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The Use of Mobile Robots in Education and Research at John von Neumann University

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Abstract
The article is an experience-based review and case study presenting the long-term use of programmable mobile robots in education and research at John von Neumann University. The paper discusses applications of robot-assisted learning at different educational levels, from primary and secondary education to university-level programming courses. Particular attention is given to the use of physical robots for developing algorithmic thinking and programming skills, as well as to their potential effects on students' attitudes towards programming and programming self-concept.
The paper summarizes several educational experiments and student projects conducted at John von Neumann University and its partner institutions. These examples illustrate how programmable robots can be used to transform abstract programming and algorithmic concepts into tangible, problem-oriented activities. The paper also discusses the use of physical robots compared with simulation environments and presents examples of robot-supported teaching in algorithms, computer networks, and artificial intelligence.
In addition to their educational applications, LEGO NXT and EV3 robots have been used as low-cost experimental platforms for research in multi-robot communication, area exploration, swarm intelligence, and robot gathering. The presented experience suggests that programmable mobile robots can serve as a common platform connecting programming education, project-based learning, and experimental research.

1 Introduction

Today's explosive development of information technology and the rise of artificial intelligence require public education to start introducing children to the basics of programming, algorithmic thinking and robotics tools at primary school age. As early as the final decades of the twentieth century, simulation tools emerged that tried to make abstract algorithms tangible by means of screen objects. Such tools were Spider World [1], Papert's turtle [2] or Karel the robot [3].

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Many researchers prefer to use real robots in education rather than virtual tools. Kamada [4] argues that computer-controlled machines and robots are present at almost all levels of society and that it is therefore useful to teach both the mechanics and the programming of these devices. In their study they used a Myurobo robot and used the Dolittle [5] programming language for programming. Kurebayashi and colleagues [6] used tri-axial robots to teach mechanics, electronics and programming in a joint system. In their view, teaching embedded systems in a complex way is more helpful than traditional teaching. The advent of LEGO's educational robots has also brought a major breakthrough in education with mobile robots. Initially, RCX robots and later NXT and EV3 models were introduced into education. For example, Fagin and Merkle in the USA investigated [7] the possibilities of teaching programming with Lego Mindstorms robots on a sample of more than 900 people around the turn of the millennium. Sartatzemi and colleagues [8] have investigated the possibilities of teaching the basics of programming with robots in Greek secondary schools, while in Hungary Istenes has also used robots to teach programming to university students [9].

Nowadays, more and more robot family elements are being used in education such as TETRIX [10] robot while others, Vex, TRIK and Arduino robots [11] [12] are also used in teaching students.

An important question for educators and researchers is to decide whether it is better to use real robots or robot simulators. One of the most interesting tasks in artificial intelligence today is the creation and use of intelligent robots. Robots must operate in a non-deterministic, noisy environment, in continuous space and time. With the advent of low-cost, high-performance computers, the question of how to operate robots in virtual worlds, i.e. using specialized robot simulation software, may arise. Using simulators in schools, teachers can build experimental environments of their own design, varying complexity and realism according to the level of knowledge and age of the students. In addition to the simulators mentioned in the first paragraph, the Lego Mindstorms Simulator (LMS) developed at the University of Paderborn [13] experienced growing popularity. Also, a more advanced simulation environment is the Webots mobile robot simulator developed by Cyberbotics [14]. Webots is capable of handling different types of robots that can roll on wheels, walk or even fly, while it can also control real robots such as Pioneer, Lego Mindstorms, Aibo. The Repast is an open-source, Java-based multi-agent simulation software package developed by Repast, Collier and colleagues at the University of Chicago [15]. However, some scholars argue that using real tools can simultaneously activate and develop learning motives and acquire the basic knowledge elements of programming, i.e. using real tools makes learning more enjoyable. The sense of knowledge gain and the pleasure of learning can create what Csíkszentmihályi calls a state of flow [16], which is a particularly powerful motive. In addition, progressively more challenging exercises can maintain the right level of challenge, thus activating the mastery motive, which plays a fundamental role in the acquisition of skills and abilities, so that the programming self-image as a learning motive can be developed through the use of robots. The experience of programming robots, the sense of achievement in solving problems, has an impact on students' self-concept, i.e. the tasks solved at the concrete operational level have an impact on the development of abstract programming knowledge.

In a study, Wu [17] compared whether real robots or robot simulators have a greater impact on the efficiency of teaching beginners to program. In their experiment, 75 participants used Lego RCX robots, and 76 participants used Lego Mindstorms simulators. The results showed no significant difference between the two groups in their understanding of and ability to create programs. The use of real robots resulted in greater progress in creating programming algorithms, they are more capable of visualizing program behaviors, but their use requires extra time. The final part of the experiment showed that the group using robots showed more positive learning attitudes than their counterparts using simulators. Programming self-image (self-concept) and programming attitudes have a positive effect on long-term learning.

My colleagues and I have also started a study with the help of the Kecskemét Digital Education Centre in terms of learning programming and algorithmic thinking or whether the use of simulators and visual programming environments is more beneficial for 8 - 12-year-olds. In the centre, children learn the basics of programming, algorithm building and robotics using LEGO WEDO, KODU, MBOT or LEGO EV3 real robots, while using real-world tools. Those who prefer a visual programming environment can choose the Scratch course. We have a sample of nearly 100 students from both

groups whose performance was measured by pre- and post-tests, which we intend to report the results in a forthcoming article [18].

In the following parts of the article, we will show how mobile robots have been used in the Department of Information Technology of the GAMF Faculty of John von Neumann University and in related secondary schools, and present some simple projects created by secondary school students. We briefly describe a long-standing experiment in which we measured the short- and long-term effects of using mobile robots in university education, and how robots can be used in the education of advanced students in other university courses. Finally, we present some examples of academic research results where robots have been used in education.

2 Mobile robot projects in secondary education

For more than ten years, the Department of Computer Science of John von Neumann University and the Bányai Júlia High School in Kecskemét have organised robot programming team competitions for secondary school teams. The competitions were held in two rounds so that in the first round the teams had to create a project with the help of several robots, which communicated with each other during the task. They had to submit a description of the finished projects, the source files of the programs running on the robots and a video of the task they had completed. The jury invited the top 10 teams to the final, where the teams had to present their work made at home and solve 3 tasks in which one or more robots performed tasks on a field table. Initially, 32-40 secondary school teams from Hungarian secondary schools entered the competitions, and later not only the number of teams increased, but also teams from foreign secondary schools sent their entries. Some of the project tasks that have been completed are presented in the following section.

2.1 Simulation of a rock - paper - scissors game

In this project, students made two hands from NXT robot parts to play rock-paper-scissors. The robot hands not only present the object they "guessed" with the accepted signals but also memorize the opponent's previous moves and "guess" their move using this information. This is where the basics of AI two-player winning games were found.

2.2 Simulation of guessing from a labyrinth

In this exercise, several robots start out in a maze along different paths. The robot that finds the exit first sends information about the path to the others via Bluetooth and the others then use this path to figure out the labyrinth.

2.3 Leader – follower algorithm simulation

The simulation simulates a chain of trucks with model robots, where the trucks move in a chain, following the position changes of the first truck, moving in each other's air shadow and achieving significant fuel savings.

A joint robotics research workshop has been set up in cooperation between JvNU and Bányai Júlia High School. Here, a lecturer from the university posed a real-world problem, discussed the theoretical background of the task, which the students worked on independently and created a simulation and the corresponding documentation. These projects went well beyond the high school IT curriculum. They served well to prepare talented, outstanding students.

2.4 Submarine swarm modelling

The team won a silver medal in the senior age category of the World Robot Olympiad - Future Innovators, the world's largest research and robotics competition, in Odense, Denmark. The team's project used swarm intelligence, a branch of artificial intelligence research, to model an oriented and operational submarine swarm that would facilitate and accelerate underwater research and the measurement of physical, chemical and biological parameters.

2.5 Implementing robotic behaviors with artificial intelligence

In this project, EV3 robots simulated the foraging behavior of animals, mainly ants, cooperating in a wild swarm. Some robots scouted an area while others collected food. Some results of the project:

- Szeged Innovative Informatics Competition (SZTE TTIK), 1st place in the Technical Informatics section [19].
- XVI. National Conference of Scientific Student Circles, Science and Engineering Conference, 1st place and qualification for the international finals.

3 Teaching beginners in universities – effects

A new subject was introduced at the JvNU GAMF Faculty (predecessor of Kecskemét College). The aim of the subject was to introduce students to the basics of programming in a different way from traditional education, using LEGO RCX and NXT programmable mobile robots [20]. The subject is called "Programming of Model Robots", where we tried to follow the principles of constructive education, to apply its methods and working forms. We introduced the new curriculum with the help of examples, we explained the necessary functions and the programming language used. Later on, students worked in groups of two or three to solve programming problems and tasks in cooperation with each other. The most important part of the students' work, the small group project, was the creation of a robot that worked according to a specific program. During the project task, the students are asked to build a robot that meets the goal, create the algorithm for the task, write the program, compile documentation of their work, video, pictures, and finally present their work to their peers and answer questions. The project will be evaluated during a joint presentation. In addition to teacher reflections, peer and self-evaluation also play a role.

By creating this subject, we wanted to demonstrate the following:

- The physical tools and the new methods used did not have a direct impact on the students' level of knowledge.
- The experimental group found the subject more enjoyable to learn than the control group and found the material less difficult.
- The main difference was in the development of the programming self-concept. While the control group's average programming self-image stagnated, the experimental sample's programming self-image showed a significant change.

To test the hypotheses, we organized a control group study [21]. The experimental sample consisted of 73 students who used LEGO NXT robots for learning, while 76 students in the control group learned using traditional programming teaching methods. Based on the similar data of the two subsamples, we hypothesized that the differences during the experimental period were mainly due to the pedagogical effects on the students. The experiment lasted for one semester and ended with the following results:

- The physical tools and the new methods used did not have a direct impact on the students' level of knowledge.
- The experimental group found the subject more enjoyable to learn than the control group and found the material less difficult.
- The main difference was in the development of the programming self-concept. While the control group's average programming self-image stagnated, the experimental sample's programming self-image showed a significant change.

This result shows that, despite the short period, the use of new tools and methods has led to a significant development of self-image. This is important for further learning, because a developed self-concept has a very strong impact on the further academic performance of the pupils [22] [23].

To examine the persistence of effects, a follow-up measurement was also conducted after 3 years [24]. We recorded as positive attitudes that members of the experimental sample found the subject easier (60.6%) or much easier than other programming subjects. 90.9% of the respondents

found the subject more fun to learn than other subjects, while 75.8% of the respondents thought that the class organization of the subject provided more or much more student activity. The study also found that the self-image component associated with the subject was significantly stronger than that associated with programming in general.

4 Robot-assisted education for intermediate programmers at university

In the previous section, we looked at the impact of robots in the early stages of teaching programming. We then looked at how we can use these tools in other subjects, such as teaching algorithms, computer networks and artificial intelligence. We also looked at whether the use of robots has a similar positive impact on the next stage of programming education, whether it has an impact on student motivation, and on the completion of parallel subjects where the aim is to develop existing basic programming.

For the simulations of some of the algorithms in the subject "Introduction to Algorithms", robots were used. A more interesting exercise for the students was, for example, to simulate the maximum selection method with LEGO NXT robots. In this task, the robot rotated around a corner of a classroom and used its light sensor to find the "brightest" point in the room, which was provided by a lamp switched on. As it spun around, the robot memorised the correct direction and then moved to the lamp. For the students, the task was much more practical and interesting than in traditional teaching, where, for example, they had to choose the largest element in a set.

In the same subject, we also used robots to simulate sorting algorithms. Instead of the number sequences studied in the theory lesson, the robots sorted coloured spheres and objects according to some criteria.

In the practical lessons of the computer networks course, we were able to create scatternet and piconet networks from the robots using NXT robots and to simulate the methods of sending messages learned in theory [25].

Robots have also been used many times in the context of artificial intelligence. These tasks already required a strong theoretical background in many areas of computer science. We used the knowledge we had learned in artificial intelligence, game theory, image processing, wireless networks. The robots can communicate with each other via their IR ports or Bluetooth. We used this opportunity to create different applications in which two or more robots followed each other, played rock-paper-scissors or even a lottery game. By the end of the semester, the students were able to implement the applications, but the better ones were happy to solve more difficult tasks as homework. Such tasks could be the creation of robots playing the noughts and crosses game [26], labyrinth guessing robots, object-carrying robots that together carry heavy objects, and soccer robots.

That robots can be well used in the education of advanced students at universities was also proved by a short study entitled "Elementary algorithms in practice with robots" [27]. The aim of the course was to simulate real-life situations using mobile robots in which the robots perform their tasks using elementary algorithms, thus demonstrating the real role of algorithms in programming and increasing the motivation of students to study Algorithms. In the study, students in two groups simulated real problems with robots. One group completed a project called "Boss in the Warehouse", which consisted of modelling the robot's path in a forklift truck in an industrial environment. While solving the problem, the robot measured distances, queued possible routes using bubble sorting and calculated minimum selection, while also communicating with other robots. The other team project was "Something Dangerous!" Here the robots mapped a specific area, searched for hazardous materials and removed them from the area. Despite the small sample size, the study clearly demonstrated that innovative tools could increase the efficiency of education at higher, more advanced levels of programming in two ways. On the one hand, they can directly support the successful completion of concurrently taught subjects with similar content, and on the other hand, they can indirectly support the successful completion of subjects by deepening existing basic knowledge. It has also become clear that it is worth continuing the study, expanding the research sample and investigating the short- and long-term impact of positive student attitudes on professional development and career loyalty through follow-up.

5 Use of programmable teaching robots in research

My colleagues and a few of my students and I have used LEGO NXT and EV3 robots as simulation tools in numerous scientific articles. Only a few of these works are mentioned in the following section.

5.1 Food collecting simulations

In nature, many species of animals collect their food in groups and cooperate. We have created a simulation where the robots mimicked the foraging habits of African desert ants [28]. The "explorer" ants first explored the area and then, when they found food, marked the locations with "pheromones". Eventually, the workers collected the food they discovered. The simulation involved two types of robots, as there were two types of tasks. In the first task, the "discoverer" robot (called "master") walked into an artificial area and memorized the Cartesian coordinates of the randomly scattered food (green discs), the slave robots received the coordinates of the food via Bluetooth and brought it into the anthill using their suction cups. In one experiment, 4 robots worked, but by improving communication, we were able to increase the size of the robot swarm to 13.

5.2 Simulation of area exploration algorithms

In real life, robots often must explore an unknown area, or search for objects or humans and rescue them from the area, by communicating with each other and working together as a robot swarm. In one of our works, we presented an area exploration algorithm that we have developed, which works for robust systems with many robots [29]. The robots communicate via Bluetooth, they are organized into a chain in terms of communication, one end of the chain is fixed and the constraint during exploration is that the neighboring robots must not move out of each other's communication range. In this paper, we simply prove that our algorithm is optimal in unobstructed areas, i.e. it explores the largest possible area with the smallest possible time expenditure. We also present a test comparing our proposed method with two benchmark methods in areas with wall-like obstacles. In this paper, we not only tested our algorithm with a screen simulator but also implemented it on a real robot set consisting of Dual NXT robots.

5.3 Simulation of gathering algorithms

An intensively studied area of artificial intelligence is the study of gathering procedures for robot groups and robot swarms. Using direct communication, robots may gather around a predefined point or object, or in an unspecified region of real space, using some kind of radio system, light signals or other communication protocol. In systems using indirect communication, everyone in the robot swarm works as an autonomous entity, providing information to their peers only through its position and movements, and thus trying to gather in as small an area as possible. Many researchers have developed theoretical algorithms to solve these problems, but their work has mainly been tested on screen simulators. In our simulation [30], a swarm of NXT robots scattered in an arbitrary area had to gather without using global positioning devices but only using odometry. Each phase of the task was executed synchronously, i.e., each robot performed the subtasks simultaneously. All robots perform the same task they move towards the other robots in the swarm. During the execution of the task, the robots did not use any communication channel (Bluetooth, voice-based communication, light signals, etc.) and only extracted information from each other's position and movement. This is also known as indirect communication. This is well observed among animals living in groups, such as fish. Robots can see only a limited part of the space around them and use their distance sensors to measure their distance from other robots. The work of Ando [31], who created a point-based synchronous gathering algorithm for robots, is considered a fundamental method in this field, but in our work, we simulated the gathering algorithm with a real swarm of robots.

6 Summary

This article has summarized the long-term experience of John von Neumann University and its partner institutions with programmable mobile robots in education and research.

The examples presented show that mobile robots can be used effectively across several educational levels, from secondary school projects to university-level programming and computer science education.

The experience suggests that the most important educational contribution of physical robots may not necessarily be a direct increase in measured programming knowledge. Rather, robots can create an active, tangible, and collaborative learning environment that can positively influence students' attitudes towards programming, motivation, and programming self-concept.

At intermediate and advanced university levels, robots can also provide a practical framework for demonstrating algorithms, communication protocols, and artificial intelligence concepts.

Finally, the research examples demonstrate that low-cost programmable robots can serve not only as teaching tools but also as experimental platforms for investigating multi-robot communication, exploration, gathering, and swarm-intelligence algorithms.

Overall, programmable mobile robots can therefore be regarded as a common platform connecting programming education, project-based learning, artificial intelligence, and experimental robotics research.

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