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LEARNING DISTRIBUTED ALGORITHMS BY PROGRAMMING ROBOTS

Flaminia L. Luccio

DAIS, Ca' Foscari University of Venice, Italy
luccio@unive.it

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The learning process of theoretical concepts such as the model of a distributed environment and different distributed algorithms together with their execution and correctness requires time and is often considered by students a hard and non-challenging issue. In this paper we suggest adopting a more practical approach based on real implementations of distributed algorithms with the help of robots. A learning-by-doing approach can, in our opinion, help students acquiring a deeper knowledge of the model and of the algorithms, and can also stimulate them, and let them improve their teamwork skills. In this paper, we present a specific case study of a practical project, run for two consecutive years at the University Ca' Foscari of Venice, inside an International Master of Computer Science course of Advanced Algorithms. The students for their final exam had to work in groups and their task was to design and implement a distributed algorithm to solve an assigned problem, using a Lego Mindstorm EV3 robot

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and a Makeblock mBot robot. In this paper, we discuss the positive effects of such a non-traditional teamwork approach by analyzing the teacher's perception, the feasible impact on the students' grades, and the students' involvement and positive feeling, highlighted by the results of some questionnaires proposed at the beginning and the end of the projects. We finally discuss the limits of such an approach and possible improvements.

1 Introduction

Robots are becoming part of our daily life. We find industrial robot arms used, e.g., in manufacturing, autonomous domestic robots that can interact with the world in human-like ways (e.g., robots that fold laundry, vacuum cleaning robots), medical robots that help elderly at home or are used for surgical operations, transport robots (e.g., autonomous cars), entertainment robots, field robots that explore dangerous areas (e.g., for demining), etc.

In this paper, we concentrate on robots that are used for educational purposes to improve the intellectual growth of students and to increase their engagement in learning activities. In the recent years, we have been facing an increase in the use of robots inside classes and this depends on many factors such as, e.g., the availability on the market of low-costs programmable robots, or the motivational benefits of introducing them inside school or University courses. Barreto (2012) proposes a review of different research articles on educational robotics and shows how, in general, but not in all cases, this teaching technique can act as an element that enhances learning. In particular, this study, together with the one of Eguchi (2010), and McLurkin *et al.* (2013), shows that robotics can be used to increase academic achievement in specific STEM (Science, Technology, Engineering and Math) concept areas through experimentation, and can also improve different skills such as creative thinking, problem solving, decision making, communication, etc. Taylor and Baek (2016) show what type of collaboration interventions can create a beneficial learning environment for students and can improve their learning motivation inside collaborative robotics projects. They also show the impact of the prior robotics experience on the skills development. The study of Alimisis (2013) critically discusses the role of Educational Robotics and emphasizes how robots should be just a tool to foster new skills (cognitive, team working, etc.), and their use should be supported by sound learning theories, a correct curriculum and an appropriate learning environment.

Other more specialized studies show how robots can result as an entertaining platform that can improve the learning process of languages, computers, electronics, etc. (Mubin *et al.*, 2013). In particular, robots can be used to present non-technical scientific subjects such as, e.g., mathematics, or kinematics (Karim *et al.,* 2015, Mubin *et al.*, *op. cit.*), to teach second languages (Chang *et al.*, 2010), to improve the cognitive development of young people (Toh *et al*., 2016). However, the focus of this paper is on the learning process of technical subjects using robots. Zaldivar *et al.* (2019) introduce an educational platform based on Lego Ev3 robots and on Matlab that can be efficiently used to support the learning process of the principles of classical and metaheuristic optimization algorithms in undergraduate engineering courses. Gyebi *et al.* (2016) present the result of the effects of Educational Robotics on an Undergraduate Computer Science course taught in a University in Ghana. In particular, the authors discuss the impact of robotic-based exercises as opposed to paper-based exercises, the effect on students' understanding of programming concepts, the engagement and the effectiveness of the method. The presented results are positive in terms of engagement, motivation and skills development. In (Damaševičius *et al.*, 2017) the authors discuss a project-based approach using robots that they have experimented during practical classes of the Robots Programming Technologies course of the Kaunas University of Technology in Lithuania. At the end of the project students gained problem-oriented skills, they were able to combine hardware and software related subjects, and they increased interest in the subject. López-Nicolás *et al.* (2009) propose an active learning experience in the field of Robotics, and in particular the design of robots for industrial applications, in the context of a degree on Industrial Engineering at the University of Zaragoza. Results show an improvement in the student's motivation and understanding of the analyzed problems. Finally, Das *et al*. (2019) present an implementation of some distributed algorithms using Lego Mindstorms EV3 robots. The developed project was not only useful to improve the students' knowledge and team work, but also to improve the quality of the proposed theoretical solutions, showing how theory can also benefit from real applications.

In this paper we present a project-based learning approach that was adopted for the exam of Advanced Algorithms at the University Ca' Foscari of Venice, Italy, in years 2017 and 2018. To the best of our knowledge, this is the first time this approach has been used to improve the knowledge and the comprehension of distributed algorithms. We here discuss the positive effects of this approach and also the limits. The paper is structured as follows: Section 1 introduces the case study describing the projects and the technology used. Section 2 presents the results achieved using this project-based approach and discusses the limits. Finally, future work is discussed.

2 Case study

The Advanced Algorithms course contains different topics. The first half includes advanced algorithms such as approximation, randomized and genetics algorithms, local search techniques, etc. The second part is all dedicated to distributed algorithms and the experimental project was devoted to this part. The students had an intermediate exam on the first part, and only those that passed the first exam were admitted to the practical exam. We point out that, our experimentation on robots was not a hands-on practical class, but the experimentations were only included as part of the final exam. The class was divided into two groups. The first group included students that took the traditional written exam; the second group included those that replaced the traditional exam of the second part with the practical project. All students had however to follow the classroom-taught lessons. 26 students attended the course in 2017, and 47 in 2018. Students that took the practical project were divided in groups of at most four people. The project dealt with autonomous robot programming. The main concepts to be learnt were: the robots' model, the change of state, communication and interaction, autonomous movements and autonomous solution of different tasks, i.e., design and implementation of different distributed algorithms.

2.1 The projects

The case study we propose in this paper analyzes two projects one developed in 2017 and one in 2018. The goal of the projects was the solution of two different problems proposed by the teacher, and the development of two different distributed algorithms with mobile robots in a group project-based educational setting.

Project 1: In 2017 we proposed a relay race between two robots: one Lego Mindstorm EV3 robot and one Makeblock mBot robot. One robot (chosen at random between the two of them) had to start the race, had to find the other robot and once found had to stop while the other one had to finish the race. The robots moved along a path and had to avoid obstacles. The path was composed of 3 randomly composed sub-paths (i.e., producing each time different paths). An example is depicted in Fig. 1 left.

Project 2: In 2018 we proposed the simulation of a known algorithm for the search of a black hole in a ring network using one Mindstorm EV3 robot and one Makeblock mBot robot. The black hole is a malicious node that kills all the robots that arrive there, so the robots should try to avoid it. At the end of the algorithm at least on robot should survive and should know the location of the black hole. An example is depicted in Fig. 1 right where the black hole is the black vertical object and the square is the homebase where the robots start the computation and where they meet during the execution of the algorithm.

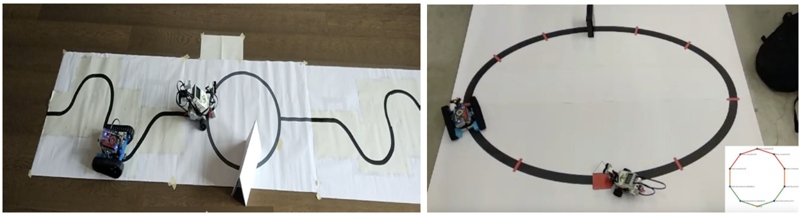

Fig. 1 - On the left a relay race with one mBot robot (on the left) and one Lego robot (on the right). On the right, the search for the black hole with one bMot and one Lego robot.

2.2 The robots

Each group was equipped with two robots: A Lego Mindstorm EV3 robot[1] and a Makeblock 90092 - mBot robot[2]. For the Lego EV3 robots, standard components and sensors were used to build the robots: 1 EV3 programmable brick with and ARM 9 processor of 300 MHz and a Linux-based operating system, 2 large motors, 1 medium motor, 1 touch sensor, 1 infrared seeking sensor, and 1 ultrasonic sensor to detect both objects and the other robot, 1 color sensor to detect colors and to be able, e.g., to follow lines, and 1 gyroscopic sensor. For the Makeblock mBot robot the available components and sensors were: a Me Auriga main control board programmable in *C\C++* language via the Arduino IDE, 2 motors, 1 ultrasonic Sensor, 2 light sensors, 1 line-follower sensor, and 1 gyroscope.

2.3 Technical issues

Both projects had some non-trivial technical issues to be dealt with. The first general constraint was the interaction between two heterogeneous robots that had different hardware and software resources. Moreover, in the first project the difficult issues were:

1. the following of a line by the Lego robot that does not have a 1 line-follower sensor. The students had to design an algorithm to follow the line and different problems turned up because of the folds on the sheet of paper that indicated the path, shadows on the paper, variable ambient lighting conditions, etc.;
2. the detection of an object given that the sensors could not distinguish the difference between an object and another robot.

[1] https://www.lego.com/it-it/mindstorms

[2] https://www.makeblock.com/steam-kits/mbot

In the second project the difficult issues were:

1. the distinction between a normal node of the ring network and the black hole;
2. the exchange of information between the two different robots;
3. the limited power of battery levels that may limit the correct behavior of the sensors.

The students had thus to discuss, collaborate and try to solve all the issues, in some cases they also interacted with the teacher proposing and analyzing different solutions, discussing problems. From all these discussions, the students improved their collaboration abilities and their technical skills, and the teacher had a very positive perception of the interaction and intellectual growth of the students. Regarding collaboration they had first to agree on how to split the different tasks (balancing the work), during the development phase they had to discuss different solutions and problems, and they had to integrate all the tasks into a final solution. From the student/teacher interaction, the teacher had an immediate feedback on how collaboration had helped students to fully understand the problem, and to improve the knowledge on the course topics.

3 Results and project evaluation

To evaluate the students perceived usefulness of this project two pilot tests were conducted running two anonymous surveys proposed as Google Forms, an initial (proposed to all students) and a final survey (proposed to those that participated to the project). The surveys were composed of both multiple choice and open questions. In 2017, 10 students out of 26 participated to the practical project, 12 filled the initial survey and 6 students that did the project filled also the final survey. In 2018, only 3 students out of 47 participated to the project, 21 students filled out the initial survey, and the 3 that did the project, filled out also to the final one. We also collected some information using paper surveys, and verbal impressions and comments from students that participated/did not participate to the project.

The purpose of the initial survey was to gain information about the students' background and knowledge before the project. The final survey evaluated the whole project experience in terms of students' motivation, engagement and level of understanding in the robotic activities:

The questions for respective surveys were divided into:

- *Initial survey*: asked for students' background such as prior education, prior experience in programming and using robots, reason why they eventually chose the project instead of the standard written exam, ex-

pectations before doing the project.
- *Final survey*: asked for students' perception about the skills, motivation and knowledge gained. We also asked if they would go through the same experience again.

To assess the students' performance and understanding of the basic of distributed algorithms we evaluated their final project both from a theoretical (with a written report) and practical point of view (with a practical demonstration). The students' engagement and improvement in the collaboration skills were assessed with the final survey.

3.1 Results of the initial survey

In the initial survey of the first pilot test we were able to access students' background. Different questions were posed:
- *Study background*: In 2017, 83.34% of the students had taken their bachelor in Computer science in Italy, 8.33% in Engineering in Italy, 8.33% in Engineering in another country. In 2018, 57,1% declared their prior bachelor in Computer science in Italy, 28,6% in Computer science in other countries, 14,3% in Engineering in other countries.
- *Known programming languages:* In 2017, all students declared the knowledge of C and Java languages, while in 2018, only of C language.
- *Prior experience in programming robots:* In 2017, 91.67% of the students had no prior experience in programming robots, 8.33% in programming Lego Mindstorm robots, while in 2018, 90,5% had no prior experience, 9.5% only in programming Lego Mindstorm robots.
- *General interest in programming robots*: In 2017, 58.34% of the students were generally interested (independently from this course) in programming robots and see real applications of algorithms, the remaining 41.66% were not, while in 2018, 85,7% were interested and 14,3% were not.
- *Reason why they chose the project* (for those that did it): in 2017, 80% of them answered that they chose the project because they thought it was interesting to program robots, the remaining 20% replied it was easier to program robots than to study for a written exam, while in 2018, 66,67% answered that was because the project was interesting, 33.33% because the project was easier.
- *Expectation on the project effects:* the students had to reply to a question by selecting one or more answers. In 2017, 66,67% of the students believed that by doing the project they would improve their knowledge on theoretical distributed algorithms, 41,66% that they would improve

their learning motivation, 33,33% that they would improve their collaboration skills, 25% that they would easily fix concepts, 33,33% that the project could make the learning process of educational activities effective, and finally 41,66% that it could improve their pleasure on studying distributed algorithms. In 2018, 66.7% thought that with the project they would improve their knowledge on theoretical distributed algorithms, 52.4% that the project would make the learning process of educational activities effective, 52.4% that the project could help then to easily fix concepts, 47.6% that it could help them improving their collaboration skills, their learning motivation, their understanding of programming concepts, 42.9% that it could help them improving their pleasure on studying distributed algorithms.

We can thus conclude that, also students had the perception that such a group work project could potentially improve their knowledge and their collaboration skills in an effective way.

3.2 Results of the final survey

After the end of the project we have run with the participants a new survey to assess the students' engagement and perception of this activity. We proposed a multiple-choice question with one or more possible answers.

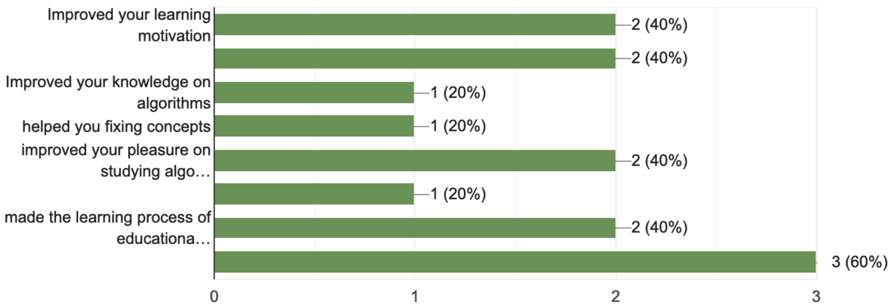

Fig. 2 - Answer to the question: "Do you think that the project with robots has …" in 2017.

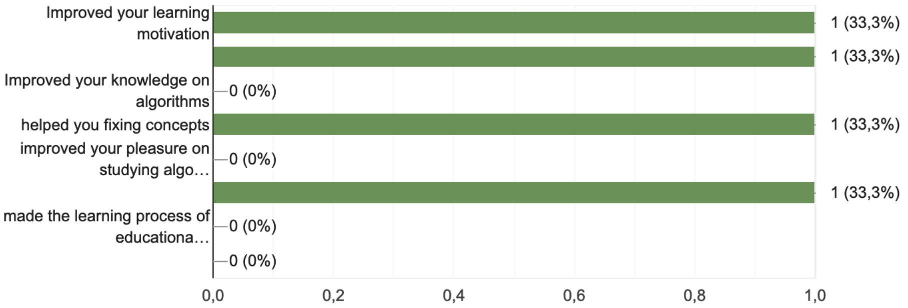

Fig. 3 - Answer to the question: "Do you think that the project with robots has …" in 2018.

Collaboration effect: to analyze this dimension, we asked what the added value in the course was of working in a group (as opposed to working individually). The results are shown in Fig. 4 for 2017, Fig. 5 for 2018. It emerges that the main effect was the increase in mutual support and motivation, and then also the group size was relevant for splitting the work.

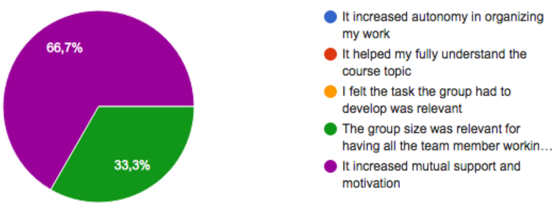

Fig. 4 - Collaboration effects. Results for 2017.

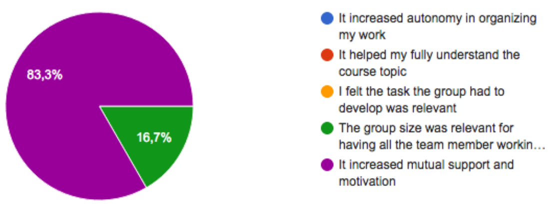

Fig. 5 - Collaboration effects. Results for 2018.

Finally, a question that in our opinion is very interesting is whether they would choose to retake the project again: in 2017, 80% of the students replied yes, but 20% of them replied no and the motivation is that the time they spent to develop the project was too long, while in 2018, 66,7% replied yes, 33,3% replied maybe, only if the project would be more focused on algorithms that have a really well-defined field of practical application.

We can thus conclude that the overall experience for students that did the project was very good, and students had the perception that they had increased their knowledge also on theoretical concepts and their collaboration skills, and most of them would repeat the experience.

3.3 Exam performance

We have analyzed the students' performance on the final exam, comparing the grades of the students that passed the exam in the traditional way, and those that presented the final project. The evaluation of the projects was based on: 1) the group presentation of the project with an oral description, and an execution of the algorithm; 2) a written report for each student, including the hardware and software description, the developed algorithm, and the technical limitations. Note that, those that worked on the project were the ones that passed the first partial exam, so this set does not include the weakest students. Also observe that all students that worked on the project were enthusiastic and made a big effort to obtain nice results and to solve all technical limitations. The presentations were all excellent and also the reports. The teacher's perception is thus that these students acquired all the basic notions of distributed algorithms. In 2017, all the students that did the project had very high grades (with a mean value of 29.7 out of 31. Note that, positive grades in Italy are between 18 and 30 cum laude, we considered 30 cum laude as 31), much higher than those that did the written exams (mean value of 22.82). Moreover, the median value of the class score was 28.5, and all the students that did the project, except one, had a score over the median. In 2018, the grades of the students that did the project had a mean value of 30.66, while those that did the written exam had grades with a mean value of 21.93, the median value of the class grade was 25, and all students that did the project had a score over the median. We can thus conclude that in both years working on the practical project greatly improved the exam performance.

Conclusion

This paper illustrates a new and original approach to introduce students to the theoretical models and algorithms in the area of distributed algorithms using a hands-on approach for the exam preparation. From the results of our tests and an analysis of the students' performance we can claim that Educational robotics and in particular this project-based approach can make the learning process more interesting, can increase the collaborations skills and the knowledge of theoretical concepts. This is also reflected by the excellent final grades obtained by students that participated to the project compared to the ones that only took the traditional written test. One limitation of this approach is that it is time-consuming, thus some students preferred to take the traditional exams. This situation is reflected by the decrease in the number of students that participated to the project in 2018, compared to the ones that participated in 2017. This can also be explained with a word-of-mouth between students of consecutive years. A solution to this problem could be to include the final project as a requirement for all students, and to replace some of the theoretical lectures in class with some practical classes devoted to the final project, thus limiting the self-organized work outside the standard class schedule.

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