is stimulating. The level of understanding between the teacher and the students is high, and a learning environment is created marked by the predisposition of the students. In terms of teaching objectives, the activities developed within the framework of the project have exceeded in quantity and depth the activities that were proposed in traditional laboratory practices. The open nature of the project has allowed students to have different approaches to their solutions, thus sparking authentic discussions about possible solutions. In short, the students have felt like true engineers who have participated in the conception of a complex system. This methodology allows much better personalization of the learning of the different entry profile. Teachers have more time for personalized attention to guide the learning process of each student, so that they can better serve students who require more attention in a specific aspect of the subject, leaving the rest of the students to focus their learning on other aspects of the subject where they had less knowledge base.

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