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Wilfried Lepuschitz · Munir Merdan ·
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Robotics in Education

Methodologies and Technologies

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Preface

We are honoured to present the proceedings of the 11th International Conference on Robotics in Education (RiE), which was carried out as a purely virtual conference from September 30 to October 2, 2020. While originally planned to be held in Bratislava, Slovak Republic, during April 10–12, 2020, the conference was shifted to autumn 2020 due to the COVID-19 pandemic. The hope to carry it out as usual just at a later time did not come true, and therefore, RiE 2020 had to be turned into a purely virtual event. The International Conference on Robotics in Education is organized every year with the goal to provide the opportunity for the presentation of relevant novel research and development in a strongly multidisciplinary context in the educational robotics domain.

Educational robotics is an innovative way for increasing the attractiveness of science education and scientific careers in the view of young people. Robotics represents a multidisciplinary and highly innovative domain encompassing physics, mathematics, informatics and even industrial design as well as social sciences. As a multidisciplinary field, it promotes the development of systems thinking and problem solving. Due to various application areas, teamwork, creativity and entrepreneurial skills are required for the design, programming and innovative exploitation of robots and robotic services. The fascination for autonomous machines and the variety of fields and topics covered make robotics a powerful idea to engage with. Robotics confronts the learners with the areas of Science, Technology, Engineering, Arts and Mathematics (STEAM) through the design, creation and programming of tangible artifacts for creating personally meaningful objects and addressing real-world societal needs. Thus, young girls and boys can easily connect robots to their personal interests and share their ideas. As a consequence, it is regarded as very beneficial if engineering schools and university program studies include the teaching of both theoretical and practical knowledge on robotics. In this context, current curricula need to be improved and new didactic approaches for an innovative education need to be developed for improving the STEAM skills among young people. Moreover, an exploration of the multidisciplinary potential of robotics toward an innovative learning approach is required for fostering the pupils' and students' creativity leading to collaborative entrepreneurial, industrial and research careers.

In these proceedings, we present methodologies and technologies for teaching and learning in the field of educational robotics. The book offers insights into the latest research, developments and results regarding curricula, activities and their evaluation. Moreover, the book introduces interesting programming approaches as well as new applications, technologies, systems and components for educational robotics. The presented applications cover the whole educative range, from elementary school to high school, college, university and beyond, for continuing education and possibly outreach and workforce development. In total, 51 papers were submitted and 33 papers are now part of these proceedings after a careful peer review process. We would like to express our thanks to all authors who submitted papers to RiE 2020, and our congratulations to those whose papers were accepted.

This publication would not have been possible without the support of the RiE International Program Committee and the Conference Co-Chairs. All of them deserve many thanks for having helped to attain the goal of providing a balanced event with a high level of scientific exchange and a pleasant environment. We acknowledge the use of the EasyChair conference system for the paper submission and review process. We would also like to thank Dr. Thomas Ditzinger and Mr. Arumugam Deivasigamani from Springer for providing continuous assistance and advice whenever needed.

November 2020

Wilfried Lepuschitz
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Promoting STEM Education in Schools Using an Adaptive Learning Scenario

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Abstract. This paper describes the workshop concept Robotikum which was designed as an adaptive learning scenario at the Philipps-University Marburg (Germany). The workshop uses humanoid robots (model: NAO) to develop the computational thinking of students (middle and high school level) with no prior programing knowledge. In this specifically developed workshop concept, robots are used as teaching tools, including appropriate applications and teaching scenarios. The genesis of the Robotikum will be described as well as the structural design and experience from several implementation instances. Furthermore, future developments will be outlined such as an adaption for teachers' education as well as an expansion of the concept. The Robotikum is part of a research project called RoboPraX which is financed by the German federal ministry of education and research (BMBF). Students' responses to the new teaching tool Robotikum are evaluated through observation and qualitative questionnaires as well as competency tests and interviews of educational stakeholders. The overall objective of the project is to develop guidelines for educational institutions to enable them to use the developments in digitization and robotics to further their educational goals.

Keywords: Educational robotics · Social robots · Digitization · STEM education · Adaptive learning · MOOCs · Block programing · NAO robots · Project-based learning · Inverted classroom

1 Beginnings of the "Robotikum"

The Robotikum was first developed as a one week pilot-workshop for a middle school group of students in fall 2017 to introduce them to programing, using humanoid robots as teaching tools. The positive evaluation of this first implementation led to a partnership with the city of Marburg. Shortly after this pilot, the concept of the Robotikum-workshop could be established as a regular offering for all middle and high schools in Marburg (Table 1). The city finances the workshop instructors and the local financial institution *Sparkasse Marburg-Biedenkopf* sponsors two NAO-robots as well as printing costs of the teaching material. Two further robots are provided by the research group at the Philipps-University Marburg. The development of the teaching material and concept are also part of the responsibilities of the Robotikum-Team at the university. The Robotikum is hosted at a local school in Marburg (Adolf-Reichwein-Schule) which provides two

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rooms (incl. WiFi) for the workshop. Additionally, the Media Center of the city supports the Robotikum with 12 laptops on permanent loan.

Table 1. Workshops in 2018/19 incl. number of workshops, participants and grades.

Year	Robotika	Participants	Grade	Comments
2018	8	161	9^{th}–12^{th}	
2019[a]	14 (incl. 5 pilots)	160	2^{nd}–11^{th}	Pilots: Girls' Day, Students' congress, Media Camp, RoboTeach

[a]The group size for each Robotikum was reduced in 2019 from 25 to 18 students (more individual support possible and more individual time with a robot for each team).

After a pilot-phase of around 1½ years, the team could acquire funding from the German federal ministry of education and research (BMBF) for a three-year research project called RoboPraX. The overall objective of the project is to develop guidelines for educational institutions to enable them to use the developments in digitalization and robotics to further their educational goals. Furthermore, a central goal is the promotion of STEM-education and of females in STEM-fields. To this end, the workshop aims at developing computational thinking alongside soft skills such as team work, collaborative and project-based learning.

2 The Workshop-Concept

The project follows an inverted classroom model of teaching. The in-class phase of the Robotikum is preceded by an online preliminary course in MOOC format (Massive Open Online Course). This model allows more practical training time on the robots for the students. During the learning process, the robot takes on the dual role of a learning tool and a learning objective. The use of robots in this dual form attributes a playful component to the learning process, since robots used in this way often have a 'toy character' [1, 2]. This is further supported by the project-based approach and a trial and error procedure during the workshop ('learning-by-doing').

Throughout the in-class phase students will program several applications for the robot making use of different concepts while using a visual software environment for easier understanding. Applications range from basic dialogs and movements to more complex object or face recognition. All apps are carried out by the robot in the real world for example having a dialog between the robot and the participant instead of just rendering a program on a screen.

Consequently, the approach to STEM-subjects in the Robotikum can be described as a form of edutainment supported by the novelty of the teaching and learning tools used, i.e. robots. Students are introduced to this new technology, using a computer and a visual programing software to program the robots. Mathematics is required to calculate the distances that the robot is supposed to walk or to create other more complex movements. Understanding the robot's motors and its degrees of freedom touches the fields of physics and engineering.

Furthermore, social learning, which is inherent to humans as social beings, can be identified as an additional supporting factor. Even though robots are no ‘real’ social partners in this workshop concept, they still play a similar role in the learning and work process in the human-machine interaction. During the pilot phase of the Robotikum, it could regularly be observed that the participants developed social bonds towards the robots. Technical disturbances were equated with human behavior[1] and terms of endearment[2] were used, analogous to human relationships. The reason for this behavior can be found in the human tendency towards anthropomorphism, the machine-programmed ‘behavior’ of robots is judged and evaluated under human behavioral norms [3–6]. Participants build a relationship with the robots within a short period of time, which can then be used to support a positive learning outcome.

In the following subsections the preliminary MOOC RoboBase and the workshop concept Robotikum are described in more detail.

2.1 The Robotikum

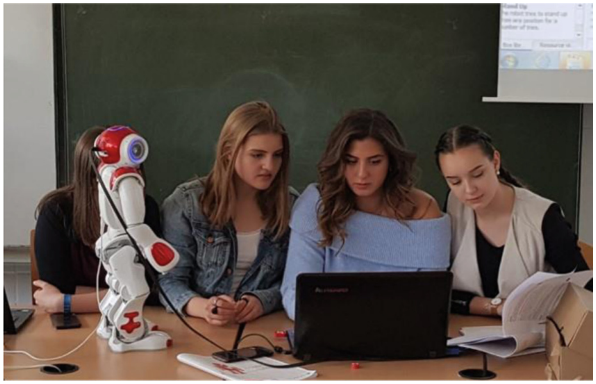

Fig. 1. One of the NAO-Robots used in the Robotikum.

The Robotikum is a three-day workshop, where students and teachers are given the opportunity to gain practical experience in the field of artificial intelligence (AI) with humanoid robots of the type NAO (Fig. 1). During the Robotikum, the participants learn how to control the robots using block-based programing with the visual code editor Choregraphe. Working in small groups, they focus on dialogues, movements, image recognition and embodiment of emotions. They develop applications for the robots, which they can immediately test on the available NAO-models. The structure of the workshop leaves plenty of room for the participants’ creativity while also guiding them through their learning process. This creates a safe space for experiments and exploration of the abilities and limits of humanoid robots.

Through project-based learning, students also strengthen their ability to work collaboratively in small groups. Other soft skills that are trained in the Robotikum include communication skills (in team and collaborative work), teamwork (through group work) and presentation skills (through a class demonstration of their final projects at the end of the workshop). The presentation of students’ final projects makes their work within the

[1] Examples: ‘The robot is in no mood today.’, ‘He’s not feeling well.’, ‘He’s tired’, etc.

[2] Examples: ‘Come to mommy, baby.’ ‘My son.’, etc.

Robotikum visible and tangible to an audience. This external validation of their learning outcomes supports their self-efficacy. Pride in their work, the end product of their work process and learning activity as well as the learning content can be developed, with positive effects on attitudes towards the STEM-field [7].

Furthermore, the participants of the workshop learn inherent programing logic (computational thinking, loops, conditions etc.) as well as necessary programing habits (e.g. computational structuring, variable naming, frequent sources of errors in coding), contributing to the promotion of STEM education. In addition, the students are trained in handling both the laptops (including folder structures, naming logic of files, shortcuts etc.) and the robots (e.g. dialog structure, technical properties, degrees of freedom, common errors in robot programming, troubleshooting, etc.) used within the workshop. By designing their own verbal and non-verbal interactions, they gain insights into human-robot interaction. This also raises questions of a moral/ethical and social nature, which can be discussed and debated in this context on a theoretical-abstract as well as on a very concrete-practical level.

The Robotikum thus takes on the topics of artificial intelligence and future working environments with a very practical approach. The project-based work on humanoid robots, offers students firsthand experience of the opportunities and challenges of this technology. They make their first initial steps in the field of programing which may aid in reducing fears and prejudices concerning the field of STEM education. The active approach enables students to test the potential of this new technology, while at the same time uncovering media-supported myths (demystification) by showing the limitations of the technology throughout the workshop. In addition to the practical experience that students gain, a balanced picture and a deeper understanding of the digital working environment of the future are created.

2.2 Development of the MOOC "RoboBase"

RoboBase is a free-of-charge MOOC in German and English, which is offered on the German e-learning platform 'oncampus' (Fig. 2). It serves as a preparation for the participants of the Robotikum, but can also be used by anyone who wants to learn more about humanoid robots and immerse themselves in the programing of NAO. This self-directed content delivery covers the basic information on humanoid robots and the basics of working with NAO. The course thus provides the foundation for NAO programing, leading to a more project-based approach and a 'trial and error' concept during the workshop.

RoboBase consists of videos, graphics and textual elements on the following topics: humanoid robots and their abilities, the visual code editor Choregraphe, example applications and further information on programing, technical details and copyright issues. Quality-assured and topic-relevant material (online or offline) is included in the course, giving the respective credit or using open educational resources (OER). Non self-produced material has to adhere to specific standards (e.g. appropriate content, credible source, high didactic quality of content presentation etc.), are quality assured by the team and are periodically checked for availability. In cases where no suitable OER could be found, own material was produced. Through a system of badges, which can be earned for each chapter, an element of gamification is added encouraging participants to further their studies.

Fig. 2. The MOOC RoboBase hosted on oncampus.de.

The course is divided into five chapters and leads the participants from definitions of humanoid robots to examples of how to program simple applications for the NAO robot model. Below is a brief summary of the five chapters of the RoboBase MOOC:

- 1st Chapter: What are Humanoid Robots?

In addition to a definition and differentiation of various forms of 'humanoid robots', the 'Uncanny Valley' phenomenon [8] is discussed and several (mainly) humanoid, robots are presented. The last section of this chapter focuses on how humanoid robots are already used in different fields of application such as education, finance or the service sector and elderly care.

- 2nd Chapter: Capabilities of humanoid robots

This chapter is dedicated to the capabilities of humanoid robots. As it is impossible to discuss all capabilities in an introductory MOOC, the main focus is on the following ones: speech and conversations, emotions, movement, perception and haptics. Each of these features is explained with a general description as textual input, an external video exemplifying a prototypical humanoid robot for the respective feature, followed by a closer examination of the robot type NAO. Finally, the hardware of the NAO robot is presented with a chart and further textual information.

- 3rd Chapter: Introduction to Choregraphe

The visual code editor Choregraphe used for programing the NAO robots is introduced in this chapter. The focus lies on the structure and functions of the software, in preparation of the in-class session. This chapter discusses the basic features of the software: introducing this specific type of software, its usages and fields of application. Furthermore, the menu and toolbar are described, the use of the virtual robot for testing is introduced as well as block-based programming (incl. how blocks work, how they are combined and connected). In Choregraphe, the building blocks for programing are referred to as boxes.

- 4th Chapter: Example applications

In the fourth chapter three exemplary applications for the NAO robot are explained. In each case, students are walked through the creation and programing process step-by-step. Students can simultaneously program the same application on their computer using the Choregraphe software and the virtual robot. The three applications are: Make NAO speak, Make NAO switch the language, Make NAO converse.

- 5th chapter: Further Information

Under 'Further Information', course participants can find information on block-based and direct programing as well as technical details on robots. In addition, this section of the course addresses social challenges. The last section provides useful links to information on programing, copyright, and more.

The MOOC will be offered in two versions at three levels of difficulty each. The two versions cover the two different production lines of NAO robots (V5 and V6). The different levels of difficulty are a result of the segmentation of the target groups for this MOOC namely secondary school without senior classes, senior classes of secondary school, and university students.

This is the first step towards adaptive learning. Each target group receives teaching material suited for their skill level and age. In the future, those MOOCs might be segmented further to reach a higher degree of personalization and adaptive learning.

As of August 2020, three MOOCs are available: the lowest and the medium level of difficulty for the V5 version (in German) and the highest level of difficulty for university purposes for the V6 version (in English). In fall 2020, it is planned to make the lowest and the medium level of difficulty for the V6 version available.

At the beginning of the Robotikum workshop, the dissemination of the contents of RoboBase is checked by means of two formative assessment forms. On the one hand, live voting applications such as Pingo (http://pingo.upb.de) are used in combination with the mobile devices of the participants or the provided laptops. On the other hand, small tasks (e.g. the implementation of dialogues or motion sequences on the humanoid NAO robot) are worked on. This way, the application skills of students can be tested in order to provide participants with individual support in line with their level of knowledge. The results can be used to address possible residual difficulties after studying the MOOC or from previous in-class phases in a group-specific manner and to design further exercise units according to the needs of the participants.

3 Teaching and Learning Material

During the pilot phase of the workshop, a provisional workbook, consisting of information with interactive parts in form of exercises, was used. Beginning fall 2019, a revised textbook and a workbook based on a new teaching approach were developed. This new concept separates content delivery on how to program the robot with block-based programing (textbook) from the exercises (workbook) for the practice sessions. This material was adapted in 2020 to cover the NAO model V6.

3.1 Textbook

With the help of the textbook, including in-depth explanations, simple application examples and many visualizations, teaching content can be repeated and deepened after in-class sessions or checked during the workshop. The textbook is available both in printed form and digitally as an e-book with links to further external sources. This textbook explains in German language how to use the software Choregraphe and contains specific explanations/ descriptions on how to program NAO. This content is also covered by the workshop leaders during the in-class sessions. It describes in detail how to build dialogs, create animations, transfer data between boxes, etc. The information is based on the online documentation for programing NAO and the programing experience of the team - slightly modified and didactically reduced to cover the pertinent information for the Robotikum. The material is translated into German as the workshop aims at students from grade 5th onwards, from whom only a certain level of proficiency of the English language can be expected. For more advanced students (in programing as well as English), who want to dive deeper into programing NAO, the textbook is linked for further information with the online documentation via hyperlinks.

3.2 Workbook

In addition to the textbook there are also workbooks with exercises available. Similar to the MOOC, three levels of difficulty (beginners, advanced, experts) as well as respective exercises for the NAO versions V5 and V6 were developed. These workbooks have already been differentiated into the particular levels according to the project objective of implementing an adaptive teaching and learning approach for the NAO-model V5.

However, these levels do not necessarily go along with the ones of the MOOCs. In practice this may mean a student that took the expert version of the MOOC but struggles with the most complex exercise book will receive individual support by the workshop leader as well as the intermediate level of the exercise book to fit their needs (adaptive learning). This might also be only temporary until the student gained enough expertise and practice to return to the expert level.

In order to receive comparable learning results, the exercises are not completely changed but rather consist of different combinations of the following components: task description, execution guide and required boxes (blocks). The expert level only presents a short description of what the robot is supposed to do. This allows a certain degree of lee way and creativity for more advanced students. In the intermediate level students additionally receive some hints and a list of boxes to use. In these boxes the parameters still need to be set and the boxes have to be connected correctly. For beginners, next to the short description and a list of the required boxes, a step-by-step guide of how to implement the program is presented. This level is mainly used for younger and more insecure students at the beginning of the workshop. Through the adaptive learning approach, the exercise book can easily be exchanged for a more advanced version when the workshop leader realizes the student no longer requires the additional supporting instructions to solve the exercises.

4 Evaluation Concept and First Observations

The evaluation concept of RoboPraX (Fig. 3) is based on explorative research. It mainly follows a qualitative approach, collecting and analyzing mostly non-numerical data to gather in-depth insights concerning our stakeholders' (students, teachers, administration, etc.) opinions and experiences. The approach is situated in action [9] and intervention research [10], which is why no laboratory or test settings are examined, but rather practical implementations in the real-life everyday business of schools. The surveys are conducted cyclically, which is partly due to the nature of the workshop, but also has its roots in a research design based on Grounded Theory [11]. The empirical, incremental and iterative process can be compared with agile processes from project management, such as SCRUM with its sprints [12, 13].

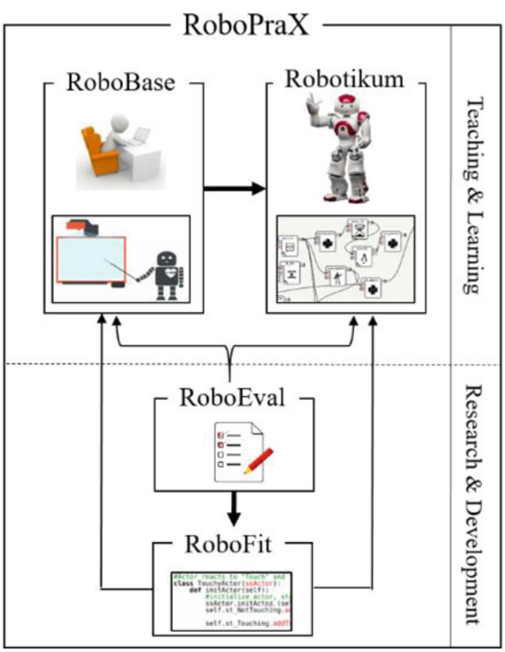

Fig. 3. Research Scheme of the Project RoboPraX.

On the one hand, the different surveys serve as a means of quality assurance in the evaluation phase (RoboEval). On the other hand, competence tests and acceptance studies are also carried out. Furthermore, interviews with all stakeholders of the educational system are planned in order to adapt the workshop concept to the needs of the schools. The surveys among the school students will take place in three different phases:

- Phase I (before MOOC): Establishment of a baseline, including an acceptance test and a comparative competence task (Part I)
- Phase II (after MOOC/at the beginning of the Robotikum): Evaluation of the MOOC and its effectiveness through competence, knowledge and acceptance tests

- Phase III (at the end of the workshop): Evaluation of the workshop and its effectiveness - comparative competence task (part II) (including evaluation of the final projects) and a final acceptance test

This user-centered approach is complemented by participatory observations carried out by the research team. The workshop leaders are included in the observations and complement the picture with written self-reflections. The level of education management and administration of the education sector is covered through interviews with all relevant stakeholders in order to get a comprehensive overview of the status quo and to identify structural factors that may support or hinder the implementation and transferability of the concept.

4.1 The Pilots

Since the official start of the RoboPraX research project in March 2019, not only has work been done on the inversion of the teaching model, the materials and research design, but also several pilot formats with differing age groups have been carried out. In the following four pilots are briefly described:

After-School Care (7–10 years old)
The Robotikum content was reduced to a very limited 4-h workshop appropriate for the after-school care group (9 students at the end of the school year, 2nd to 4th grade) and carried out as part of the after-school summer holiday program 2019. To make the concept implementable, a special supervision effort (one supervisor per group) was necessary. The tasks were designed in such a way that they also included a haptic component via the interactive smart board, which led to the children jointly solving the tasks in the plenary session. In addition, regular breaks as well as free time for recreation were scheduled, in order to meet the needs of the target group. Under the conditions described, this pilot proved to be a great success. According to the anecdotal feedback from the day care center management, the children still spoke enthusiastically about their experiences in the Robotikum months after the workshop.

Girls' Day (10–13 years old)
As part of the project objective of promoting girls in the STEM-field, a Robotikum with a girls-only group for Girls' Day[3] 2019 was offered. The group of the one-day workshop (14 girls) showed a relative heterogeneity in terms of age, personal motivation and school affiliation. In their self-reflection on the workshop, the workshop leaders specified that the statements of the participants would confirm the assumed inhibition thresholds for girls to get involved in the STEM-field (e.g. male-dominated field; deterred by technology etc.). These observations and statements reinforce the need to further implement special offers within STEM education for girls as specified in the research project RoboPraX.

[3] Girls' Future Day - Nationwide vocational orientation day for girls from 5th grade onwards.

Media Camp Marburg (11–16-years old)
The Robotikum was incorporated into the Media Camp 2019 with a one-day workshop. This camp is an annual one week holiday offer organized by the Media Center and the youth education center in Marburg for younger students who want to get to know technology. The participating group (8 students) confronted the team of the Robotikum with the greatest heterogeneity (age, schools etc.) yet. The fact that the group already had time to grow together during the previous parts of the Media Camp had a positive effect. Thus, a certain familiarity prevailed; in addition, the students mainly worked in relatively homogeneous age groups and in a self-chosen gender separation. This phenomenon could already be observed in the regular Robotikum and will be the focus of future observations. In this all-day workshop, the participants worked on both dialogues and movements. The one-day Robotikum concept was positively evaluated by all participants without exception (both in the final evaluation in the group discussion/ feedback round and in an anonymous voting). A continuation of this cooperation is planned for fall 2020.

RoboTeach (university students: 21–23 years old)
Since winter term 2019, teaching degree students at the Philipps-University Marburg have the opportunity to take the course RoboTeach to cover the requirements of the module "New Media in Foreign Language Teaching". RoboTeach consists of the above-mentioned online preliminary course RoboBase and the practical workshop Robotikum as a block course. Students must have acquired all badges of the MOOC RoboBase before the start of the Robotikum. Afterwards, the Robotikum takes place in four 4-h in-class meetings scheduled in a 1–2 weeks-rhythm. The course ends with the presentation of individual final projects. The students have to develop teaching-related applications based on their respective subject perspectives and implement them on the robot within 6 weeks.

In addition to the described intended learning outcomes of the Robotikum for school children, RoboTeach also contains general aspects of digitization (data organization, data security, licensing models, media technology, multimedia, artificial intelligence), which can be experienced not only theoretically but also practically thanks to the robots used. Furthermore, the technical skills of robot programing are supplemented by a special focus on the didactics, pedagogy and educational schemes including robotics to promote STEM-education and computational thinking at schools. University students reflect on the teaching concept of the Robotikum as well as on the topics of digitization in education and robotics (also from a societal and ethical perspective).

4.2 First Observations

First comparative studies to test the students' computational and structural thinking before and after the workshop were carried out during the pilot and initial phase of the project. In both executions, students briefly had to explain how to carry out a specific action. The two actions to be explained are:

- You are standing in front of a closed door and want to get to the other side of the door. What to do? Describe your action as briefly and precisely as possible.

- You sit at a table with a full glass of water on it. You want to drink it up. What to do? Describe your action as briefly and precisely as possible.

The hypothesis was that students explain the actions in more details and more precisely after they worked with a robot for several days because robots need very precise and clear commands compared to humans. Even though a comparative analysis of students respective answer sets did not always show a dramatic improvement of computational and structural thinking, in many cases changes were visible. The nature of changes will be described in the following:

- more detailed (step-by-step) description of necessary action in second study
  - E.g.: turn door handle, push door forward, pass through vs. *reach hand out*, *grab cup*, move to mouth, tip cup towards mouth, put cup down
- more precise terminology used such as degrees for movement to locations or specification of status and conditions
  - E.g..: I raise my right hand and put it on the doorknob vs. I raise my *right open hand* and lead it to the glass *on the right side*
  - E.g.: Extend hand, grasp door handle, push down door handle, pull with hand, release vs. Move hand towards the glass, grasp glass, bring glass to mouth, tilt glass *45° towards mouth*, *swallow*
- Description of common subsequent action
  - E.g.: I pull or push the door open vs. I empty the glass *and do the same process backwards to put the glass back in place.*

Possible reasons for the fluctuating competencies gain might be found in the sociodemographic data where different educational levels as well as language difficulties due to the educational background and/or immigration background were identified. Additionally, there were interpretation mistakes as some students interpreted closed as locked.

5 Conclusion and Outlook

The second version of the MOOC RoboBase was developed in fall 2019, with an adapted level of difficulty, so that the MOOC is now available in a version for middle and high school students (Versions for NAO V5). For this purpose target group specific content and language adjustments were made. This differentiation of the MOOC as well as the supporting teaching materials (textbook & workbooks) will be intensified in the future. First of all, however, the existing materials have to go through the iterative evaluation and quality assurance process, as does the whole workshop concept.

As next steps, courses are planned to cover the different versions of the NAO robot (V5 and V6), as they have different programing requirements. Furthermore, a design of the MOOC and all other teaching materials in English will be finished in August 2020. Additionally, a specific MOOC for the RoboTeach and university use is in development and will be used in winter term 2020 at the Philipps-University Marburg.

The research team is working on adapting the workshop formats to the initial ideas of the participating schools (e.g. one-day workshop, shorter weekly dates in the afternoon program of all-day schools etc.) and on extending the concept to younger target groups (primary school children - 3rd and 4th grade). This also requires an adequate, needs-oriented design of the teaching materials.

The project currently works on content and structural concepts concerning the curricular implementation of humanoid robots into school subjects (MicroProjects). The wish was also expressed to offer a first RoboTeach for fully trained active teachers. The design process for this new format is in progress (first planning stage). And finally, it should be mentioned that an expansion of the Robotikum, which is currently only available in Marburg, is already being worked on in two neighboring districts. The district Marburg-Biedenkopf is the first of them to start with two new Robotikum-schools (Georg-Büchner-Schule, Stadtallendorf and Lahntalschule, Biedenkopf) in September 2020.

References

1. Zeaiter, S.: Roboter trifft Menschen mit Behinderung: Robotereinsatz zur Lehr-Lernunterstützung für Lerner mit Behinderung. In: Zeaiter, S., Handke, J. (eds.) Inverted Classroom – The Next Stage, pp. 105–113. Tectum Wissenschaftsverlag, Marburg (2017)
2. Standen, P.J., Brown, D.J., Hedgecock, J., Roscoe, J., Galvez Trigo, M.J., Elgajiji, E.: Adapting a humanoid robot for use with children with profound and multiple disabilities. In: Proceedings of the 10th International Conference on Disability, Virtual Reality and Associated Technologies (ICDVRAT 2014), pp. 205–211. The University of Reading: Reading, UK (2014)
3. Fong, T., Nourbakhsh, I., Dautenhahn, K.: A survey of socially interactive robots. Robotics Autonomous Syst. **42**, 143–166 (2003)
4. Greczek, J., Short, E., Clabaugh, C.E., Swift-Spong, K., Matarić, M.: Socially assistive robotics for personalized education for children. Artificial Intelligence for Human-Robot Interaction: Papers from the 2014 AAAI Fall Symposium, pp. 78–80 (2014)
5. Cooper, M., Keating, D., Harwin, W., Dautenhahn, K.: Robots in the classroom - tools for accessible education. In: Assistive Technology on the Threshold of the New Millennium, Assistive Technology Research Series, 6, pp. 448–452. IOS Press, Düsseldorf (1999)
6. de Graaf, M.M.A., Allouch, S.B., van Dijk, J.A.G.M.: Long-term acceptance of social robots in domestic environments: insights from a user's perspective. In: AAAI Spring Symposium Series, pp. 96–103 (2016)
7. Zeaiter, S.: Projektorientiertes Lernen mit studentisch produzierten Trailern. In: Großkurth, E.-M., Handke, J. (eds.) Inverted Classroom and Beyond, pp. 143–161. Tectum Wissenschaftsverlag, Marburg (2016)
8. Mori, M.: The Uncanny Valley [From the Field]. IEEE Robot. Autom. Mag. **19**(2), 98–100 (2012)
9. Von Rosenstiel, L., Hockel, C., Molt, W.: Handbuch der angewandten Psychologie. Landsberg, Ecomed (1994)
10. Krainer, L., Lerchster, R.E.: Paradigmen, Methoden, Reflexionen. Springer VS, Wiesbaden (2012)

11. Glaser, B.G., Strauss, A.L.: The Discovery of Grounded Theory – Strategies for Qualitative Research. New Brunswick & London, AldineTransaction (1967)
12. Agile Atlas. https://improuv.com/sites/default/files/publikation/AgileAtlas-DE.pdf. Accessed 21 Dec 2019
13. Scrum Alliance. https://www.scrumalliance.org/ScrumRedesignDEVSite/media/ScrumAllianceMedia/Files%20and%20PDFs/State%20of%20Scrum/2013-State-of-Scrum-Report_062713_final.pdf. Accessed 20 Dec 2019

ROSSINI: RobOt kidS deSIgn thiNkIng

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Abstract. ROSSINI is a DiY educational robotics project launched in Tyrol in 2017. ROSSINI aims at providing a platform for children and youngsters to gain their first experiences with robotics and related technologies, viz., mechanical and electrical, as well as software engineering, embedded in the context of both design thinking and upcycling.

Keywords: Educational robotics · Design thinking · Do it yourself

1 Introduction

In an effort to address industry's growing need for qualified personnel in STEM-related professions, recent years showed an emerging trend of, broadly speaking, educational *digitalization* workshops and tools. After hosting the RoboCup Junior Austrian Open in 2016 we saw that there were not many such workshops in Tyrol. Most of the educational robotics initiatives took place in eastern and southern Austria; only some Lego Mindstorm robotics courses were offered in Innsbruck. Seeing the need to bring educational robotics not only to schools but also to children directly, we launched ROSSINI in 2017.

Before starting the ROSSINI initiative, we surveyed other existing initiatives and robotic kits (e.g. [6,7,9]), attended a workshop on educational robotics[1] organized by the Austrian Computer Society (OCG), and talked to several teachers and coaches at the RoboCup Junior Austrian Open to obtain a broad overview on different educational robotics initiatives in and around Austria. Having these initiatives in mind we decided that ROSSINI participants, apart from getting in touch with robotics, should not only improve the skills of 4C (collaboration, communication, critical thinking, and creativity) but also learn problem-solving strategies, and additionally the course/workshop should raise

[1] OCG Educational Robotics (ER) work group: https://www.ocg.at/de/educational-robotics.

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their curiosity. The ROSSINI initiative targets children aged seven to twelve and, importantly, also children whose parents cannot afford expensive robotic kits.

All the workshops are built around five core concepts (see Sect. 2) to bring robotics to children, enhance their collaboration, communication as well as their problem-solving skills, and children experience all or part of them depending on the workshop duration:

– Design Thinking
– Computational Thinking
– Upcycling and Waste management
– Free Software and Open Hardware
– DiY Rapid Prototyping

Finally, to give the children the ability to pursue by themselves their exploration of robotics and technology, we aimed at making both the workshop and its material easily accessible. Whereas many educational platforms exist and are used at various educational levels ([11]; among which e-puck [9], Thymio [6,12], Lego Mindstorms [1], etc.), their price is usually too expensive for modest families. We thus focused on a custom platform that possesses most of the necessary sensors and actuators to express interesting behaviors but can nevertheless be provided to families at a low cost (see Fig. 2). For ROSSINI workshops, the robot value amounts to 30 EUR and for ROSSINA to 65 EUR, whereas other available platforms start around 100 EUR (excluding any workshop registration cost). We also made the workshop fee affordable for a wide range of families: registering for one workshop day cost 5 EUR. At the end of a workshop, the families could choose to buy the platform built by their children. Whether or not they keep the robot, the material to build them is available online (see Sect. 3).

2 Five Pillars of ROSSINI

To implement the self-imposed goals for this workshops (enhance collaboration, communication, critical thinking, creativity and problem-solving skills of participants) while maintaining an environment-friendly course we decided to create the workshop on these 5 pillars:

Design Thinking

Design thinking is generally defined as an analytic and creative process that engages a person in opportunities to experiment, create and prototype models, gather feedback, and redesign. Design Thinking is used because it encourages innovative thinking and finding creative problem solving strategies. It also results in experiences that are effective and informative for learners [10].

Computational Thinking

Computational Thinking guides youngsters to express real-world problems in computational terms. This includes the concepts of loops, updating sensor measurements, and how to compute suitable output values for either a decision process or a controllable device on microcontrollers. To avoid confusion and overexertion it is important to impart this way of thinking in a fashion that makes it easily accessible and suitable for children. The goal is to keep the design as simple as possible for the desired task to learn.

Upcycling and Waste Management

Just like recycling, upcycling is a way of reusing waste. In a particularly creative way, worthless material is transformed into something new and valuable. Important issues for our workshops about upcycling and recycling are that it is relatively easy to do, it reduces waste, and children learn how to make great new things for their robots. It also enables creativity in finding solutions for their prototyping.

Free Software and Open Hardware

There are many good and important arguments for using Free Software (exclusively). We conjecture that schools have a social mission to promote this strongly; unfortunately this is very much neglected in Austria's educational institutions and (for various reasons) strongly neglected in Austria's school system (see e.g. [4, p. 4]). We made this one of the pillars of ROSSINI, most importantly for the following reasons:

Cooperation: By using free software, children learn to share and cooperate.

Independence: The possibility and freedom to create and try things motivates children to learn more (e.g. programming)

Easy to manage: Free software is stable, secure and reliable. It offers unlimited access to the source code – the software can therefore be adapted to the individual needs and, even more importantly, it also allows you to see how it works.

Flexible: Free licensing of software means that the programs can be adapted and modified.

Sources of supply: Due to the license terms of Free Software it is possible for any person or institution to offer a software on the one hand and to download and use it on the other hand.

With free software we can give copies to all participants without having to worry about legal security – because the license does not pose any danger of illegal use. We are convinced that with ROSSINI we are also giving children and young people a start towards more frequent use of Free Software.

DiY Rapid Prototyping

Teaching the workshops in a fablab has several advantages. We can directly use different prototyping technologies such as 3D printers, laser and vinyl cutters, and many different tools are at hand. Not only is it easy to prototype and construct physical objects at the fablab; we can speedily create them with many types of materials. Using block-type programming for microcontrollers we can easily demonstrate different concepts and speed up the prototyping process. Therefore the whole prototyping process can be done in a fun, do-it-yourself way.

3 Workshops

Two types of workshops were designed:

ROSSINI long workshop,
ROSSINA short workshop

They are organized such that there is a supervision rate of one teaching person per two to three groups, each group including no more than two members. As pointed out by Magnenat et al. [8], this low student-per-teacher ratio allows for higher-quality supervision than at school. Whereas ROSSINI workshops cover the five pillars described above, the ROSSINA workshop focus on a subset of them for shorter events (e.g. Girlsdays, Youth University courses). As we set *Free software and Open Hardware* as a pillar of the ROSSINI initiative, technical details, including design, software, hardware and wiring of the robots are publicly available online[2].

3.1 ROSSINI

The full ROSSINI workshop is a three (half)-day course. During this extended period of time, children experience the "design thinking" way of addressing a complex problem, namely building a functional robot. Children are assisted by experts during the process, and the activities range from attending a presentation to solving technical problems and then sharing their solutions. The focus of the workshops is not on technical problems that occur when building a robot – we rather show how to learn problem solving efficiently in a team. A typical workshop schedule is briefly described below (Fig. 1):

Understand & Observe: The children receive a short introduction to the history and fields of robotics.

Define: After groups of two children have been formed, they receive a work assignment: What should our robot look like? What should it be able to do? This is discussed and debated in the teams. Usually, enthusiasm in the groups quickly leads to a productive working atmosphere. The children exchange and discuss their ideas.

[2] https://git.uibk.ac.at/informatik/rossini/resources.

Fig. 1. ROSSINI workshop at the fablab facilities.

Ideas are found: Teams work collaboratively. In each group the children summarize their ideas and draw their robots and team logos. Additionally, children are encouraged to find their perfect team names. This leads to co-identifying as a team and with the robot.

Sharing: The teams show their work to each other.

Developing a prototype (hardware): Experts present a short introduction to electronics and soldering.
With wood scraps, cardboard and scrap materials (upcycling), a robot base platform is built. The children fetch materials, cut, glue, think about it, talk it over. This leads to different divisions of work within the teams.

Developing a prototype (software): After a small lecture and introduction to block-type programming small tasks are set and solved together. The children find out how to connect and program their sensors and actuators for their robots correctly.

Developing a prototype: The children improve and fix all electronic and mechanical parts where some parts might be 3D printed or laser-cut. The team logos are engraved onto a part of the robot. The children finalize the software of their robot.

Outcome: The outcome of the workshop is a working robot. Now it is time to present the achievement; additional time is given for feedback and reflection.

3.2 ROSSINA

ROSSINA workshops are 2 to 4 h long. Due to the limited amount of time for these sessions, the children use pre-built, 2-wheeled robots and focus on the software part on the embedded BBC Micro:Bit (see Fig. 2). They are given an introduction to robotics (Understand & Observe), and then have to program the robot to solve a set of tasks (Developing a prototype). They then compare their solution between teams (Sharing, Outcome).

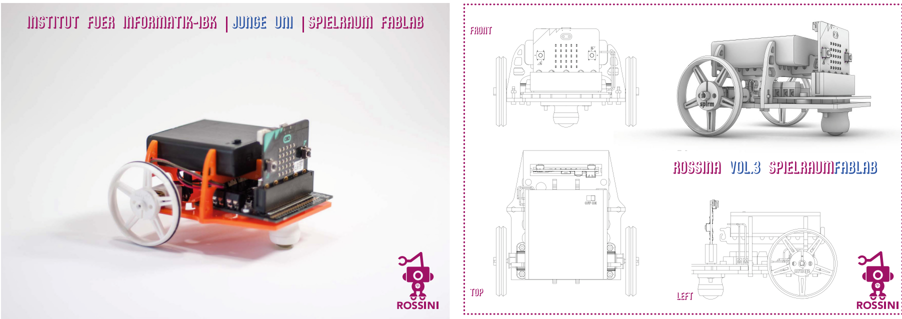

Fig. 2. ROSSINA robot build at the fablab, designed for workshops of up to 4 h.

4 Evaluation

Three ROSSINI and two robotics courses within the Youth University were evaluated in 2018. In those one- to three-day courses 48 children participated, and at the end of each course these participants filled out a questionnaire. The questionnaire was developed at the Youth University in collaboration with two sociology students for their master thesis [3]. It has been in use since 2007 and is adapted slightly to the current requirements every year. The questionnaire contains quantitative and qualitative questions and was thoroughly tested and re-evaluated in 2015. It however does not include workshop-specific questions. All other children university summer activities around Innsbruck were evaluated as well and were examined the same way. From those courses all 360 questionnaires were processed.

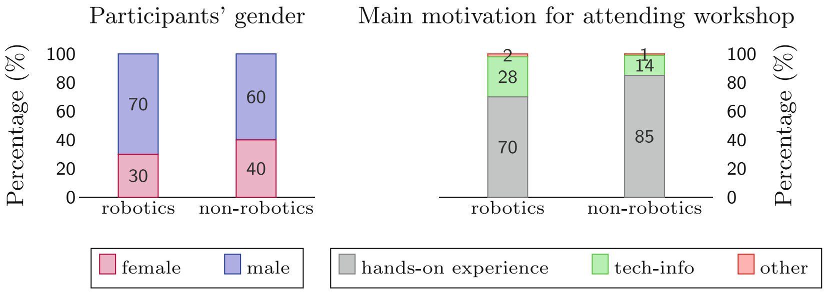

Fig. 3. Left: Participants in robotics (48 children) and non-robotics (360 children) workshops in percent. Right: Main motivation for attending a workshop.

The activities of ROSSINI represent about 14% of the children's university workshops for this period. Roughly 70% of the attending children were boys and only 30% were girls. This percentage is nevertheless higher than the about 20%

that were reported in computer science studies in 2014 in the USA [13]; however, male participants are still more represented than female for non-robotic activities (see Fig. 3, left).

The children were asked to evaluate the following points: (a) What kind of jobs are the parents working in? (b) What was their motivation to enroll for the robotics course or another course from the Youth University summer program 2018 in their free time? (c) What job were the children willing to do in the future? The answers were classified into academic/tech jobs and jobs in other fields using the international job classification ISCO-08 [5] and the national occupational classification system BIS [2]. Examples of academic/tech jobs as defined in the ISCO-08 standard (e.g. main groups 2 and 31,35) are science and engineering (associate) professionals. All other answers were classified as jobs in other fields. These results are compiled in Fig. 4 on the left. There is a higher proportion of children from families with tech jobs attending robotic workshops than non-robotics workshop. We observe that the main motivation for children to attend a workshop is to gather hands-on experience on a specific topic (70–85%). However, due to the nature of robotics as a technical field, getting knowledge about technology is provided as a reason twice more in the case of ROSSINI workshops (28% as compared to 14%). We interpret this difference as the fact that topic-specific workshops are a good occasion for children to learn about topics not discussed at school and thus expressing their own interests. For ROSSINI participants, we can however see (Fig. 5) that children are primarily motivated by hands-on experience, and this motivation is independent from their family environment.

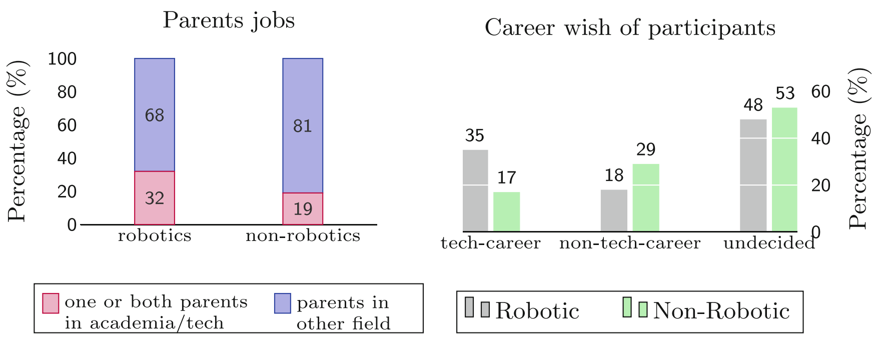

Fig. 4. Left: Coarsely-categorized jobs of parents of workshop participants. Right: Career wish of workshop participants (Grey: Participants of robotic workshops; Green: Participants of other workshops).

Figure 4 on the right shows the expressed career wish of children. For both robotics and non-robotics workshops, the percentage of undecided children is high (resp. 48% and 53%) which is a predictable result for this age group. For the other children, there is a higher interest expressed towards tech careers for participants of the robotics workshops. This is also consistent with the hypothesis that

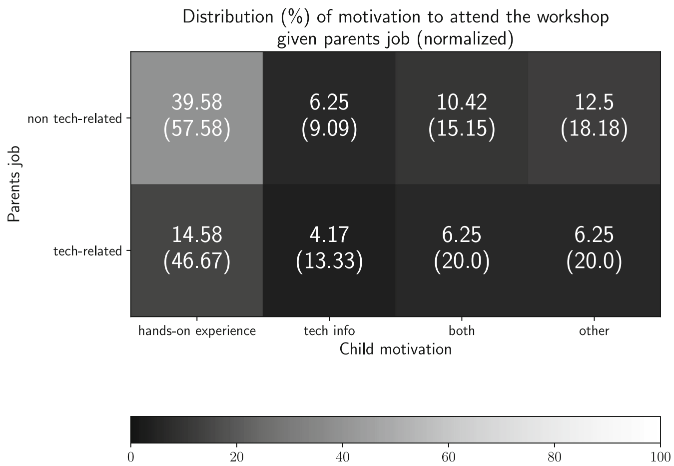

Fig. 5. Relation between the child's motivation to attend the workshop and their parents' relation with technical and academic fields. The top values represent the overall distribution of children among motivation and parents' relation with technology whereas the bottom values (in parentheses) are normalized given the parents' relation with technology.

children interested in technology engage with robotics due to the recent publicity of developments in the field (e.g. Boston Dynamics videos). For ROSSINI specifically, children from a tech-related environment seem not particularly biased towards technology whereas it is the case for children without such environment (see Fig. 6). This is a surprising result as we would expect the opposite bias. It is hard to provide a strong explanation without more social information on the participants. This is thus a limitation in the analysis of the workshop from a social perspective.

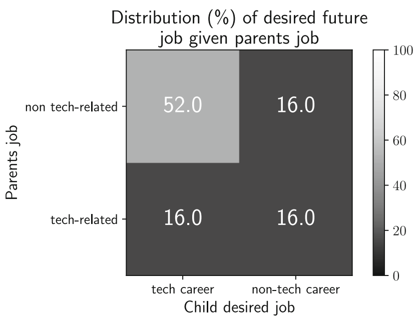

Fig. 6. Relation between the child's will to work in a tech job and their parents relation with technical and academic fields

5 Conclusion

We managed to establish age-appropriate robotics workshops for children at the age from seven to twelve. In the workshops the children start with a drawing and successively develop and build a robot with a creative spirit, which is needed when making something from upcycled materials with do-it-yourself ideas. We see that the combination of the ROSSINI pillars provide an exciting learning environment. None of the ROSSINI pillars is new by itself, but the importance of keeping and teaching those together is paramount. We think that Austrian school education would benefit from combining such strategies especially if they strengthen their effort in using free software and open hardware.

Looking at the evaluation of the ROSSINI and Youth University courses, we hardly find influence of the parents' job on the children's motivation or career aspiration. A sound explanation lies in the limitations of our study. The focus of this work is to present the initiative in an area (Tyrol/West Austria) that lacks such accessible technical workshops for children. The social reproduction phenomenon has been highlighted before; ROSSINI aims at tackling this effect. A future development of the project is to provide more easily-accessible courses with digital content. This would be a suitable step in the direction of educational equality.

References

1. Akin, H.L., Meriçli, Ç., Meriçli, T.: Introduction to autonomous mobile robotics using "Lego Mindstorms" NXT. Comput. Sci. Educ. **23**(4), 368–386 (2013)
2. Arbeitsmarktforschung und Berufsinformation des AMS: Berufsinformationssystem (bis). Arbeitsmarktservice Österreich, December 2019. https://www.ams.at/bis/bis/
3. Bauer, M., Moser, C.: Evaluation der Jungen Uni Innsbruck 2007 - eine empirische Untersuchung (2008). Diplomarbeit
4. Haller, S.: Über "Bildung 4.0", "Schule 4.0" und andere Dinge, die keine Versionierung brauchen. Medienimpulse **26** (2018). https://journals.univie.ac.at/index.php/mp/article/view/mi1187
5. International Labour Organisation: International standard classification of occupations (isco 08). Statistik Austria, October 2017. https://www.data.gv.at/katalog/dataset/2bf2a6eb-69b8-39b6-917d-42fdc1dfebf3
6. Kradolfer, S., Dubois, S., Riedo, F., Mondada, F., Fassa, F.: A sociological contribution to understanding the use of robots in schools: the thymio robot. In: Beetz, M., Johnston, B., Williams, M.A. (eds.) Social Robotics, pp. 217–228. Springer, Cham (2014)
7. Lammer, L., Lepuschitz, W., Kynigos, C., Giuliano, A., Girvan, C.: ER4STEM educational robotics for science, technology, engineering and mathematics, vol. 457, October 2017. https://doi.org/10.1007/978-3-319-42975-5_9
8. Magnenat, S., Riedo, F., Bonani, M., Mondada, F.: A programming workshop using the robot "thymio ii": The effect on the understanding by children, pp. 24–29, May 2012. https://doi.org/10.1109/ARSO.2012.6213393

9. Mondada, F., Bonani, M., Raemy, X., Pugh, J., Cianci, C., Klaptocz, A., Magnenat, S., Zufferey, J.C., Floreano, D., Martinoli, A.: The e-puck, a robot designed for education in engineering. In: Proceedings of the 9th Conference on Autonomous Robot Systems and Competitions, **1**(1), 59–65 (2009)
10. Razzouk, R., Shute, V.: What is design thinking and why is it important? Rev. Educ. Res. **82**, 330–348 (2012). https://doi.org/10.3102/0034654312457429
11. Toh, L.P.E., Causo, A., Tzuo, P.W., Chen, I.M., Yeo, S.H.: A review on the use of robots in education and young children. J. Educ. Technol. Soc. **19**(2), 148–163 (2016). http://www.jstor.org/stable/jeductechsoci.19.2.148
12. Vitanza, A., Rossetti, P., Mondada, F., Trianni, V.: Robot swarms as an educational tool: the thymio's way. Int. J. Adv. Robot. Syst. **16**, 172988141882518 (2019). https://doi.org/10.1177/1729881418825186
13. Wang, M.T., Degol, J.L.: Gender gap in science, technology, engineering, and mathematics (STEM): current knowledge, implications for practice, policy, and future directions. Educ. Psychol. Rev. **29**(1), 119–140 (2017). https://doi.org/10.1007/s10648-015-9355-x

Using Robots for Digital Storytelling. A Game Design Framework for Teaching Human Rights to Primary School Students

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Abstract. Telling stories and playing games are important for the development of children language, cognitive and social skills. Using robots as characters of digital stories and agents of embodied cognition will further advance children's creativity, teamwork and other 21st century skills. Additional use of gamification techniques improves emotional engagement and helps young children more easily grasp abstract concepts.

In this study we describe a general framework for designing robotics-based board games for primary school students, aiming at the assimilation of abstract concepts. The purpose of such games is to provide additional environments promoting children's personal development and improving their socialization skills. The case study in this paper specifically relates to human rights, both as a general concept and as a set of principles helping to prevent inappropriate behavior in different social situations. In this case, having a general framework simplifies the board game design procedure, allowing focusing on a particular set of human rights (or more generally, any other abstract concepts) in everyday life situations.

Field-testing observation indicates that students enjoy this way of learning. Use of robots as their embodied external agents helped students to learn behavior principles. We propose that further field studies should assess and measure long term learning benefits, compared to appropriate control groups.

Keywords: Technology-enhanced learning · Digital storytelling · Gamification · Robot-supported teaching · Research-based design

1 Introduction

Human rights (HR) education is a step towards a society that allows everyone to freely exercise their human rights. Besides enlightening people about their rights, HR education also encourages the social and emotional development of involved students. For best effects, HR education should start as early as possible, using students' age appropriate methods [1]. Our intention was to introduce education of a subset of HR, such as self-determination, freedom of expression and thought, at primary school level, by using tools

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that can make teaching more engaging and fun, taking into consideration the young age of the students.

Telling stories is an efficient ancient communication tool of passing knowledge, including traditions, heritage and history, to younger generations in an entertaining and educational way. The stories told influence people's actions and identities, and they provide us an opportunity to live in and through them [2]. In general, storytelling is a powerful approach in education, useful to enhance learning outcomes for general, scientific and technical education [3].

In education, storytelling with modern digital technologies has opened up the space for action and meaning making for students and teachers, transcending the boundaries of conventional classrooms [4]. Studies report that *digital storytelling* (DST) has a wide variety of beneficial effects. It is useful for:

- Increasing student motivation and engagement [5];
- Supporting student's understanding of subject area knowledge and overall academic performance, improving 21st century skills like collaboration, problem-solving and critical thinking [6, 7];
- Developing student's higher order thinking, deep learning and their ability of understanding complex ideas [7–9].
- Helping students to develop their creativity to solve important problems in innovative ways [10].

The variety of digital devices suitable for conducting DST is wide, with the preference on multi-media devices. These, however, are unable to provide students with percepto-motor experiences in real world, needed by students to make sense of the world [11]. For subjects of abstract and conceptual nature, it is beneficial to counterbalance this nature with tools that allow our situated human mind for grounding the concepts in bodily experiences [12]. *Embodied* cognition scholars refer that human mental processes are deeply influenced by the human body and its perceptual and motor systems [13]. To some extent, this means that our conceptual system is metaphoric in nature [14] and can only discover and understand new concepts (e.g., the idea of commutativity) if an abstract domain (e.g., arithmetic) is mapped to physical domains, such as object collections and their manipulations [12]. This approach emphasizes that "feeling" abstract concepts can help students to learn them more efficiently [15]. In the abstract domain of human rights, a robot can act as a physically embodied agent, or a simplified model of an interaction partner, making it possible for a student to project her perception and understanding on the robot, allowing the student to mirror her own thinking [15, 16].

Another powerful educational tool for increasing student learning engagement, *gamification*, has been successfully used for a long time for creating awareness about HR [17]. Gamification helps to employ strategies similar to the ones of commercial games to catch and hold the player's attention. Successful games harness the player's attention and lead it to desired outcomes, achieving this by evoking in players strong emotions of varying nature and intensity [18].

With HR topics, the balance of deeper message and more fun playing experience has to be carefully designed in order to keep the game playable and enjoyable without losing its educational purpose [17, 19]. Integrating game elements like offering rewards and skill points helps students keep their attention on the lesson, test their knowledge without the risk of failing their grades, and improve their learning outcome [20]. In games, users often operate physical controllers and mobile devices for interacting with learning systems, helping students thus use their cognitive systems for better comprehension [20, 21]. *Educational robots* can take the role of such an embodied game controller while simultaneously acting as an external visualizing agent of the student's thinking process - allowing students to interact with the game objects in the learning system [20].

A robot-based game can be (and in our case, it is) a type of a board game. As such, the game is also subject to *board game design*, since good design is essential for achieving the desired goals (the term *board game* is used here as a general concept in contrast with other terms such as *tabletop* or *hobby games* [22]). Some authors, such as Salen and Zimmerman [23], consider that the basic ingredients of the game design process are game mechanics, game materials and theme, concepts that have been used for establishing game taxonomies [24].

With educational games, the theme can be used for engaging players or as a direct mean for teaching. On the other hand, specific topics can be learnt, for example, through game themes based on history [25], STEM [26], arts [27], biology [28], etc. Therefore, the choice of the game's theme can be the first step in reaching its learning goals. Also, an engaging theme can act as an envelope for a topic that is normally not interesting or engaging for students, driving the narrative towards the educational goals.

Game mechanics can be defined as the means of interaction between player and game elements, trying to influence the game state towards the attainment of a goal [29]. Game mechanics define how the play progresses, what and when happens, and which conditions determine victory or defeat [30]. A thorough list and classification of game mechanics can be found in [29], and a summary of the most relevant mechanics, based on playing experience, in [31]. Some of the classical game mechanics [32] are easily applicable to the environment described in this paper.

The overall goal of this paper is to propose a framework for the development of robot-based board games, exploring different ideas related to designing games for helping younger students in learning abstract concepts such as HR in physical world experiences. For that, we considered it essential to look for a child-friendly approach of HR teaching that is both engaging and educative. We are especially focusing on using robotic board games as a DST tool for supporting children in maintaining a focused state of attention.

This paper is focused on the design of suitable board games for DST of HR topics, dealing specifically with the proposal of a framework for game design. For these games, we will also choose a proper robotic device to enhance child's attention control. In combination with the board game, the robot will provide a suitable environment for multiple children to discuss about given HR topics while their teacher acts as a guide and provider of information. The effectiveness of the robotic HR board game will be evaluated in the course of different iterations. For these purposes, we have formed the following research question:

- How to design a robotic board game for teaching human rights topics by using a storytelling approach?

2 Methodology

One of the approaches for bringing innovative, technology-centered methods into learning sciences is using design-based research (DBR). In DBR, researchers identify a problem, design an intervention as a solution for the problem, and then, test it (iteratively) in real educational contexts [33]. The purpose of DBR is to advance an innovation from an experimental classroom to any average classroom, operated by and for average students and teachers, having realistic technological and personal support [34]. In our paper we use DBR to overcome the challenge of creating games that simultaneously meet the requirements of both game and instructional design. DBR methods, using continuous iterations of analysis, creation and reflection steps, provide a suitable structural framework, needed for the complicated nature of creating game based learning environments [35].

2.1 The Ozobot Bit Robot

Designing a framework and methodology for robotics-based board game design is heavily dependent on the selected robot or robot family. Nowadays there are many educational robots that have been designed with some didactic purpose and that could have been chosen for the practical part of the work described here. We have selected the Ozobot Bit robot (Ozobot), by Ozobot (Fig. 1), which is a small (2.54 cm tall) self-contained robot with two separate motors, line-following sensor with the ability of reading color codes, and multi-color LED. Ozobot can be programmed by using a graphical programming environment, but also by using simple color codes, drawn with red, green and blue felt-tip markers. Ozobots are relatively cheap (under 100 €) and simple to use. However, this robot only has one sensor, located underneath the robot body, and its batteries only last up to 90 min with a 30 min charge. Due to its small size, friendly shape and simple features, Ozobot is well suited for DST board games. In our game setup we are using the Ozobot's ability to follow a pre-drawn black line (game track) and to read color codes placed on this track.

Fig. 1. The Ozobot Bit robot.

2.2 Experimental Setup

We have tested four games (Fig. 2) with two groups of children (n = 2 and n = 4), with ages ranging from 7 to 11. All the games were based on the evolutions of Ozobots traveling through tracks designed according to each game story and mechanics. The games were based on three themes and five different stories. Then, some of the games used a simple, linear scheme, while others used a more complicated design and structure, in order to include penalties for incorrect answers.

Fig. 2. Game design testing with children.

The robot progression through different tracks depended on track features as well as on different options that open up during the game as a consequence of the questions posed to and the answers given by children during the game. The design of the situations presented to players, set of questions, admissible answers and their consequences on the modification of robot's trajectory within the game track depended on the game design, and in consequence, on the global learning goals set forth at the beginning of the whole process.

The design of the games and the general framework presented here have been performed in parallel, in the sense that preliminary versions of the framework have been used for designing the games and the acquired experience has been used for refining the design framework. The gained experience pointed that there are two different situations that require the framework to provide different tools and design approaches:

1. Game design as a top-bottom procedure carried out by educators;
2. Game co-design between educators and students.

For the first case, standard graphical PC applications can be used, although it is convenient to provide designers with a number of pre-drawn templates, which can be combined for the easy drawing of robot tracks matching both the board game story and game mechanics. Paper prototypes are also useful for the introduction of student-modifiable stages in top-bottom designed games, a somehow intermediate case, where using paper templates facilitates finding an appropriate solution by constraining the range of available options presented to students.

In the second case, rapid prototyping tools that exploit Ozobot's features can be used (in particular, its ability to follow hand-drawn lines and read stickers or hand-drawn color codes as instructions). Physical templates can be provided, such as cardboard templates including instructions or circuit sections for modifying robot evolutions along the circuit. This allows the inclusion of embodiment experiences and facilitates the task of track design, as hand-drawing tracks and introducing color codes is a time consuming and error prone job. Like in many interaction design procedures, the use of paper prototypes is recommended for getting fast feedback about the effectiveness of different game features.

The first approach relies only on the educator's criteria, generating tracks ready to be used by players. The second approach, however, facilitates student interaction and game customization, since it is based on the availability of "tangible bricks" (such as paper templates) that can be placed and oriented by hand and mixed with previously designed tracks. This simplifies the process of on the fly game modification, within teacher-student co-design processes, following the discussion of abstract concepts.

2.3 Board Games and Game Mechanics

In accordance with the taxonomy of narrative-centric board games by Sullivan and Salter [36], the proposal presented here fits into the category of *Ordered Story Games*. Additional elements of *Story Crafting* were added in the last stage of the game, when children were encouraged to change the last part of the game narrative and create their own track modifications. The design of each specific activity (learning sessions using Ozobot-based board games, taking advantage of the framework proposed here), requires the definition of a number of elements that constitute the activity design space:

- Overall goals
- Game theme and story
- Game mechanics
- Actual situations, questions and answers that are presented to the children playing the game
- Game outcome evaluation
- Children involvement in the game customization process

The first point, the *overall goals*, is the set of HR that are taken into consideration in the specific game to be played. They could be selected in accordance to internal factors (interests of the students or teaching institution, etc.), or according to external factors, such as the presence of specific sensitizing campaigns about specific HR.

The theme and *story* used in each game is to a large extent independent of the overall goals, since they create just a conducting line that presents the situations in which specific HR issues (Fig. 3) can be brought up and discussed. A number of pre-designed game stories can be previously prepared and offered within the activity design framework; in general, stories following, for example, a *hero's quest* structure, are well suited for this purpose, facilitating the introduction of rewards and penalties.

Regarding game mechanics, there are several issues that need to be considered. The following are relevant in the case studied in this paper: first, the game structure (availability of different paths, levels, or "universes" in which situations and rules might change, etc.). Second, how players evolve through the game, the options that are offered to them

Fig. 3. Presentation of a specific HR issue.

and the way players enter their choices, including whether any degree of randomness is introduced in the game or not. Third, optional reward and penalty schemes; the way the game ends, and how player performance is assessed.

For game structure, any decision taken has to be in accordance with the capabilities of the participating children. In general, younger children should use simpler game structures (such as purely linear ones, probably). Depending on the group, additional paths or levels can be included in order to preserve player interest on the game.

With respect to the way users evolve through the game, this has to be based on the robot capabilities. Using Ozobots, the simplest option is to base player evolution on the line following capabilities of these robots, together with programming them through color coded instructions; players can then be confronted with questions related to the game universe and the human rights overall goals. Each question can have different answer cards (Fig. 4) with associated programming color codes that can guide their robots in the right direction or through different track detours, or affect their evolution through the game. The consequences of each answer will vary depending on the game structure and the two penalty/reward mechanisms that Ozobots offer:

- If time is used for evaluating user performance:
  - Leading players to track detours or even mazes that might be difficult to exit.
  - Making robots perform funny actions or complex motion patterns that might delay its progression, such as spinning, zig-zag, etc.
  - Making robot move slower or faster, whether for a limited time or constantly until the following speed change code is encountered.

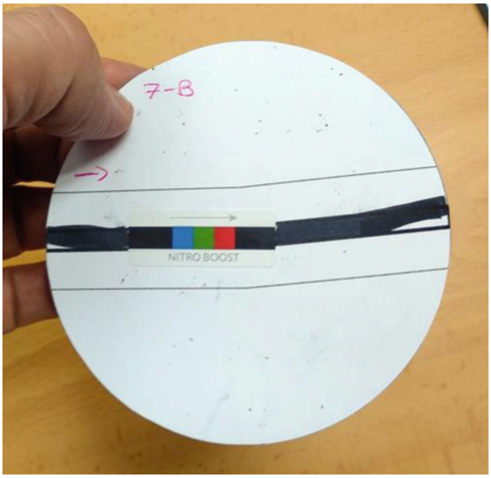

Fig. 4. An answer card: color code to be placed on the track.

- Using a counter. Ozobot allows using counters that are initialized to a value of five and are decreased until the count reaches 0 (count increases back to the initial count of 5 are also allowed).

Both mechanisms can be combined in game design. Using counters might not be appropriate for younger children, as Ozobots do not show the actual count value, requiring players to have some abstraction capabilities.

Last, in order to take full advantage of the activity, there are two wrap-up mechanisms that can be used (depending on student's age and maturity level):

- Discussions with children about the importance of the concepts included in the game.
- Co-design (students-teacher) of the general storytelling layout, game mechanics and Ozobot layout.

The second option issue requires the availability of tools for customizing games as described above.

2.4 Field Testing

We have tested the ideas described in earlier this paper through field-testing. The first test was carried out with three different games that shared the same game mechanics but had different goals, stories and aesthetics[1]. All three games had a quest structure, where participants had to reach the final stage after answering correctly a set of questions. The last stage was blank, offering the possibility of including an additional question or issue, together with its solution using a card with a track and possibly a color coded instruction for the Ozobot. The games were followed without any problem and the

[1] An example of game storyline is on this link: http://bit.ly/2FuvzNw.

overall test results were satisfactory. The game resulted appropriate for children of that age, although adapting the game to older kids will possibly require changes to make it more challenging.

The second test included a more complicated story and game mechanics, and used some graphical material of one of the first test set games. The game story was about a situation where each player had to take a map to the final game station in order to win the game. At each of the game stations, they were asked a question and, according to their answers, they received instructions that would help them to finish the game or introduced delays by sending them through a detour. The game goal was to have children experience frustration because of having their robot, acting as avatars of themselves, being treated unfairly (within some kind of discriminatory situation). It was tested with a heterogeneous group of children of 11, 7, 7 and 3 years old. In general, the children played according to the rules, but they got more interested on the game mechanics themselves than in the HR goals.

The third test introduced several modifications. First, the children had a short briefing before the game started, explaining what human rights are and telling them that the goal of the whole activity was to learn why HR are important and how their lack could actually affect the way they live. The game story was very simple (just a race to get to the end first), and incorrect answers would get the players' robots delayed through a detour. Additionally, another Ozobot was sent behind them to capture delayed Ozobot that got sent to the "start" position. The result of this game was interesting, because the short briefing about HR allowed children to be more sensitive to the questions, and resulted in long discussions about why some specific rights were important, and whether a specific issue should be included as a right to be recognized.

3 Results

At the beginning of our study we formulated the following research question: How to design a robotic board game for teaching human rights topics by using a storytelling approach? This question is answered below.

Based on the conducted iterations we are proposing the following steps for creating a robotics board game for children:

- **Choosing the robot**. Out of several robot's features, the most important ones are its **size**, **ability to function independently**, and being **easy to program**. In our example Ozobots automated and combined the roles of dice and game pieces. Ozobots were also able to illustrate the storyline of the game, due to its pre-built line-following ability. In addition, players could easily influence the Ozobots' behavior and directions on the board by using color-code stickers.
- **Designing game mechanics**. To ensure player engagement, the reward/punishment mechanisms have to be **tested iteratively**. We recommend **involving students** into the design process to ensure that the game mechanics works on the selected target groups and to promote student centered teaching/learning approaches.
- **Choosing the production method for the game board**. Computer designed board games with printed color codes ensure **robot's error-free work**. However, in the early

iterations we recommend using p**aper prototyping** as this makes it easier for children to use their creativity and test several options.

- **The instructions** need to be easily understood by players. Depending on student age, the instruction may be verbal (presented by teacher), written or pictorial. We recommend using instruction cards that are associated with the choices available to players.

4 Discussion and Further Research

Using robots is a promising way to realize DST in a manner that looks at the human mind and its development as being embodied and grounded in physical world experiences. This will open up new ways of transformative learning especially when teaching sensitive socio-cultural issues. In our study we have discovered that robotics has a great potential in merging the best sides of digital storytelling and gamification. Considering robots as versatile teaching aids, or mediating agents between students and information, rather than as programmable things, is promising for introducing new teaching practices and promoting TEL among teachers. Such an approach is easy enough for regular teachers in regular classrooms, teaching regular students [34] and makes it thus easier for those teachers to start using TEL practices.

Our underlying objective behind the research questions was to understand whether it is possible to combine such different promising technologies like robotics, gamification and digital storytelling. Our study has some limiting factors, mainly the small sample size and usage of only one robotic platform. Nevertheless, its results are cautiously suggesting that this approach can expand the possibilities of digital storytelling by creating robot-supported digital storytelling (RSDST) that is easy to use by students and teachers alike.

For further research we find it necessary to examine how RSDST can be integrated into curricula, how it can be used for promoting TEL practices, how it influences students' learning engagement and learning outcomes as well as the extent to which it depends on cognitive abilities, such as a student's working memory capacity (e.g., scope and control of attention). We also consider it vital to study the limitations and opportunities when using RSDST with students with special educational needs or with students of different cultural backgrounds.

References

1. Osaka, H.: Human Rights Education in the Northeast Asian School Systems: Resource Material, Takada (2013)
2. White, M., Epston, D.: Narrative Means to Therapeutic Ends. W.W. Norton, New York (1990)
3. Sharda, N.: Applying movement oriented design to create educational stories. Int. J. Learn. **13**(12), 177–184 (2007)
4. Vivitsou, M.: Digital storytelling in teaching and research. In: Natnall, A., Multisilta, J. (eds.) Encyclopedia of Education and Information Technologies, Springer (2018)
5. Dogan, B.: Educational uses of digital storytelling: research results of an online digital storytelling contests. In: Conference: Proceedings of Society for Information Technology & Teacher Education International Conference (2010)

6. Robin, B.: The effective uses of digital storytelling as a teaching and learning tool. In: Flood, J., Heath, S., Lapp, D. (eds.) Handbook of Research on Teaching Literacy through the Communicative and Visual Arts, no. 2, pp. 429–440. Lawrence Erlbaum Associates, New York (2008)
7. Sadik, A.: Digital storytelling: a meaningful integrated approach for engaged student learning. Educ. Technol. Res. **56**, 487–506 (2008)
8. Yuksel, P., Robin, B. McNeil, S.: Educational uses of digital storytelling all around the world. In: Koehler, M., Mishra, P. (eds.) Proceedings of SITE 2011–Society for Information Technology & Teacher Education International Conference, Nashville, Tennessee, USA, pp. 1264–1271. Association for the Advancement of Computing in Education (AACE) (2011)
9. Smeda, N., Dakich, E., Sharda, N.: The effectiveness of digital storytelling in the classrooms: a comprehensive study. Smart Learn. Environ. **1**, 6 (2014)
10. Ohler, J.: Digital storytelling in the classroom. Corwin Press, Thousand Oaks (2008)
11. Stolz, S.A.: Embodied learning. Educ. Phil. Theo. **47**(5), 474–487 (2015)
12. Guhe, M., Pease, A., Smaill, A.: A cognitive model of discovering commutativity. In: Taatgen, N., van Rijn, H. (Eds.) CogSci 2009 Proceedings, pp. 727–732. Cognitive Science Society (2009)
13. Alibali, M.W., Nathan, M.J.: Embodiment in mathematics teaching and learning: evidence from learners' and teachers' gestures. J. Learn. Sci. **21**(2), 247–286 (2012)
14. Madden, J.J., Lakoff, G., Núñez, R.E.: Where mathematics comes from: how the embodied mind brings mathematics into being. Am. Math. Monthly **109**(7), 1182 (2002)
15. Han, I.: Embodiment: a new perspective for evaluating physicality in learning. J. Educ. Comput. Res. **49**(1), 41–59 (2013)
16. Kopcha, T.J., McGregor, J., Shin, S., Qian, Y., Choi, J., Hill, R., Mativo, J., Choi, I.: Developing an integrative STEM curriculum for robotics education through educational design research. J. Form. Des. Learn. **1**(1), 31–44 (2017)
17. Gabriel, S.: How to analyze the potential of digital games for human rights education. Revista Lusófona de Educação **41**, 29–43 (2018)
18. Mullins, J.K., Sabherwal, R.: Beyond enjoyment: a cognitive-emotional perspective of gamification. In: Conference: 51st Hawaii International Conference on System Sciences (2018)
19. Swain, C.: Designing games to effect social change. situated play. In: Proceedings of DiGRA 2007 Conference (2007)
20. Wang, S., Hung, I., Lin, L., Chen, N.: On the design of embodiment-based gamification activities for learning fundamental projectile motion (2015)
21. Howison, M., Trninic, D., Reinholz, D., Abrahamson, D.: The mathematical imagery trainer-from embodied interaction to conceptual learning. In: Fitzpatrick, G., Gutwin, C., Begole, B., Kellogg, W.A., Tan, D. (eds.) Proceedings of ACM Conference on Human Factors in Computing Systems (CHI 2011), pp. 1989–1998. Association for Computing Machinery. ACM (2011)
22. Woods, S.: Eurogames - The Design, Culture and Play of Modern European Board Games. Mc Farland & Company Inc, Publishers (2012). ISBN 978-0-7864-6797-6
23. Salen, K., Zimmerman, E.: Rules of Play – Game Design Fundamentals. MIT Press (2003). ISBN 978-0-2622-4045-1
24. Parlett, D.: The Oxford History of Board Games. Oxford University Press (1999). ISBN 978-0-1921-2998-7
25. Gupta, A., Matthews, J.: Twilight Struggle. Board game by GMT Games (2005)
26. Knemeyer, D.: Tesla vs Edison: War of Currents. Board game by Artana (2015)
27. Cruz-Diaz, M., Dionisio, A.: Ars Universalis. Board game by Meridiano 6 (2015)
28. Coveyou, J.: Cytosis: A Cell Biology Board Game. Board game by Genius Games (2017)

29. Järvinen, A.: Games without frontiers: theories and methods for games studies and design. PhD Thesis, University of Tampere (Finland) (2009). ISBN 978-951-44-7252-7
30. Adams, E., Dormans, J.: Game Mechanics - Advanced Game Design. New Riders Games (2012). ISBN 978-0-321-82027-3
31. Berlinger, Y.: The Modern Eurogame Revolution. In: Paper presented at the Board Game Studies Colloquia XII, Jerusalem (2009)
32. GameDesigning. Beginner's Guide to Game Mechanics. https://www.gamedesigning.org/learn/basic-game-mechanics. Accessed 7 Jan 2020
33. Anderson, T., Shattuck, J.: Design-based research: a decade of progress in education research? Educ. Res. **41**(1), 16–25 (2012)
34. Brown, A.: Design experiments: theoretical and methodological challenges in creating complex interventions in classroom settings. J. Learn. Sci. **2**(2), 141–178 (1992)
35. Boyer, D.M., Akcaoglu, M., Pernsteiner, S.: Connecting game and instructional design through development. In: Baek, Y. (ed.) Game-Based Learning: Theory, Strategies and Performance Outcomes, Hauppauge, New York, pp. 67–82. Nova Science Publishers (2017)
36. Sullivan, A., Salter, A.: A taxonomy of narrative-centric board and card games. In: Proceedings of FDG 2017, Hyannis, MA, USA (2017). https://doi.org/10.1145/3102071.3102100

Key Factors for Keeping Students Engaged in Robotics Learning

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Abstract. Educational robotics is an effective tool for facilitating students' learning when students engage in making or creating with robotics tools. Making with robotics creates a fun and engaging hands-on learning environment for students. Throughout traditional K-12 education, especially in upper grades, students learn mainly by following teacher's instruction and lectures in a more disciplined and structured way. Students, even undergraduates, need to unlearn this more passive approach to learning in order to take initiative in their learning in a hands-on making environment. Making with robotics engages students in manipulating, assembling, disassembling, and reassembling materials while going through the design learning process. However, educational robotics itself does not keep students engaged in their learning once its novelty diminishes. This paper examines how several key elements are necessary for the use of robotics as a learning tool to keep motivating students to continue to learn. The projects completed by undergraduate students during the Fall 2019 quarter are evaluated in order to identify what the factors that contributed to their engagements and creativities.

Keywords: Educational robotics · Robotics as a learning tool · Collaboration · Creativity · Flow state · Audience

1 Introduction

In January 2011, my college students and I visited a local urban elementary school to showcase their robotics creations to 45 4th graders who had never seen robots before and were eager to see what robots could do. The 4th graders were anxiously waiting in the gymnasium. The experience was captured as follows;

> The robot that excited the students the most was a pink Barbie-tank robot that followed a black line. It was about the size of a large shoebox. A line-following program made it follow a black tape circle on a large white paper. The students were amazed to see the robot following the black line. One of the students asked if it could follow a green line outlining the basketball court in the gymnasium. My initial reaction to the question was to doubt that the robot would follow the green line because the robot had been programmed to detect the specific reflection of black electric tape against a white surface. However, the student's question was

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> so engaging and interesting that I replied, "Let's try it!" As I predicted, the robot did not follow the green line. The students were very disappointed. I explained that the program was set to follow a black line and the measurements for light reflected from the black and green were probably different. My explanation led to a new question from another student, "Can the robot follow a black line on the gym floor?" I predicted that the robot would probably not follow the black line because the brown color of the floor could be too close to black for the NXT light sensor to detect the difference. In the spirit of encouraging experimentations, I agreed to give their idea a try. The students were thrilled and excited. Luckily, we had a roll of black electric tape, with which the students made a long strip of a black line, from the stage all the way to the end of the gymnasium. Amazingly, the robot did start to follow the black tape. The students screamed with excitement and cheered the robot to keep going. They all lined up on the black line, making a tunnel with their legs spread apart. The robot went through their leg-tunnel all the way to the end, where it searched for the line by swinging in a circle until it found the line again and made its way back to the beginning. The students all applauded the robot, celebrating the joy of their new discovery and understanding. [1]

This experience triggered the 4th graders' imaginations, which was shown in the essays and drawings made by the students describing the robots that they dreamed of creating.

Every time we bring our robotics creations to classrooms, similar excitements, and creative effects are observed. In December 2018, my college students presented their robotics creation using recycling materials and boxes to pre-school students, where we observed the same reactions from the students who were working on their box project. Our visit triggered them to create their imaginary box robots as their final productions. Similarly, in December 2019, thirty 3rd graders visited the University of California, San Diego (UCSD) campus for the showcase of robotics creations by my undergraduate students. The 3rd graders were excited to learn about the robots created by the UCSD students. The UCSD students were also tasked in teaching the 3rd graders how their robots were programmed by either explaining the concept or showing the code and explain it step-by-step. Since all robots were required to use at least one sensor, the 3rd graders were also learning how sensor inputs can control a robot's actions.

Educational robotics first gathered attention from the education community after LEGO Mindstorms RCX was produced in the late 1990s. It has gained in popularity and demand since the worldwide focus on STEM and computer science education started to become more widespread. It is widely accepted and understood that educational robotics brings excitement and motivation to learn as well as fosters curiosity and creativity in students [1–5]. Robotics excites not only the K-12 population of students, but also undergraduate students who are not even computer science or engineering majors. This paper examines how robotics as a learning tool can keep motivating students to continue to learn and, to do so, what the crucial elements that must be in place to keep them motivated and engaged are. The paper evaluates the projects completed by undergraduate students during the Fall 2019 quarter and identifies what factors contributed to student engagements and creativity.

2 Learning with Educational Robotics

Educational robotics is an effective tool for facilitating students' learning. Educational robotics becomes an effective tool when students engage in making or creating using robotics. Making with robotics creates a fun and engaging hands-on learning environment for students. Throughout traditional K-12 education, especially in upper grades, students learn mainly by following teacher's instruction and lectures in a more disciplined and structured way. Even undergraduate students need to unlearn this practice and instead, change to initiating their own learning in hands-on making environments. Making with robotics engages students in manipulating, assembling, disassembling, and reassembling materials while going through the design learning process. Students also engage in problem-solving processes through trial and error while improving the codes for their robot. The learning approaches that make learning with robotics successful are project-based, problem-based, learning by design, student-centered, and constructionist. The central focus must be on the process of learning, rather than the final product [6].

In addition, educational robotics is an effective tool for fostering collaboration among students while working on a robotics project. It is highly recommended that students engage in a group project where a small number of students (2-3 students) work together [6–9]. Through a robotics project, students engage in a collaborative process while sharing ideas, making collective decisions, providing constructive criticisms aimed at improving their project, and acquiring communication skills [10–12]. Group work provides students various opportunities to explore and solve real-world problems with their peers [6]. Moreover, it is suggested that working on a project-based robotics project as a group helps students struggling with low self-esteem to improve their technical capacity, teamwork skills, and communication skills [12].

It is important to point out that a robotics project must provide an authentic connection with the students' life through real-world problems and/or challenges [6]. While engaging students in real-world problems, developing solutions, and demonstrating their learning by physically testing solutions with their robotics creation, their active engagement in authentic learning ensures deeper subject knowledge acquisition among the students [13]. In addition, such making with robotics projects creates trans-disciplinary learning environments where students discover, learn, and utilize various concepts in STEM and other disciplines in a contextualizing fashion. With contextualized learning, using robotics as a learning tool makes abstract concepts, such as friction and momentum, visible and concrete for students to grasp as they try out their ideas with their robotics invention [14].

3 Robotics as a Learning Tool

EDS 114 Cognitive Development and Computing Environments: Robotics as a Learning Tool is an interdisciplinary course offered under the Department of Education Studies at the University of California, San Diego, in the Fall 2019 quarter. EDS 114 can be taken to satisfy one of the Education major or minor requirements or an elective for many other majors. The course description states:

> This integrated, interdisciplinary methodology course will introduce students to the use of educational robotics as alternative means of fostering learning. The

main focus of the course will be a hands-on experience through which students will learn concepts of science, technology, engineering, mathematics, computer science, and AI while working with a robotics tool and its programming software.

The 10-week course consisted of four mini-projects and one final project. Students worked in groups throughout the quarter. There were 29 students taking the course. They were divided into eight groups. Each group was composed of three to four group members with both programming and building (construction of robot using LEGO pieces) skills being evenly distributed among the group members. For each project, students were required to use LEGO Mindstorms NXT with its sensors and motors, various LEGO pieces, and any other materials they could find to make their project authentic. LEGO is a useful tool since some of the students played with LEGO growing up and there are a variety of useful resources online that students could find on their own to help their projects. LEGO Mindstorms ev3 software was used for programming. Instead of lecturing, students obtained programming skills through sample programs provided by the instructor. They could learn programming by testing the sample programs and tweaking them to use with their projects. Since most of the students have some programming experiences, either with text- or block-based programming, it was not difficult for students to learn programming independently as a group. Students could ask questions about coding in class while they worked on a project, or during their weekly lab hours.

3.1 Mini-Projects

The students worked on four mini-project in the Fall 2019 term. They were:

1. Drawing Robot - Create a robot that draws different shapes on an easel paper. The robot should be able to draw the following shapes – circle, triangle, square, rectangle, and a unique shape of your choice (difficult shape can receive extra points).
2. Robotic Animal - Create a robotic animal that can sense the environment (using sensor input(s)) and react to the input (using motors or other outputs).
3. Robotic Instrument - Create a robotic musical instrument that can play by reacting to at least one sensor input, or a robot plays a musical instrument reacting to a sensor input(s).
4. Home Robot - Create a robot that works in a home environment. For this project, the home robot is a miniature size robot (consider the size of a desk-top as one room). Your robot needs to 1) be able to move around without crashing into furniture or a person/figure using a sensor. Use two or more sensors with this task. In addition, your robot needs to 2) follow a person/figure around in the room/house, and 3) move an object from one place to the other (from a tabletop to on a floor or from one table to the other table).

Mini-projects 2 and 3 were open-ended projects where students could decide what robot they would build and what it does as long as it was within the definition of the mini-project. On contrast, mini-projects 1 and 4 had specific tasks that the robot they build had to accomplish (task-specific project).

With each mini-project, groups could spend at least two full class sessions and lab sessions. Also, each group could choose to work outside of the class or lab session by checking out their robot or coming to another lab session.

3.2 Final Project

The final project asked to create an educational/interactive robotic toy. The project instruction states:

> Educational (Interactive) Robotic Toy: Children learn from interacting with their environment. Children will benefit from having an object to play with when they learn from their interaction with their environment (especially young children, but you know that you can also benefit from it). A toy that is interactive and offers plenty of room for their imagination can provide a positive experience for children. The goal of your final project is to create an educational (interactive) robotic toy for 3rd graders that supports their interactive play/learning. Be creative! In addition, you are tasked in teaching the students how robots work - program - step-by-step interaction, input vs. output, etc. Your robotic toy should help you complete this task as well.

Students were given at least five full class sessions and lab sessions for the final project. As same as mini-projects, each group could decide to use additional time to complete the project. Similar to mini-project 2 and 3, the final project was an open-ended project where students could decide what robot they would build and what it does as long as it was within the definition of the final project.

4 Student Work Results

The comparison of groups' work on each mini-project showed an interesting trend. With mini-projects, extra points were given for creativity, extra sensor uses, etc. The comparison of the average points from each mini-project shows higher scores for mini-projects 2 (102.9) and 3 (102.3) which are open-ended projects, while students scored lower with projects 1 and 4 (an average of 100.4 with mini-project 1 and 92.6 with mini-project 4) which are with specific tasks.

Looking at the individual project, all groups could complete only one shape out of three in addition to the shape of their choice with mini-project 1. Four groups scored below 100 points while three groups scored extra 5 points for creating a moving arm that moved a marker up and down to control its drawing instead of drawing a shape with one stroke. The lowest score was 92 points.

With mini-project 4, only one group scored 100 points, and only one group (different group from the group that scored 100 points) completed all three tasks. Other groups could complete two tasks out of three required. The lowest score was 84.

With mini-project 2, six groups scored over 100 points. Seven groups received extra points for creativity, extra sensor use or extra motor use to make the movement similar to the animal that they are creating (Figs. 1 and 2). The lowest score was 97.

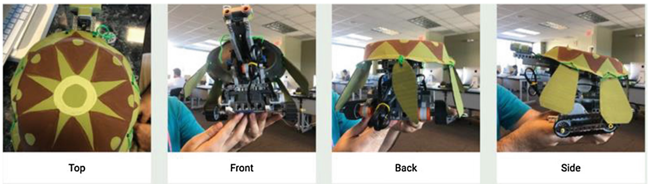

Fig. 1. Turtle robot

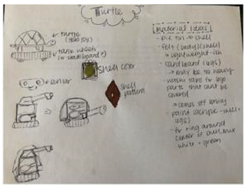

Fig. 2. Turtle robot design and planning drawing

With mini-project 3, all groups scored 100 points or above, with 110 as the highest score (Figs. 3, 4 and 5). All groups earned extra points for their creativity or the use of extra sensors. One group earned extra points for creative construction and creative use of multiple sensors.

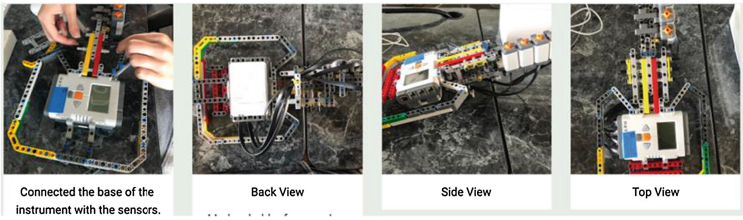

Fig. 3. Robotics guitar

Fig. 4. Robotics guitar buttons and score

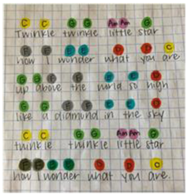

Fig. 5. Robotics guitar buttons and score

For the final project, there were no extra points given for extra work. However, all groups earned 100 points for their robot creations. A reflective essay was also required for the individual students with the final project. The students clearly addressed that having the 3rd graders as both their audience and as well as students to teach robotics, engaged the undergraduates more as they prepared for the showcase and encouraged them to put extra work into their project (Figs. 6, 7 and 8).

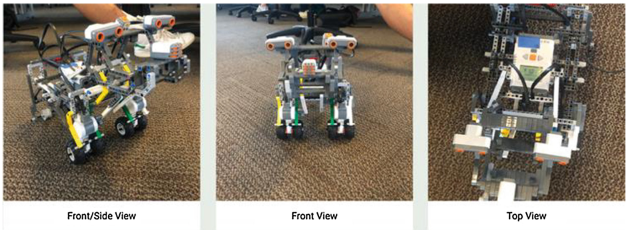

Fig. 6. Dog robot structure

Fig. 7. Dog robot costume

Fig. 8. Dog robot costume

When comparing the final product with the mini-project 1, the final project shows that students added more efforts to the final product than the mini-project 1. With the mini-projects, adding decoration or costume to make it look authentic could gain extra points. With the final project, the only requirement was to make it look like an authentic toy rather than a LEGO creation and no extra points were awarded for appearance.

Shown below are three examples illustrating the difference between the two projects (mini-project 1 and final project). All groups did not have costumes on the drawing robots (mini-project 1). Some groups decided to add LEGO people to their robot as decorations, but craft materials or costumes were not used to make the final product look authentic. With the final project, all groups including the groups that rarely used decoration or costume with their mini-projects, added some decoration to make their robot look like a toy (Figs. 9, 10, 11, 12, 13 and 14).

Fig. 9. Group A's Drawing Robot (mini-project 1) and Kicker Robot (final project)

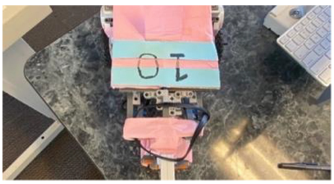

Fig. 10. Group A's Drawing Robot (mini-project 1) and Kicker Robot (final project)

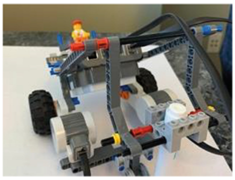

Fig. 11. Group B's Drawing Robot (mini-project 1) and Mouse Robot (final project)

Fig. 12. Group B's Drawing Robot (mini-project 1) and Mouse Robot (final project)

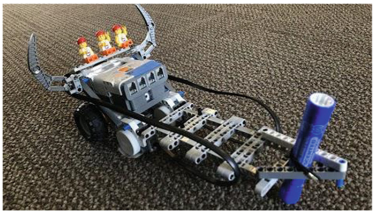

Fig. 13. Group C's Drawing Robot (mini-project 1) and Dancing Humanoid (final project)

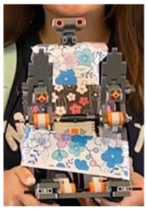

Fig. 14. Group C's Drawing Robot (mini-project 1) and Dancing Humanoid (final project)

Although the assessment of the projects is qualitative and anecdotal, the results show that the students invested more effort into the open-ended projects. Students struggled more with completing the task-specific projects. In the case of the final project, having a targeted audience made the undergraduate students work harder to accomplish their goals. In the following sections, the importance of keeping a flow state and having a targeted audience helps keep students focused, engaged, and creative while working on their robotics projects, will be discussed.

5 Flow State

The *flow state* is defined by Csíkszentmihályi [15] as the state that people are so absorbed in a challenge with which the optimal experience itself becomes enjoyable enough to make them feel that the experience itself gives them enough reward to continue the activity. It is indicated as one of the important concepts in game development as explained by Prensky [16]:

> Achieving a true "flow" experience, however, requires a second factor besides just "leveling up," a factor that complex games also provide. That factor is always being kept in a narrow zone between the game's being too hard ("I give up") and too easy ("I'm not challenged at all.") (p. 59).

To keep the flow state, the skill level required to successfully solve a presented challenge needs to be at a manageable level, not too hard or too easy [17]. The flow state creates an incentive for a person to learn new skills, which contributes to his/her engagement in increasingly difficult challenges. Csíkszentmihályi explains that we are all capable of reaching the state of flow. It also provides mental energy promoting attention and motivating action [17]. Csíkszentmihályi suggests that people become most creative, productive, and happy when they are experiencing the flow state.

Csíkszentmihályi describes eight characteristics of the flow state:

1. One is in complete focus on the task;
2. S/he has clear goals and reward in mind and immediate feedback is provided;
3. S/he experiences the transformation of time (speeding up/slowing down);
4. The experience is intrinsically rewarding;
5. The experience is effortlessness and ease;
6. There is a balance between challenge and skills;
7. Action and awareness are merged, losing self-consciousness; and
8. There is a feeling of control over the task [18].

While working on robotics projects provides a clear goal, rewards, and immediate feedback when testing code on the robot, it is also important that the instructor provide the eight conditions for successful learning in open-ended and task-oriented projects. Nakamura and Csíkszentmihályi point out that the challenges presented and the skills of the person play key roles in the flow state [19]. When a task or challenge is bigger than the level of skills that students possess, students become anxious and stressed. However, when a task is too easy or less challenging for their skill level, they can get bored, distracted, and less motivated to tackle the challenge. With the task-oriented mini-projects, the tasks in hand and time allowed for students to complete the projects seemed higher than the students' skill levels since most of the groups could not complete all the tasks. This indicates that with the task-oriented mini-projects, students could not stay in the flow state throughout the project period. With the open-ended mini-projects and final project, the students had full control over defining the goals and tasks that they would tackle as long as the final product meets the requirements of the project. Because the goals were set by themselves, they could adjust their goals based on their acquired skills and the time they had to complete the project successfully, which allowed them to keep their flow state active. In addition, accomplishing the goals set by themselves could provide students with intrinsic motivation to complete the tasks in hand. The openness of the projects allowed the students to balance the difficulty of the challenges and the level of their skills for experiencing the continuous flow state.

6 Audience/Showcase

Providing an opportunity for students to present their work publicly contributes to keeping students engaged in their project [1]. Having a presentation or showcase at the end of a project helps students to set a timeline or goal. This motivates them to complete their project by the deadline since, without the completion of the project, they will not be able to present their work in front of the audience. Presenting in front of the outside audience seems to give the students higher incentive and motivation to complete their project successfully than presenting just to their instructors/teachers. With the final project, all groups successfully completed their projects by the deadline for presenting to the 3rd graders. Moreover, the task of teaching the 3rd grader using the robotic toy provided extra motivation for the students to do better and work harder.

It is suggested that with educational robotics focusing on the construction of an artifact or a concrete object, a presentation at the end of a project to a wider classroom or outside audience is crucial for keeping students engaged in meaningful learning [1]. Providing an opportunity to share their creation reinforces learning by making their learning explicit, concrete, and visible as well as meaningful to their audience. Teaching is the highest level of learning, which the students experienced while presenting the 3rd graders their robotics creation.

7 Conclusion and Next Step

The paper examined the work presented by a group of undergraduate students through an upper-level college course using robotics as a learning tool. Although anecdotal and qualitative, the results show that using open-ended projects keeps students in flow state and contributes to their successful completion of the projects. In addition, having an audience, specifically, an outside audience, might have contributed to their focus and the success of the final project.

Educational robotics is an attractive learning tool because it is still new in K-12 classrooms. Although educational robotics is an effective learning tool that creates a hands-on learning environment, it does not automatically create a learning environment that keeps students engaged throughout. Careful attention to the balance between the difficulty of the tasks presented to students and their skill levels is critical to keeping them in the flow state necessary for success in their learning. In addition, having an outside audience at the end of a project helps them stay engaged in their project, thereby contributing to their success and cultivating meaningful learning.

The paper presented a small case study from one undergraduate course using qualitative and observational data, thus the findings are not generalizable. The next step is to organize a larger scale study involving a larger sample to assess whether the findings from this small study are scalable.

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References

1. Eguchi, A.: Educational robotics theories and practice: tips for how to do it right. In: Barker, B.S., et al. (eds.) Robotics in K-12 Education: A New Technology for Learning, Information Science Reference (IGI Global), Hershey, PA, pp. 1–30 (2012)
2. Eguchi, A.: Learning experience through RoboCupJunior: promoting STEM education and 21st century skills with robotics competition. In: Proceedings of the Society for Information Technology and Education (SITE) (2014)
3. Eguchi, A.: Educational robotics for promoting 21st century skills. J. Automation, Mob. Robot. Inf. Syst. **8**(1), 5–11 (2014)
4. Eguchi, A.: Computational thinking with educational robotics. In: Proceedings of the Society for Information Technology & Teacher Education International Conference (2016)

5. Zawieska, K., Duffy, B.R.: The social construction of creativity in educational robotics. In: Szewczyk, R., et al. (eds.) Progress in Automation, Robotics and Measuring Techniques, Advances in Intelligent Systems and Computing. Springer International Publishing (2015)
6. Eguchi, A.: Bringing robotics in classrooms. In: Khine, M.S. (ed.) Robotics in STEM Education, pp. 3–31. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-57786-9_1
7. Eguchi, A.: Student learning experience through CoSpace educational robotics. In: Proceedings of the Society for Information Technology & Teacher Education International Conference (2012)
8. Eguchi, A.: Educational robotics as a learning tool for promoting rich environments for active learning (REALs). In: Keengwe, J. (ed.) Handbook of Research on Educational Technology Integration and Active Learning, 2015, Information Science Reference (IGI Global), Hershey, PA, pp. 19–47 (2015)
9. Eguchi, A., Uribe, L.: Educational robotics meets inquiry-based learning. In: Lennex, L., Nettleton, K.F. (eds.) Cases on Inquiry Through Technology in Math and Science: Systemic Approaches. Information Science Reference (IGI Global), Hershey, PA (2012)
10. Eguchi, A.: Educational robotics for elementary school classroom. In: Society for Information Technology and Education (SITE), San Antonio, TX (2007)
11. Eguchi, A.: Educational robotics for undergraduate freshmen. In: Proceedings of the World Conference on Educational Multimedia, Hypermedia and Telecommunications, pp. 1792–1797 (2007)
12. Miller, D.P., Nourbakhsh, I.R., Sigwart, R.: Robots for Education. In: Siciliano, B., Khatib, O. (eds.) Springer Handbook of Robotics, pp. 1283–1301. Springer-Verlag, New York, LLC, New York, NY (2008)
13. Edutopia. Project-Based Learning. n.a. 28 February 2008. http://www.edutopia.org/project-based-learning. Accessed 20 Oct 2012
14. Blikstien, P.: Digital fabrication and 'making' in education: the democratization of invention. In: Buching, J.W.H.C. (ed.) FabLabs: of Makers and Inventors, vol. 1013, Transcript Publishers: Bielefeld, Germany
15. Csikszentmihalyi, M.: Flow: The Psychology of Optimal Experience. HarperCollins Publishers, New York (1990)
16. Prensky, M.: Don't Bother Me Mom - I'm Learning! Paragon House, St. Paul (2006)
17. Csikszentmihalyi, M.: Finding flow - Reviews the book 'Finding Flow' by Mihaly Csikszentmihalyi. Psychology Today 1997, July 1997
18. Oppland, M.: 8 Ways To Create Flow According to Mihaly Csikszentmihalyi. Positive Psychology 2019. https://positivepsychology.com/mihaly-csikszentmihalyi-father-of-flow/. Accessed 5 Jan 2020
19. Nakamura, J., Csikszentmihalyi, M.: Flow Theory and Research. In: Lopez, S.J., Snyder, C.R. (eds.) The Oxford Handbook of Positive Psychology, pp. 195–206. Oxford University Press, Oxford (2009)

Compiling ROS Schooling Curricula via Contentual Taxonomies

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Abstract. The Robot Operating System (ROS) is the current de-facto standard in robot middlewares. The steadily increasing size of the user base results in a greater demand for training as well. User groups range from students in academia to industry professionals with a broad spectrum of developers in between. To deliver high quality training and education to any of these audiences, educators need to tailor individual curricula for any such training. In this paper, we present an approach to ease compiling curricula for ROS trainings based on a taxonomy of the teaching contents. The instructor can select a set of dedicated learning units and the system will automatically compile the teaching material based on the dependencies of the units selected and a set of parameters for a particular training. We walk through an example training to illustrate our work.

Keywords: Robot Operating System · ROS · Robotics education · Curriculum · Targeted views · Dependency management · Sphinx

1 Introduction

The Robot Operating System (ROS) has evolved into the current de-facto standard in robot middlewares. ROS provides all features necessary to operate robotic systems and it enables the development of robotic applications in C++ and Python. It comes with libraries for state-of-the-art solutions for robotics tasks such as localisation, path planning, image processing, collision avoidance, and motion control. The run-time environment manages the execution of applications as well as inter-process communication.

The increasing popularity comes with an increased demand for training and education in ROS. Since different audiences need different individual levels of detail and the particular training instance depends on the robotic platform being used as well as on the domain and scope of the training. It is not appropriate to deliver a standard one-size-fits-all training. Instead, instructors should tailor the teaching content and the material to the target audience. Still, there is a set of commonalities in the structure of teaching the robotic contents and there are inter-dependencies between individual learning units.

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In this paper, we present an approach that facilitates the compilation of individual curricula for ROS trainings based on a taxonomy of the teaching contents. By selecting a set of dedicated learning units the instructor can design a particular training and the system will automatically compile the teaching material based on dependencies.

1.1 Background

The Robot Operating System (ROS) is the de-facto standard middleware for robot applications today and is very popular among academics. With its successor ROS2, the Robot Operating System has a great chance of also becoming a standard middleware for industrial applications. A current H2020 project ROSIN[1] aims at exactly this: establishing ROS as a standard middleware for industrial robot applications, called ROS-Industrial. ROSIN does this by pursuing the following three actions: (1) support the development of new industrial ROS components by partially funding them, (2) establish novel quality assurance measures to improve the ROS-Industrial software quality, and (3) start a massive education programme to train professionals and university students in ROS/ROS-Industrial.

As part of the ROSIN consortium, the authors are responsible for developing education materials and conducting teaching activities for university students and for professional robot programmers and developers. Usually, the audiences we cater for in a schooling activity is very diverse. There are participants who are professionals in developing ROS components while other participants barely know how to handle Linux.

This poses diverse challenges in robotics education in general, and teaching ROS in particular. A general survey of robotics education can for example be found in [1]. Why teaching robotics with ROS is a useful thing to do besides its widespread use has already been discussed in [2]. Also, that teaching robotics is important with respect to the ever increasing popularity of the so-called Industry 4.0 [3] does not come as a surprise. There are different ways of going about teaching robotics though. It appears that application-oriented settings are as popular as they are useful. Duckietown [4], for example, uses a street scenario to make the learning experience more tangible and fun in higher education. There is also work on connecting theory and practical application as well as higher education, vocational training, and industry [5].

We are also trying to maintain training material for both, academic and industry audiences and we try to provide task-oriented learning experiences that fit at different levels of proficiency. We have been doing ROS training for more than seven years now [6,7]. Also, we have organised workshops to exchange experiences with teaching ROS [8] and we have even reached out beyond Europe [9]. Based on these experiences we developed the ROSIN education concept [10] that also this work builds on.

[1] http://rosin-project.eu.

With respect to existing efforts we need to mention two works in particular. For some time already there is eLML [11], an XML-based format for creating e-learning lessons following a pedagogical structure. While we could certainly orient our lessons' structure like in eLML our units a more fine-grained and our annotations go beyond what is done in eLML. EDUportfolio [12] on the other hand is a system for curriculum management that follows similar intentions to what we are trying to achieve. However, our approach is intended more for teachers/trainers and it is particularly focused on compiling teaching material for different and heterogeneous groups of learners from one source.

1.2 Motivation and Overview

This diversity is the key motivation for the current work: we need the most flexibility in a training to be able to meet changing requirements of a possibly heterogeneous group of participants. This can only be done if the teaching material is set for eventualities that might come up. For example, the instructor might realise that not all of the participants are proficient enough on a certain topic to follow the content as planned. In such a case, being able to reiterate the missing content depends on having the corresponding teaching material available. Conversely, skipping content that everybody already knows about is easier. Also, focusing on the relevant parts of the material helps in being efficient and prevents distracting participants. Finally, different audiences have set different goals for a training. Industry professionals might care more about how to use things while students in an academic setting want (or need) to dive more into the theoretical background. However, application-oriented teaching of ROS to either industry professionals or students requires the participants to be aware of a minimum amount of the theory at least. The limited time available for courses requires lecturers to find an efficient way of ensuring the coverage of several Intended learning outcomes (ILO), depending on the target group.

The general idea of our approach is the following. All the teaching material is organised in so-called *units* that reflect a block of content. These units are annotated with semantic meta-information such as the subjects that are being covered or the dependencies to other units. A unit may contain different versions of the content, for example in different application domains, and it can also collect content on different levels of detail in one place. Finally, the unit also contains different views on the content, namely a version for the student, one for the instructor as well as for potential teaching assistants. These semantic annotations enable us to provide a system that allows instructors to design a particular course instance and compile all the necessary material from a central and consistent material pool.

The rest of the paper is structured as follows. First, we lay ground for our proposed approach in Sect. 2 with describing the methodology and nomenclature that we build upon. Subsequently, in Sect. 3 we present our approach, also showing an example course and giving details of the implementation. We conclude with a discussion in Sect. 4.

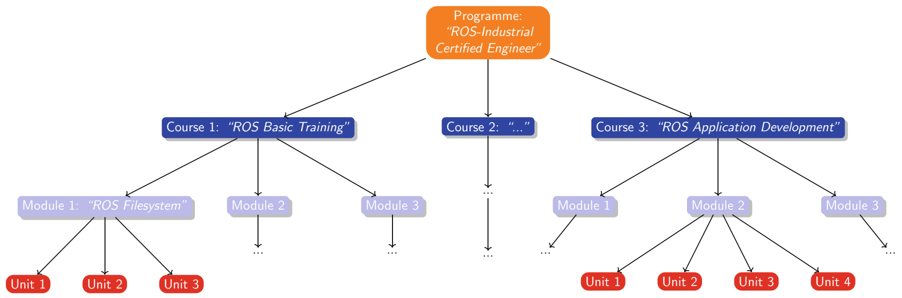


Fig. 1. Structure of schooling activities

2 Methodology

Before we can go into detail on how we intend to compile teaching materials we need to lay ground in terms of a methodology and nomenclature.

2.1 Training Structure and Learning Entities

In our ROS training activities any particular training is supposed to be part of *programme*. A programme then is comprised of a set of *courses*. Courses in turn are organised in *modules* which cover a certain subject. Finally, every module is divided into *units* which build the atomic entities. Figure 1 illustrates this structure for an example programme.

Units as the Atomic Entity. Being the smallest component we define a learning *unit* to cover a certain topic. A common learning unit in tertiary education is usually set to take around 45 min and we take this value as an orientation for our units. However, smaller (and sometimes also larger) units are possible. Each unit should not cover more than one topic to allow for units to be dependencies of other units (and possibly also of modules and courses). A unit should be generalized in order to enable re-using it in different modules. Since units are our atomic entities they are used to formulate dependencies. Thus, it is at the unit level that we formulate if being able to understand the contents of one unit depends on having understood the content of another unit before. To give the lecturer the ability to examine whether the remaining time available should cover a unit, each unit should contain an approximate amount of time required.

An exemplary aspect covered in a unit could be the 'Theory Behind Quaternions' That unit might be the dependency of a unit on 'Using Quaternions'. Quaternions in turn are required to understand 'Transforms in ROS'.

Modules as an Arrangement of Units. The next level in our training structure are *modules*. A *module* groups together several topics (represented by units) on a subject in a particular order. Following up on the example for units above we could imagine the following units to form a module on `tf`:[2] – Quaternions – Transformations – ROS Messages – ROS Communication.

Courses as a Collection of Modules. One level up in our hierarchy are courses. A *course* consists of a set of modules in a didactically meaningful order, thus serving task-oriented learning material to master a certain challenge in a robotics application. This can, for example, be localization and mapping with a robot where the course covers the following modules:

1. Using the `tf` package
2. Processing laser scans in ROS
3. Processing odometry in ROS
4. Simultaneous Localization And Mapping (SLAM)
5. Adaptive Monte-Carlo Localization (AMCL)

In this example scenario both modules that require map usage (SLAM and AMCL) have a dependency on a unit covering 2D grid maps represented as occupancy grids. When a module in a course already covers a certain unit it does not have to be covered by another module again. As a result, creators of units can focus on creating generalized training material isolated from other units.

Programmes as a Sequence of Courses. Finally, a collection of courses with a common theme is referred to as a *programme*. That is to say, we have dedicated programmes for different target groups and qualification goals. For example, industry professional who eventually want to plug together applications in their productive environment but who do not want to dive into the details of the theoretical background and the underlying algorithms too much, would enter a programme such as "ROS Certified Application Engineer". Certain developers with an academic background might follow a programme like "ROS Certified Algorithm Developer" instead. In these programmes learners then master one or several courses. On an introductory level participants with no previous knowledge on robotics might get a procedural hands-on experience with increasing complexity while more advanced users dive into the content more deeply. A course featuring ROS Navigation for beginners for example equips the TurtleBot3 platform and is aimed at newbies unfamiliar with robotics in general. Some more examples of courses might be as follows: – Basic ROS Navigation – Intermediate ROS Manipulation – Advanced ROS Mobile Manipulation.

2.2 Semantic Annotations

In order for our system to work, we need to annotate our teaching material with semantic information. We organise these annotations along several taxonomies which we explain in the following.

[2] http://wiki.ros.org/tf.

Subjects and Topics. As we mentioned before, we label courses, modules, and units with the subjects and topics that are being covered. Since there is no commonly agreed upon taxonomy of robotic subjects and topics, we rely on the keywords of the IEEE Robotics and Automation Society (RAS). Agreeing to restrict the possible values for subjects and topics to these keywords allows for a common label pool and should simplify the formulation of dependencies between different units.[3]

Stakeholder Groups and Roles. One of the assumptions or rather desiderata we have in our approach is that we want to create and to maintain a central consistent pool of training material. However, there are several stakeholders in our ROS training activities, and different stakeholders have different views on the training material. Also, there are different organisational roles in the training activities. For example, instructors and tutors should have access to the solutions while learners should not, and authors and teachers want to see didactic comments with the material in order to be able to deliver a lecture or conduct a tutorial in an appropriate manner. This is why we allow for annotating the material according to the above stakeholder groups and roles. It enables us to generate stakeholder- and role-specific views on and versions of the material from the same base pool.

The available roles are the following:

learner the first and foremost role is of course the *learner*, i.e. the participant of the training activity.

teacher the training is conducted by an instructor; we use the role *teacher* for this.

author the material might have been created by someone different from the teacher. Hence, we need an explicit role *author* to be able to allow for comments from the author of the material.

tutor the final role is called *tutor*. It is used to all annotations that exceed what the learner needs to see. The most common example use is for tutors where one might add some hints for helping learners with the material in a tutoring context or a sample solution.

Levels (of Knowledge/Proficiency). As is common with many educational structures, we distinguish between different levels of proficiency, either with respect to the previous knowledge or with the expected outcome. While we stick with a basic distinction of three levels for now, namely *beginner*, *intermediate*, and *advanced/expert*, a more fine grained subdivision with more levels is possible, of course.

Scenarios. Finally, we use different scenarios in our application-oriented teaching activities. The *scenario* is influenced by a number of factors. The most important influence is given by the hardware available for the training. For example,

[3] https://www.ieee-ras.org/publications/ra-l/keywords.

learners from industry might prefer some industry-grade heavy duty manipulator while in a university setting a collaborative lower cost manipulation device serves the purpose just as well. Other aspects influencing the scenario are whether real hardware or simulation is being used and, of course, the target application.

3 Method and Approach

Quite a challenge for our instructors of ROS courses is that the participants have diverse backgrounds and very different prerequisites when they enter one of our ROS trainings. In general, ROS trainings are offered on different levels ranging from *beginners* to *experts*. There is no pre-assessment of skills and courses are open to all participants relying on the self-assessment of participants' skills. Therefore, the course structure and the content must be very flexible to meet the needs of the participants, while at the end of the course, everybody should still be able to reach the ILOs of the course. This means that for those participants who are faster in fulfilling their given subtasks, optional materials needs to be available. In this section we describe how the course designer can compile the course content in a flexible way allowing her to cater for a diverse group of learners in Sect. 3.1. In Sect. 3.2 we outline our implementation in Sphinx.

3.1 Flexible Compilation

To address this, the lecturer has the ability to compile the programme at several levels of knowledge. A programme for industry professionals should not focus on theoretical aspects as for industry professionals it is more important to learn how to make use of the software. So instead of using the available time for theoretical aspects a more practical approach is preferred. For industry professionals, for example, a module on localization would mostly cover hands-on sessions on how to start and configure the respective ROS packages by practical examples.

Making the course contents available via Sphinx as shown in the next section also allows for on-the-fly recompilation with additional topics in the case that all participants reached the ILO before the intended end of the course. This way, the available teaching time can be used more effectively thus maximising the outcome of the course for the participants. Each unit should also contain a predefined time frame; the lecturer can determine whether additional teaching units can be added, should the progress in class be faster than expected.

3.2 Realisation in Sphinx

A major part of our concept has already been implemented for the Sphinx documentation generator. Sphinx is capable of generating various output formats such as HTML, or PDF as well as many others, from reStructuredText (rST) input files. rST is a kind of markdown text that is easy to understand and to write. Despite its limitations in the formatting options, it comes with what is necessary for marking and structuring the course materials in a flexible way including

```
.. meta::
   :subject: guideline
   :author: Marcus Meeßen
   :keywords lang=en: stylistic hints, teaching approach, version control
   :description lang=en: A guideline that helps learners, tutors, teachers,
   ↪  and authors to communicate in the same way.
   :time: all/30
   :depends: restructuredtext_basics, git_basics
```

Fig. 2. Extensions in the preamble of an rST file taken from our guidelines

highlighting and cross-document referencing. Based on past experiences (mainly with LaTeX), we realized it is easier to prepare and maintain course materials with rST for many people. This is also important as within the ROSIN project also third-parties contribute to create new course material which is integrated into the teaching curriculum.

As Sphinx is extensible, it can be tailored to our use case. In addition to providing new directives and roles, which give the author the ability to integrate her own didactic concepts more comfortably, it is also possible to manipulate the different steps of the output generation. Among other things, this allows us to hide specific documents entirely and to ultimately generate individual courses.

Description of Learning Units. Each individual learning unit is represented by a single rST file in the actual file system. Via the `meta` directive of the original Sphinx software, we added a number of options which help to structure the course content. The directive is originally used to provide a resulting HTML page with the meta information `description` and `keywords`. They both are options of the `meta` directive. At this point we have added four additional options that we use to further describe the learning unit. Figure 2 shows these options. With the `:subject:` option, we can tag course contents according to the semantic annotations defined in Sect. 2. The `:depends:` option allows for defining prerequisites for the current learning unit. This allows to automatically retrieve all prerequisites that a unit relies on be included in the higher learning entity, i.e. a course or programme. Further, the author of the material is added through the `:author:` option. Further options that can be used in the preamble are `:time:` to indicate how much time the teaching should take and `:type:` indicating what kind of unit it is, that is, whether it is a theory, a practical, or a mixed unit.

These extensions have been implemented in the `rosin.Didactic` extension[4] The package also allows for the automatic creation of several freely combinable editions (views) during the generation process, that are configurable per course or program. For example, the source code presented in Fig. 3 produces different outputs depending on the edition set in the configuration. Different (partial)

[4] We provide the extension and sample teaching material in a Github repository at https://github.com/nlimpert/crosscut.

views of the result are shown in Fig. 4. The figure shows the same course material once compiled for an author, a teacher, a tutor, and a learner. Each edition reveals additional information that is only for their eyes. For instance, the tutor's view shows additional comments to be added in class, while the learner's edition just shows the course content. While the font in the figure is rather small, it can be observed that the views generated from the same source differ and only the last paragraph appears identically in all four versions.

Level of Knowledge. Besides general content, such as introduction and synopsis that is always included, there is content designed for different levels of knowledge or proficiency. For this, we use a classical three-level classification scheme comparable to CEFR,[5] i.e. 'beginner' ≈ A1, 'intermediate' ≈ B1, and 'advanced' ≈ C1. The indicated level of knowledge is always to be understood from two perspectives. First, what we want to achieve: the expert content should make learners experts in the topic of a learning unit, and the beginner content should make them beginners. Second, what the learners current knowledge is: a beginner needs at least the beginner content, an intermediate may not necessarily require it.

Scenario. There are significant differences between the actual teaching environments in which a learning unit is used. We face that there are various operating systems, hardware – or sometimes just a simulation, software, interfaces, etc., on which a hands-on approach can be applied to teach a specific topic. So the last dimension by which a learning unit can be formed is the 'scenario' in which it is taught.

Generating Courses and Modules. From the learning units larger entities can be assembled. These are primarily modules, then courses, and finally entire programmes. Assembling such a programme is not trivial, since, as mentioned above, dependencies and the times needed for completion are not always predictable. This is why we are developing Python scripts to solve a dependency graph, create virtual index files and generate tags that are used to show and hide content.

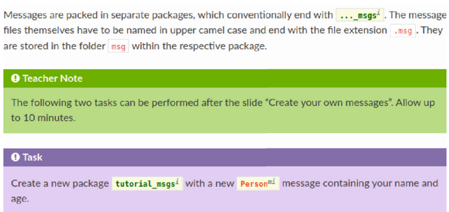
To specify larger learning entities like modules and courses we use the YAML format. The YAML files contain information about the subjects they contain, i.e. the learning units that are needed, and the desired dimensions described above. In particular, they specify (1) who the user is, (2) what level of knowledge should be taught, and (3) what scenario is being used. These values are configurable per containing subject, and a default can be defined as well. An example for how a module on `tf` can be formed by a YAML file is shown in Fig. 5. The same principle can then be followed for higher level learning entities. That is, courses would refer to several YAML files for modules and so on.

[5] https://www.cambridgeenglish.org/exams-and-tests/cefr/.

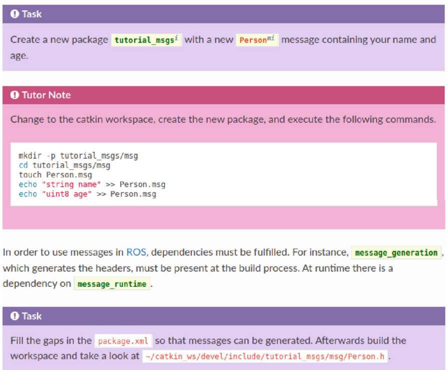
```
.. role:author:: Before you change anything, please read the conventions:

   - https://www.ros.org/reps/rep-0144.html
   - http://wiki.ros.org/ROS/Patterns/Conventions#Messages

Messages are packed in separate packages, which conventionally end with :ros:package-i:`..._msgs`. The message files themselves have to be named in upper camel case and end with the file extension :file:`.msg`. They are stored in the folder :file:`msg` within the respective package.

.. role:teacher:: The following two tasks can be performed after the slide "Create your own messages". Allow up to 10 minutes.

.. task:: Create a new package :ros:package-i:`tutorial_msgs` with a new :ros:message-i:`Person short tutorial_msgs` message containing your name and age.

.. role:tutor:: Change to the catkin workspace, create the new package, and execute the following commands.

   .. code-block:: bash

      mkdir -p tutorial_msgs/msg
      cd tutorial_msgs/msg
      touch Person.msg
      echo "string name" >> Person.msg
      echo "uint8 age" >> Person.msg
```

Fig. 3. Assigning content to a specific user role with custom rST directives

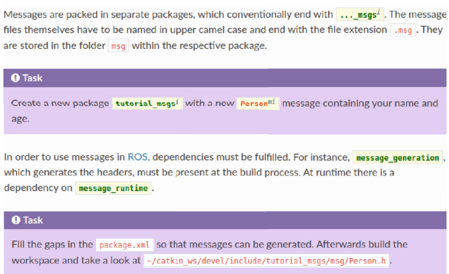
(a) Author's edition



(b) Teacher's edition



(c) Tutor's edition



(d) Learner's edition

Fig. 4. Different user groups can be shown different content.

```yaml
title: tf
default_scenarios: [TurtleBot3]
default_levels: [beginner]
subjects:
  using_quaternions:
    level: [default, intermediate] # -> beginner, intermediate
    scenarios: [all] # not be filtered by any scenario
  transformations: null # will use all the default values
  ros_messages_basic:
    levels: [intermediate] # -> intermediate
  ros_communication: null
```

Fig. 5. Composition of a module from several units using a YAML file

Tailoring Sphinx to Our ROS Education Background. While some of the Sphinx extensions presented would also be conceivable for courses beyond robotics education, we have developed further extensions that are more tailored towards our particular domain. First, that is an extension for the `ros` domain which highlights various ROS elements and automatically generates links to the official ROS documentation.

4 Discussion

Being very active in teaching ROS within the H2020 project ROSIN, we face the challenge that different learner groups have quite different experience levels and prior knowledge of robotics and ROS. This demands for a way to compile teaching materials in a flexible way. We follow also the idea of compiling ROS courses from very small entities which only touch upon one specific topic. The idea of micro courses are also interesting against the backdrop of MOOCs (Massive Open Online Courses) where only small teaching units can be deployed at a time. We make use of Sphinx, which compiles a mark-up language into different output formats. We compile all materials into HTML.

In this paper, we describe our Sphinx extension allowing to use a number of additional directives such as the topic names for teaching content, durations or dependencies between course materials. There exists options to indicate things like the learners' proficiency level or background. With these directives, it is possible to compile a complete course from micro-units for different target groups. With our approach we want to facilitate the creation and maintenance of a consistent pool of high quality teaching material. We alleviate to quickly create a curriculum for a particular instance of a training. The approach allows to compile a tailored set of teaching materials for the different stakeholders of a training from the central pool. This compilation also incorporates additional factors such as the hardware platform used in the particular training. The approach substantially eases the job of preparing a training and it provides learners, instructors, and tutors with an individually optimised version of the training material. It allows to flexibly conduct the training and thus helps to maximizes the achievement for all parties involved.

One of the possible future enhancements could be a graphical editor in the creation of modules, courses, and programmes. The extensions package `rosin.Didactic` will be made available on Github by the time of the conference.

References

1. Esposito, J.M.: The state of robotics education: proposed goals for positively transforming robotics education at postsecondary institutions. IEEE Robot. Autom. Mag. **24**(3), 157–164 (2017)
2. Michieletto, S., Ghidoni, S., Pagello, E., Moro, M., Menegatti, E.: Why teach robotics using ROS? J. Autom. Mob. Robot. Intell. Syst. **8**, 60–68 (2014)
3. Tosello, E., Castaman, N., Michieletto, S., Menegatti, E.: Teaching robot programming for industry 4.0. In: Educational Robotics in the Context of the Maker Movement, pp. 107–119. Springer, Cham (2020)
4. Tani, J., Paull, L., Zuber, M.T., Rus, D., How, J., Leonard, J., Censi, A.: Duckietown: an innovative way to teach autonomy. In: Educational Robotics in the Makers Era (Edurobotics 2016). Advances in Intelligent Systems and Computing, vol. 560, pp. 104–121. Springer, Cham (2017)
5. Haddadin, S., Johannsmeier, L., Schmid, J., Ende, T., Parusel, S., Haddadin, S., Schappler, M., Lilge, T., Becker, M.: roboterfabrik: a pilot to link and unify German robotics education to match industrial and societal demands. In: Robotics in Education, pp. 3–17. Springer, Cham (2019)
6. Ferrein, A., Kallweit, S., Scholl, I., Reichert, W.: Learning to program mobile robots in the ROS summer school series. In: Proceedings of the 6th International Conference on Robotics in Education (RIE 2015) (2015)
7. Wiesen, P., Engemann, H., Limpert, N., Kallweit, S.: Learning by doing - mobile robotics in the FH Aachen ROS Summer School. In: Schiffer et al. [8], pp. 47–58 (2018)
8. Schiffer, S., Ferrein, A., Bharatheesha, M., Corbato, C.H. (eds.): Proceedings of the Workshop on Teaching Robotics with ROS (held at ERF 2018) (TRROS2018). No. 2329 in CEUR Workshop Proceedings, Aachen (2019)
9. Limpert, N., Wiesen, P., Ferrein, A., Kallweit, S., Schiffer, S.: The ROSIN project and its outreach to South Africa. R&D J. S. Afr. Inst. Mech. Eng. **35**, 1–6 (2019)
10. Ferrein, A., Schiffer, S., Kallweit, S.: The ROSIN education concept - fostering ROS industrial-related robotics education in Europe. In: ROBOT 2017: Third Iberian Robotics Conference - Volume 2. Advances in Intelligent Systems and Computing, vol. 694, pp. 370–381. Springer (2017)
11. Fisler, J., Bleisch, S.: eLML, the eLesson Markup Language: developing sustainable e-Learning content using an open source XML framework. In: International Conference on Web Information Systems and Technologies (WEBIST) (2006)
12. Karolyi, M., Scavnický, J., Bulhart, V., Ruzicková, P., Komenda, M.: EDUportfolio: complex platform for curriculum management and mapping. In: Proceedings of the 11th International Conference on Computer Supported Education, CSEDU 2019, Volume 2, pp. 352–358. SciTePress (2019)

Robot Security Education: Hands-on Lab Activities Based Teaching Approach

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Abstract. Security is particularly important in robotics. The inclusion of robot security education in curricula offering courses on robotics is therefore considered a valuable extension. However, robot security is covered very briefly in most curricula and there is a clear lack of education publications that discuss related teaching materials and hands-on lab activities. This paper contributes to fill this gap by providing a method for enhancing the teaching of robot security, using a hands-on lab based educational approach. The details of comprehensive hands-on lab activities that can be used in didactic environments to evaluate and enhance robot security are presented. Practically, throughout the hands-on lab activities, the resilience and robustness of a popular robot, called NAO, are evaluated against common Denial of Service (DoS) attacks. The hands-on activities demonstrate clearly that NAO robot is very vulnerable to DoS attacks and does not deploy built-in efficient security features to prevent and limit the success of the attacks. Moreover, the discussed hands-on lab activities can be considered as the basis to develop similar activities using other types of robots and attacks and are designed to accompany and compliment any existing trade or academic press text.

Keywords: Robot security · Hands-on lab activities · Denial of Service (DoS) attacks · ARP cache poisoning · Firewall

1 Introduction

A robot is a machine built to allow organizations and individuals to lower production costs and execute specific tasks faster, more precise and more reliable. There are many different types of robots as there are tasks for them to perform. In the near future, robots will become part of our daily life, and be used routinely to carry out many tasks, especially the routine ones, such as driving students' buses, building machines, and helping elder people.

Robots are expected to execute tasks in most environments, such as homes, hospitals, schools, supermarkets, and military fields. As a consequence, security should be a major component and concern while designing and building robots, in order to protect them from potential attacks which intend to maliciously alter their normal functioning and behavior. Basically, robots' sensors, arms, memories, Operating Systems, exchanged data with external devices and computers should be all protected.

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In [1], an analysis of potential offenders revealed that robots are very vulnerable to attacks by the intruder. The offender does not even need to possess special skills, abilities and knowledge to attack robots. The Internet offers a large number of tools for conducting attacks, as well as descriptions of the possibilities of using these tools.

On the other hand, robot security education is important for curricula offering courses on robotics, and its inclusion in curricula is considered a valuable extension. However, robot security is covered very briefly in most curricula and there is a clear lack of education publications that discuss related teaching materials and hands-on lab activities. However, robot security is covered very briefly in most curricula and there is a clear lack of education publications that discuss related teaching materials and hands-on lab activities.

This paper contributes to fill this gap by providing a method for enhancing the teaching of robot security, using a hands-on lab based educational approach. The details of comprehensive hands-on lab activities that can be used in didactic environments to evaluate and enhance robot security are presented. Practically, throughout the hands-on lab activities, the resilience and robustness of a popular robot, called NAO, are evaluated against common Denial of Service (DoS) attacks. NAO is an autonomous, programmable robot which can listen to you, walk, talk, interact with movement, and recognize human faces. Moreover, it is a humanoid robot that can be used for education, healthcare, and research. Built of hardware and software, NAO robot consists of sensors, motors, and software driven by NAOqi, and Linux operating system. NAO robot can interpret what it has detected and activate programmed responses using the embedded software. This robot, producing elaborate behaviors, provides access to data that is captured by the sensors. Also, graphics tools, such as the Choregraphe programming software [2], allow controlling and monitoring the robot.

The rest of the paper is organized as follows. Section 2 discusses related work. Section 3 provides the basic knowledge that students and educators should have about DoS attacks. Section 4 discusses the experiments setup requited to conduct the hands-on lab activities. Section 5 provides technical details on the implementation of the hands-on lab activities and the corresponding obtained results. Section 6 analysis the conducted experiments' results. Section 7 proposes basic mechanisms and solutions to enhance robot security. Section 8 concludes the paper.

2 Related Work

In [3], Raven II Surgical robot's vulnerabilities have been evaluated. Raven II is a teleoperated robotic system meant to help research in advanced techniques for robot-assisted surgery. It uses full standards software, such as Linux and Robot Operating System. It is a remotely controlled robot, which means operators can be nearby or at a separate location. It was found out that there was no encryption for the data transmitted in the communication link and no authentication. Indeed, the authors were able to conduct successfully Man-in-the-Middle (MiM) attacks. In addition, they performed three attacks, namely intention modification, intention manipulation, and hijacking attacks. Recent developments have shown that the use of robots in medical proceedings leads to the best surgical outcomes and faster recovery, thus enhancing the provision of medical services to patients. The Raven II robot can be attacked by tapping the network and knowing the sequence number of the packets and by controlling the robot for sending any desirable command. This attack may have consequences and problems during real surgery.

According to [4], cyber-attacks focus on mobile systems, such as automobiles, drones and robotic vehicles. They focus on DoS attacks that can affect robotic vehicles by blocking commands from reaching the system, in addition to command injection attacks that provide the robot with conflicting control commands.

Based on [5], industrial robots are sometimes discovered on networks without being properly secured. The authors built an attacker model and showed how an attacker can compromise a robot controller and gain full control of the robot, altering the production process. Moreover, the authors explored the potential impacts of such attacks and experimentally evaluated the resilience of a widespread model of industrial robot against cyber-attacks. The domain-specific barriers that make smooth adoption of countermeasures a challenging task are also discussed.

According to [6], the world of robotics continues to rapidly advance and security risks increase. There are different types of robots that perform different functions in different fields. Therefore, it is essential to protect these systems from exploitation and malicious activities since they perform sensitive and complex tasks. The robot industry increased and associated with Computing Environment Cloud. Therefore, cyber security violations will increase on robots, which damages the financial aspects and reputation. Moreover, in the past, robots used authentication protocol to ensure authenticity of the information. However, they use TCP/IP protocols to control robots without encrypt communication. In [7], there was a study of three robots to explore the vulnerabilities for analyzing security and privacy. The few vulnerabilities faced were remote identification and discovery, passive and active eavesdropping, operational notifications, controlling the robot, and network security.

Based on [8], robot's designers and manufacturers consider cybersecurity as not a high priority because security is not one of the significant interests of customers. Still, as robot's development and speed growth in the future, we will need to pay attention to cybersecurity. In fact, robots are a type of embedded system, which can be affected by any type of cyber-attacks. These attacks are mainly hardware attacks, OS attacks, and application attacks. Most cyber-attacks on a military robot aim to conduct surveillance or DoS attacks. Such attacks may lead to loss of innocent civilians or military lives. Furthermore, to limit the effect of cyberattacks, robot manufacturers need to emphasize on secure application code. Moreover, the communication protocols between the robots and other devices need to be secured and encrypted.

According to [1], the majority of incidents in the area of the violation of the security of robotic systems are connected with the conduct of terrorist acts. The obtained statistics indicate that first of all the interests of the state and civilians may be affected. It is necessary to pay more attention to the security of robotic systems, since so much depends on it. In addition, the attacker does not always need to develop a means to attack its targets or use special technical means. In fact, most of the incidents on robotic systems were carried out using software that is freely available.

In [9], a study shows that a number of research robots are accessible and controllable from the Internet, demonstrating a risk to user safety and privacy. Practically, the results of a scan of the entire IPv4 address space of the Internet for instances of the Robot Operating System (ROS), a widely used robotics software platform were presented and discussed. Hosts supporting ROS that are exposed to the public Internet were identified, thereby allowing anyone to access robotic sensors and actuators. The paper authors claim that they were able to read image sensor information from a physical robot present in a research lab in an American university. Additionally, the paper offers recommendations on best practices to mitigate these security issues in the future.

Despite the inclusion of robot security education in curricula, offering courses on robotics is considered a valuable extension, education publications and work that discuss teaching materials and approaches on robot security are not available in the literature.

3 DoS Attacks: Basic Concepts

To lay the ground for the proposed hands-on lab activities and conducted experiments, students and educators should have the following basic knowledge on DoS attacks.

3.1 Land Attack

Land attack occurs when an attack host sends spoofed TCP SYN packets (connection initiation) with the target host's IP address and an open port, as both source and destination. The Land attack traffic causes the machine to reply to itself continuously. That is, the target host responds by sending the SYN-ACK packet to itself, creating an empty connection that lasts until the idle timeout value is reached. Flooding a system with such empty connections can overwhelm the system, causing a DoS situation (Fig. 1).

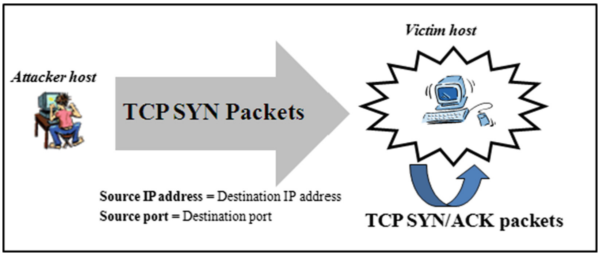


Fig. 1. Land attack

3.2 SYN Flood Attack

A SYN flood occurs when a host becomes so overwhelmed by TCP SYN packets initiating incomplete connection requests that it can no longer process legitimate connection requests. In fact, when a client system attempts to establish a TCP connection to a system providing a service (the server), the client and server exchange a set sequence of messages known as a three-way handshake. The client system begins by sending a SYN (synchronization) message to the server. The server then acknowledges the SYN message by sending a SYN-ACK (acknowledgment) message to the client. The client then finishes establishing the connection by responding with an ACK message. The connection between the client and the server is then opened, and the service-specific data can be exchanged between the client and the server.

The potential for abuse arises at the point where the server system has sent an acknowledgment (SYN-ACK) back to the client, but it has not yet received the final ACK message. This is what meant by a half-opened connection. The server has in its system memory a built-in data structure describing all pending connections. This data structure is of finite size, and can be made to overflow by intentionally creating too many partially-opened connections (Fig. 2).

Creating half–opened connection is easily accomplished with IP spoofing. The attacker's system sends SYN messages to the victim's server, that appear to be legitimate. But, the source address is spoofed to a system that is not currently connected to the network. This means that the final ACK message is never sent to the victim server. Because the source address is spoofed, there is no way to determine the identity of the true attacker when the packet arrives at the victim's system.

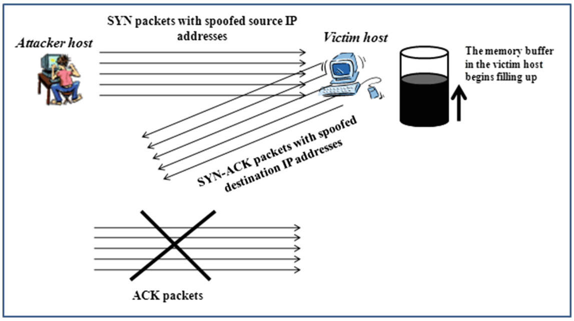


Fig. 2. TCP Syn flood attack

3.3 DoS Attack Based on ARP Cache Poisoning

DoS attack based on ARP cache poisoning consists into preventing a victim host from communicating with one or more host(s) in a LAN network. First, a malicious host poisons the ARP cache of a victim host using ARP cache poisoning technique. That is, the victim host's ARP cache is updated with fake entries corresponding to invalid association of IP addresses and nonexistent MAC addresses. Later, when the victim host attempts to send packets to a host, the packet will be sent to a nonexistent host, causing consequently a DoS attack. Therefore, the victim host will be prevented from sending packets to the legitimate destination host. Figure 3 shows the contents of the victim host's ARP cache after the ARP cache poisoning attack. The cache includes a fake entry corresponding to the association of the IP address of Host B with a nonexistent MAC address. Consequently, any packet sent to Host B by Host A will be redirected to a nonexistent host. This is a DoS situation, since Host A's packets are prevented from reaching Host B. Hence, Host A and Host B cannot communicate properly unless the fake entry in the ARP cache of Host A is removed. This can be done manually, or when

Host A refreshes its ARP cache. However, the malicious Host C may keep sending the fake ARP request to Host A to keep its ARP cache corrupted.

This attack can be performed by novices or script kiddies, using widely available and easy to use tools specially designed for that purpose [10], such as ARP Spoof Tool, Cain & Abel, Winarp_mim, WinArpSpoof and WinArpAttacker.

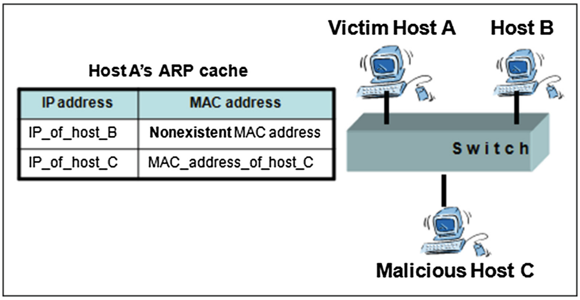


Fig. 3. Host B's ARP cache after the ARP cache poisoning attack

4 Experiment Setup

4.1 Network Architecture

Figure 4 shows the network architecture used during the proposed hands-on lab activities to conduct experiments. It consists of four computers and NAO robot connected together by a network switch. Three computers are called attack hosts and used to generate DoS attack traffic; however, the fourth computer, called testing host, is used to test the effect of the attacks on NAO robot. Each network' device has an IP address and a MAC address, as shown in Table 1.

Table 1. Network devices' IP and MAC addresses

	IP address	MAC address
NAO robot	169.254.150.108	00:13:95:0B:D6:46
Attack host #1	169.254.159.178	98:90:96:B1:0C:F5
Attack host #2	169.254.17.168	34:17:EB:CA:9C:AC
Attack host #3	169.254.8.71	30:9C:23:90:63:77
Testing host	169.254.154.17	A7:47:2A:0C:33:F0

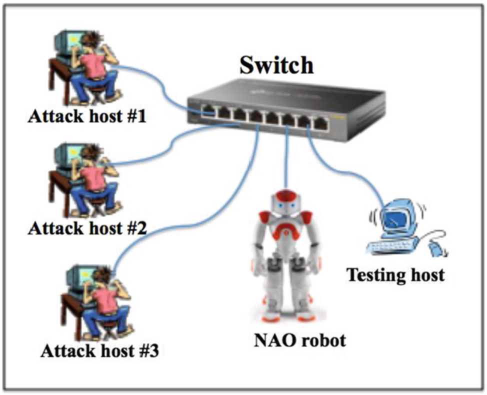


Fig. 4. Network architecture

4.2 Software Tools

The following lists the tools used to perform the experiments during the hands-on lab activities. The list includes tools to build and generate DoS attack traffic, capture and analyze network traffic, ask NAO robot to execute specific tasks, monitor the robot's activities, and upload codes on the robot, like firewall code:

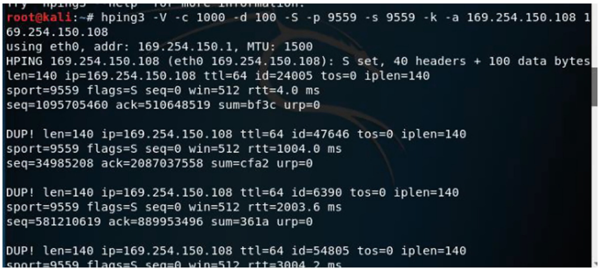
1. *CommView tool* [11]: used to build specific packets for generating DoS attack traffic.
2. *Wireshark* [12]: used to capture and analyze exchanged network traffic between network devices.
3. *Kali Linux tools* [13]: used to generate a diversity of DoS attacks. Kali Linux is a Debian-based Linux distribution aimed at advanced Penetration Testing and Security Auditing. Kali Linux contains several hundred tools which are geared towards various information security tasks, such as Penetration Testing, Security research, Computer Forensics and Reverse Engineering.
4. *Choregraphe software* [2]: used for giving NAO robot tasks to execute and for monitoring.
5. *WinSCP* [14]: used to upload additional codes on robots to be run, such as firewall code.

5 Hands-on Lab Activities Implementation and Results

The following sub-sections describe the implemnattion of three hands-on lab activities and the obtained results.

5.1 Lab Activity #1: Land Attack Generation

The objective of this experiment is to evaluate the robustness of NAO robot against the Land attack. In Kali Linux, hping3 tool allows to build specific network packets and generate Land attack traffic, as explained in Sect. 3. The following hping3 command allows to flood NAO robot (whose IP is 169.254.150.108) with Land attack traffic:



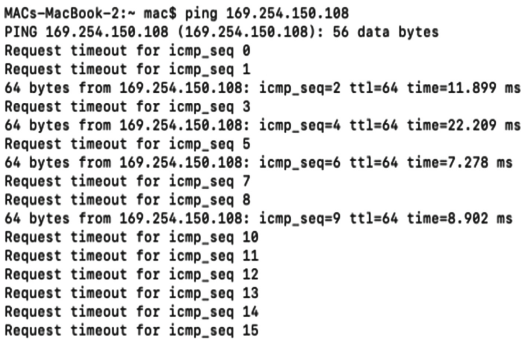
```
root@kali:~# hping3 -V -c 1000 -d 100 -S -p 9559 -s 9559 -k -a 169.254.150.108 1
69.254.150.108
using eth0, addr: 169.254.150.1, MTU: 1500
HPING 169.254.150.108 (eth0 169.254.150.108): S set, 40 headers + 100 data bytes
len=140 ip=169.254.150.108 ttl=64 id=24005 tos=0 iplen=140
sport=9559 flags=S seq=0 win=512 rtt=4.0 ms
seq=1095705460 ack=510648519 sum=bf3c urp=0

DUP! len=140 ip=169.254.150.108 ttl=64 id=47646 tos=0 iplen=140
sport=9559 flags=S seq=0 win=512 rtt=1004.0 ms
seq=34985208 ack=2087037558 sum=cfa2 urp=0

DUP! len=140 ip=169.254.150.108 ttl=64 id=6390 tos=0 iplen=140
sport=9559 flags=S seq=0 win=512 rtt=2003.6 ms
seq=581210619 ack=889953496 sum=361a urp=0

DUP! len=140 ip=169.254.150.108 ttl=64 id=54805 tos=0 iplen=140
```

Performance Testing: This test consists into trying to ping NAO robot from the testing host (Fig. 4), just after launching the Land attack. The result of this test is that NAO robot was not able to respond to most ping requests received from the testing host (Fig. 5). This is because NAO robot became overwhelmed when processing the Land attack traffic. Consequently, the Land attack affected considerably the performance of NAO robot.



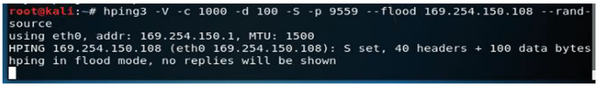
```
MACs-MacBook-2:~ mac$ ping 169.254.150.108
PING 169.254.150.108 (169.254.150.108): 56 data bytes
Request timeout for icmp_seq 0
Request timeout for icmp_seq 1
64 bytes from 169.254.150.108: icmp_seq=2 ttl=64 time=11.899 ms
Request timeout for icmp_seq 3
64 bytes from 169.254.150.108: icmp_seq=4 ttl=64 time=22.209 ms
Request timeout for icmp_seq 5
64 bytes from 169.254.150.108: icmp_seq=6 ttl=64 time=7.278 ms
Request timeout for icmp_seq 7
Request timeout for icmp_seq 8
64 bytes from 169.254.150.108: icmp_seq=9 ttl=64 time=8.902 ms
Request timeout for icmp_seq 10
Request timeout for icmp_seq 11
Request timeout for icmp_seq 12
Request timeout for icmp_seq 13
Request timeout for icmp_seq 14
Request timeout for icmp_seq 15
```

Fig. 5. Effect of Land attack on NAO robot

5.2 Lab Activity #2: TCP Syn Flood Attack Generation

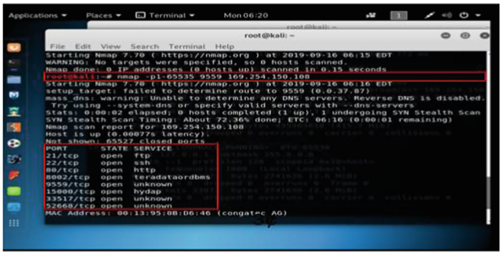
The objective of this experiment is to evaluate the resilience and robustness of NAO robot against the TCP Syn flood attack. Kali Linux offers mainly two methods to generate TCP Syn flood attack traffic. The first method uses hping3 tool to create an online command that allows generating the attack. The second method uses a tool called Synflood, in Kali Linux's Metasploit framework, designed specifically for generating TCP Syn flood traffic. Metasploit Framework is a software platform for developing, testing, and executing exploits. It can be used to create security testing tools and exploit modules and also as a penetration testing system. The following provides practical details on generating the attack using the two methods.

TCP Syn Flood Attack Generation Using hping3 Online Command: From Kali Linux, the following hping3 command allows to flood NAO robot with TCP Syn flood traffic. The target port on NAO robot is 9559.

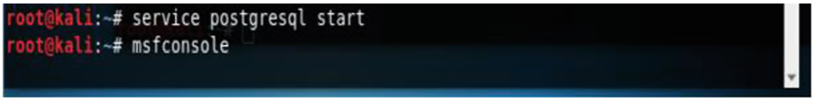


TCP Syn Flood Attack Generation Using Metasploit Framework: To generate TCP Syn flood traffic from Kali Linux, the following steps are required:

1. Use Nmap tool to detect open ports at NAO robot, as shown in the following screenshot:

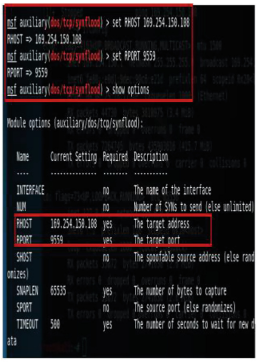


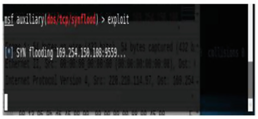
2. Run Metasploit, as shown in the following screenshot:



3. Type search to find the Syn flood attack tool.

4. Then, set up the target IP address (i.e., NAO robot's IP address), and the target port on NAO robot. After that, start the attack, as shown in the following screenshots:





Performance Testing: This test consists into trying to ping NAO robot from the testing host (Fig. 4), just after launching TCP Syn flood attack. The result of this test is that NAO robot was not able to respond to most ping requests received from the testing host (Fig. 6). This is because NAO robot became overwhelmed when processing the TCP Syn flood attack traffic. As a consequence, the TCP Syn flood attack affected considerably the performance of NAO robot.

```
MACs-MacBook-2:~ mac$ ping 169.254.150.108
PING 169.254.150.108 (169.254.150.108): 56 data bytes
Request timeout for icmp_seq 0
Request timeout for icmp_seq 1
64 bytes from 169.254.150.108: icmp_seq=2 ttl=64 time=11.899 ms
Request timeout for icmp_seq 3
64 bytes from 169.254.150.108: icmp_seq=4 ttl=64 time=22.209 ms
Request timeout for icmp_seq 5
64 bytes from 169.254.150.108: icmp_seq=6 ttl=64 time=7.278 ms
Request timeout for icmp_seq 7
Request timeout for icmp_seq 8
64 bytes from 169.254.150.108: icmp_seq=9 ttl=64 time=8.902 ms
Request timeout for icmp_seq 10
Request timeout for icmp_seq 11
Request timeout for icmp_seq 12
Request timeout for icmp_seq 13
Request timeout for icmp_seq 14
Request timeout for icmp_seq 15
```

Fig. 6. Effect of TCP Syn flood attack on NAO robot

Moreover, the user could not give a task to NAO robot to execute when it is under TCP Syn flood attack, since the Choregraphe tool has crashed, as shown in Fig. 7.

5.3 Lab Activity #3: ARP Ache Poisoning Based DoS Attack Generation

The objective of this experiment is to evaluate the robustness of NAO robot's ARP cache against ARP cache poisoning attack. Practically, using a packet generator, a fake

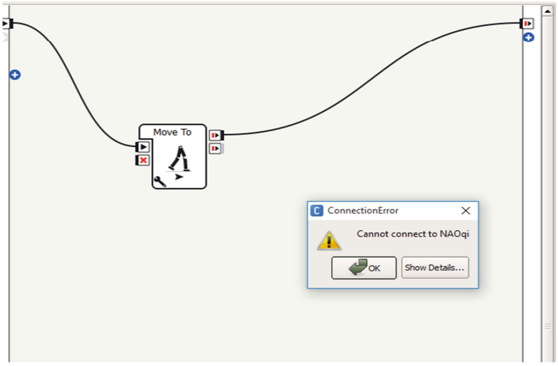


Fig. 7. Choregraphe tool crashes following TCP Syn flood attack

ARP request packet with invalid IP/MAC addresses is build and sent to NAO robot, as explained in Sect. 3. The objective is to attempt to corrupt the robot's ARP cache by inserting an invalid IP/MAC entry [10]. The conducted experiment consists of the following steps:

1. First, the testing host (Fig. 4) pings NAO robot to allow creating the following valid IP/MAC entry in the robot's ARP cache:

IP address	MAC address
169.254.154.17	A7:47:2A:0C:33: F0

2. Then, as a network packet generator, CommView tool [11] is used to create and send a fake ARP request packet carrying an invalid IP/MAC entry [10]:

ARP header	
Operation code	1
Source IP address	169.254.154.17 (Testing host)
Source MAC address	*Nonexistent MAC address*
Destination IP address	169.254.150.108 (NAO robot)
Destination MAC address	00:00:00:00:00:00
Ethernet header	
Source MAC address	A7:47:2A:0C:33:F0 (Testing host)
Destination MAC address	00:13:95:0B:D6:46 (NAO robot)
Ethernet Type	0 × 0806 for ARP message

3. After sending the fake ARP request packet to NAO robot, the testing host attempts to ping again the robot. If the testing host does not receive any ping response, then the fake ARP packet succeeded to corrupt NAO robot's ARP cache. Otherwise, the testing host would receive a ping response from NAO robot. Hence, NAO robot's ARP cache is vulnerable against ARP cache poisoning attack.

Performance Testing: Unfortunately, this experiment's result showed that the testing host did not receive any ping response from NAO robot. Consequently, NAO robot is not robust against ARP cache poisoning attack.

6 Analysis of Results

Based on the aforementioned experimental results, NAO robot showed clear weak resilience and robustness against the tested DoS attacks. The behavior of the robot while under the DoS attacks was unusual and the effect of the attacks on NAO robot's performance was evident. While it was under DoS attacks, NAO robot was unable to respond to most ping requests. Moreover, the LED pattern of NAO robot's eye has changed from white to red; meaning that the robot behavior became anger while it was under DoS attacks, as show in Fig. 8. In addition, NAO robot's hands and feet movements became relatively slow, just after starting the DoS attacks. NAO robot's response to execute tasks

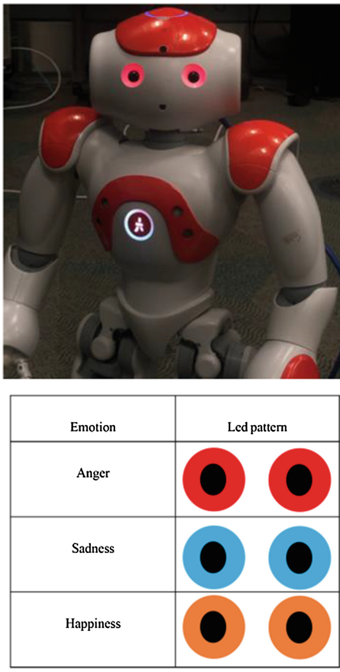


Fig. 8. NAO robot eyes' color when under DoS attacks

became also slow; its voice has changed, and it started talking slowly. In such a situation, NAO robot begun to ask for a rest, and its motor became hot.

7 Robots Security Enhancement

As an additional hands-on lab activity, robot security can be enhanced by implementing more efficient security measures and solutions on the robot. The following discusses a hands-on activity on implementing a firewall on NAO robot to enhace its robustness againt DoS attacks.

According to the conducted above experiments' results, it is clear that to be able to prevent and thwart potential attacks and offer reliable and efficient services, robots should be designed with sufficient security considerations. To achieve that objective, basically, common security solutions should be implemented in robots, mainly firewalls and intrusion prevention software. Moreover, the communication channels between the robots and other network devices should be encrypted. For example, the open-source firewall code [15] has been uploaded on NAO robot using WinSCP tool [14]. Experiments have been carried out to evaluate the performance of NAO robot against a number of DoS attacks under the following conditions:

- NAO robot is not running the uploaded firewall code.
- NAO robot is running the uploaded firewall code.

Two types of tests have been conducted while NAO robot is under DoS attacks, namely (1) pinging the robot, and (2) asking the robot to execute specific tasks. Table 2 summarizes the effectiveness of the uploaded firewall code in protecting NAO robot from the performed DoS attacks. In fact, Table 2 shows that when the uploaded firewall code is running, NAO robot demonstrated more robustness against the DoS attacks.

However, the uploaded firewall code was not completely efficient. This is because some ping packets were lost despite NAO robot was running the firewall code. In addition, when NAO robot was given tasks to execute, it took longer time to respond compared

Table 2. Evaluation of Nao Robot's Performance Against A Number Of Dos Attacks When It Is Running A Firewall

	Firewall code is NOT running	Firewall code is running
TCP Syn flood attack	Ping: No response Tasks: Not executed	Ping: Response Tasks: Executed
Land attack	Ping: No response Tasks: Executed	Ping: Response Tasks: Executed
SMURF attack	Ping: No response Tasks: Executed	Ping: Response Tasks: Executed
ICMP flood attack	Ping: No response Tasks: Not executed	Ping: Response Tasks: Executed

to the normal situation when the robot is not under DoS attacks. Therefore, a better firewall code is required to protect more efficiently NAO robot and to not degrade its performance.

On the other hand, most robots have limited computing and energy resources [1], and the use of software and hardware protection tools is not at all possible. Thus, research and development in this area is very relevant and necessary.

8 Conclusion

Robot security education is important for all curricula offering courses on robotics. Nowadays, robots can be deployed in untrusted and unsafe environments. As a consequence, robots are highly susceptible to attacks and can be easy targets, if they are designed and built without efficient security considerations. Therefore, the inclusion of robot security education in curricula is therefore considered a valuable extension. However, robot security is covered very briefly in most curricula and there is a lack of education publications discussing related teaching materials and hands-on lab activities. This paper discusses a model of hands-on lab activities that can be used in didactic environments to evaluate the robustness of robots under DoS attacks. The hands-on lab activities demonstrate clearly that the tested example robot is very vulnerable to DoS attacks and does not deploy built-in efficient security features to prevent or limit the success of the attacks. Student and educators can use the proposed activities to enhance their hands-on skills and knowledge on robot security. As a future work, similar hands-on lab activities, using other types of robots and attacks, can be discussed and tested.

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References

1. Basan, E., Makarevich, O., Abramov, E., Popov, D.: Analysis of the initial security of the robotics system. In: Proceedings of the 12th International Conference on Security of Information and Networks - SIN 2019 (2019)
2. Choregraphe software. https://www.robotlab.com
3. Bonaci, T., Herron, J.,Yusuf, T., Yan, J., Kohno, T., Chizeck, H.J.: To make a robot secure: an experimental analysis of cyber security threats against teleoperated surgical robots. ACM Trans. Cyber Phys. Syst. **02** (2015)
4. Vuong, T.P., Loukas, G., Gan, D., Bezemskij, A.: Decision tree-based detection of denial of service and command injection attacks on robotic vehicles. In: 2015 IEEE International Workshop on Information Forensics and Security (WIFS), November 2015
5. Quarta, D., Pogliani, M., Polino, M., Maggi, F., Zanchettin, A. M., Zanero, S.: An experimental security analysis of an industrial robot controller. In: 2017 IEEE Symposium on Security and Privacy (SP), May 2017
6. Priyadarshini, I.: Cyber security risks in robotics. In: Cyber Security and Threats, pp. 1235–1250 (2018)

7. Iida, F.: Autonomous Robots: From Biological Inspiration to Implementation and Control. In: George A.B. (ed.) Hardcover, p. 577. ISBN 0262025787. Artificial Life, vol. 13, no. 4, pp. 419–421, October 2007. (2005, MIT Press)
8. Clark, G.W., Doran, M.V, Andel, T. R.: Cybersecurity issues in robotics. In: 2017 IEEE Conference on Cognitive and Computational Aspects of Situation Management (CogSIMA), March 2017
9. DeMarinis, N., Tellex, S., Kemerlis, V.P., Konidaris, G., Fonseca, R.: Scanning the internet for ROS: a view of security in robotics research. In: 2019 International Conference on Robotics and Automation (ICRA), May 2019
10. Trabelsi, Z.: Hands-on lab exercises implementation of DoS and MiM attacks using ARP cache poisoning. In: Proceedings of the 2011 Information Security Curriculum Development Conference on - InfoSecCD 2011 (2011)
11. CommView tool. https://www.tamos.com
12. WireShark tool. https://www.wireshark.org
13. Kali Linux. https://www.kali.org
14. WinSCP. https://www.winscp.net.
15. Open-source firewall code. https://github.com/jlaine/python-netfilter/blob/master/netfilter/firewall.py

Robotics and Vision Station for Education

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Abstract. In an industrialized society like the one that the new generations face, it is important for them to have the skills that provide significant advantages over their competitors; therefore, institutions of higher education must be at the forefront of manufacturing technologies. The manufacturing region of the north in this country (Mexico) needs engineers with knowledge in robotics for industrial applications, according to the information provided by graduates and industry professionals. Such engineers are usually trained on how to operate equipment technically, sometimes bypassing the fundamentals of the operation of such machinery, leaving them without the tools to innovate and improve processes. The methodology proposed in this article provides a broad view of integrated manufacturing systems and includes the handling of materials and storage elements and parts processing. As technology for education, this exercise gives students the opportunity to develop a comprehensive project within their vocational training. Three robots were built in known industrial configurations based on 3D printing. The developed disciplinary skills focus on mechanical design, electronic design, mathematical design of the manipulator, and performance of industrial tasks using computer vision tools.

Keywords: Technologies for education · Industrial robotics · Innovative spaces · Higher education · Educational innovation

1 Introduction

The teaching of disciplinary competencies at the professional level increasingly requires in a timelier manner the combination of justified theoretical content with practical activities that help students assimilate acquired knowledge better. The main components of the Tec21 Educational Model of Tecnologico de Monterrey focus on promoting programs that are flexible in how, when, and where learning occurs, as well as generating interactive and challenging learning experiences in educational spaces that promote collaboration and innovation and the use of technology in the teaching-learning process [6].

"The robotics and vision station for Education" described in this article aims to be a space for educational innovation in which students can perform Hands-on experimentation trough robotic platforms from their earliest stage of design, construction, and programming to know in-depth how the most common industrial tasks are carried

W. Lepuschitz et al. (Eds.): RiE 2020, AISC 1316, pp. 76–85, 2021.
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out, such as palletization, detection and selection of objects, handling, and storage of materials, and transformation processes, etc.

This report has relevance since robotics in education is often far from the real needs of the industry, and the students do not have the opportunity to experiment with the whole elements involving the design, theory, and practice. With the acquisition of these skills and knowledge, the student is able to make proposals for innovation and improvement of industrial processes. Some additional transversal skills developed in students lie in the multi-disciplinary experiences in which they exploit their ingenuity within an ethical environment, learning to work collaboratively.

The following sections of this document describe in detail the development of the educational innovation proposal of this research, showing the details of implementation and the evaluation of results and, finally, the conclusions.

2 Development

2.1 Related Work

In some countries, the teaching of industrial robotics has engaged in the creation of both face-to-face and virtual laboratories with the intention of developing competencies in the students and equipping them with skills in the design, construction, and control of robots, specifically, the industrial robots that have a demand in the market keeps growing at a pace with technological advances. An example of one initiative of this type is at the Polytechnic University of Valencia, Spain [1], where the importance of the experimentation platforms for the teaching of robotics and the advantages of using technology for education is emphasized. In their project, they propose the use of LEGO Mindstorm® as a basis for experimentation.

On the other hand, Mansoor et al. [5] propose an open-architecture platform for object manipulation in which robot control and computer vision techniques are merged in an educational application. The research yielded favorable results related to the ability of students to comprehend the concepts better when the phenomenon studied is physically viewed. This advantage lies in this present project, which gifts the student with an experimentation station where he will see directly reflected the design of the robot in question, applying his knowledge in the development of industrial applications.

In the matter of pedagogy, Barrera [4] describes the application of playful activities with educational robots to reinforce the creativity of students with the use of technology. The availability of suitable spaces and the necessary equipment provide the proper conditions for the development of creativity and the impetus for critical and innovative thinking by the students.

2.2 Description of the Educational Innovation

Because robotic platforms on the market represent a high investment and their control characteristics are limited to the software provided by the manufacturer, the creation of robotic stations by students becomes an attractive and feasible proposition, giving rise to the development of multidisciplinary skills in project planning, technological search, budget management, communication with suppliers, executive presentation of results, technical reports, etc.

The educational innovation in this project focuses on creating an experimentation space where experiential learning can be developed. In principle, the design and construction of the prototypes give the student additive manufacturing tools using 3D printing for the creation of essential parts in the mechanism of the robots, right away, the electronic instrumentation with the selection of sensors and actuators that are correct for each prototype. An important and regular part of university courses in industrial robotics is the mathematical design and use of simulators that, in this case, is validated with the functional prototype for, finally, the generation and control of the trajectories applied in the industrial processes at scale. In addition to the projects done by students, computer vision tools are added for process control, parts identification, inspections, pattern recognition, etc.

2.3 The Implementation Process of the Innovation

Table 1 presents the methodology used to follow up on the development of the project was applied research where students are expected to address topics and activities related to technological development in the phases of prototyping and construction with 3D printing, scientific development in the mathematical design phase for control of the platforms, and computer vision, covered by the professor in class and implemented by the students on the experimentation platforms. Finally, the students have the opportunity to develop innovative ideas for industrial applications. The focus of this research was qualitative, as one of the objectives was to identify the positive factors in the learning of the students who were using innovative spaces to learn industrial robotics and the integration of manufacturing systems. The group considered for the study was constituted by 24 students of 8th semester in mechatronics engineering, with the presence of 4 female and 20 male students.

In the first stage, the correct functioning of the platforms was reviewed by measuring the impact generated on students through surveys and a review of the documentation. In the second stage, a satisfaction survey was done with respect to the use of mathematical tools, the construction of prototypes, and the review of documentation. Finally, the third stage looked at the innovative factor in the proposed applications, analyzing the social and industrial problems that were resolved, generating process improvements. The record of student satisfaction, along with the review of the documentation and the progress achieved in the different phases, yield the criteria required to evaluate the implementation.

Phase 1. Technological Development

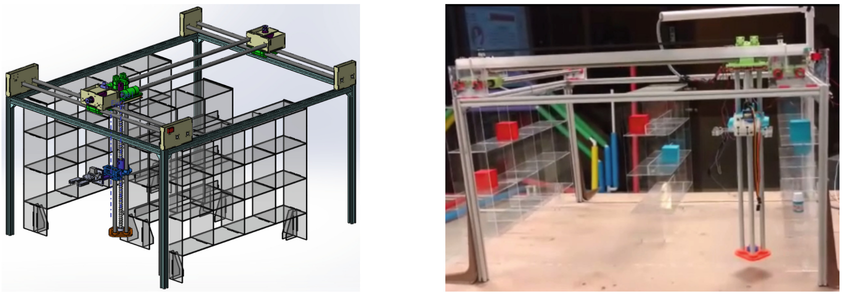
Stage 1 consisted of the design and construction of the prototypes. Three typical architectures of industrial robots were selected. These prototypes were designed in SolidWorks® using the actual measurements of the different components, such as motors and bearings, mainly because 90% of the structure was 3D-printed using ABS plastic as raw material.

- Figure 1 shows the AS/RS Robot *(Automatic Storage and Retrieval System)* with four degrees of freedom and storing spaces. The main purpose of the prototype is for "Materials handling and storage".

Table 1. The stages of implementation of the educational innovation.

Phase	Focus	Tasks	Instrument applied
1	Technological development	Design and construction of prototypes	Preliminary survey Documentation
2	Scientific development	Mathematical design and computer vision tools	Satisfaction surveys Documentation
3	Innovation and process improvements	Design of industrial applications	Impact on learning Final survey Documentation

- Figure 2 shows the SCARA Robot (*Selective Compliant Articulated Robot Arm*) with four degrees of freedom. The main purpose of the prototype is for “Handling and assembly tasks”.
- Figure 3 shows the Articulated Robot with 6 degrees of freedom. Positioning tasks that require complex positioning, e.g., Selection of elements, welding or airbrush painting, etc.



a) 3D Model b) Prototype

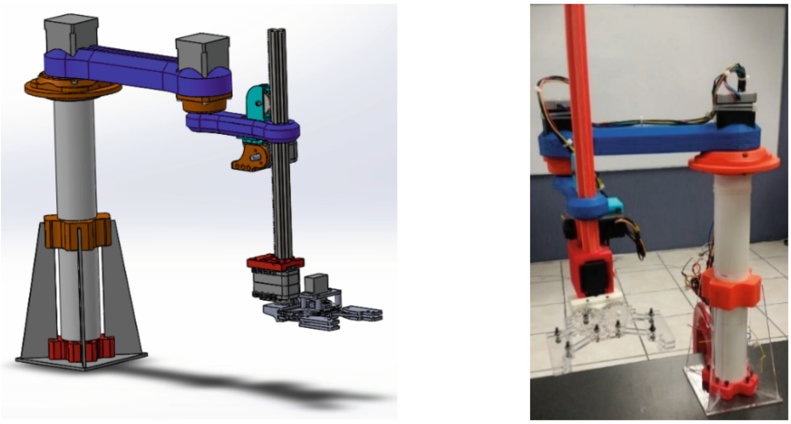
Fig. 1. Design and construction of the AS/RS system.

Phase 2. Scientific Development

Stage 2 consisted of the mathematical design and the use of computer vision tools. The mathematical design mainly consisted of the development of the direct kinematics, differential kinematics, and kinematic control of the proposed models. To illustrate this, Fig. 4 shows the simulator of the 3 platforms using the Matlab® robotics toolbox [2], which allows visualizing the kinematic chains.

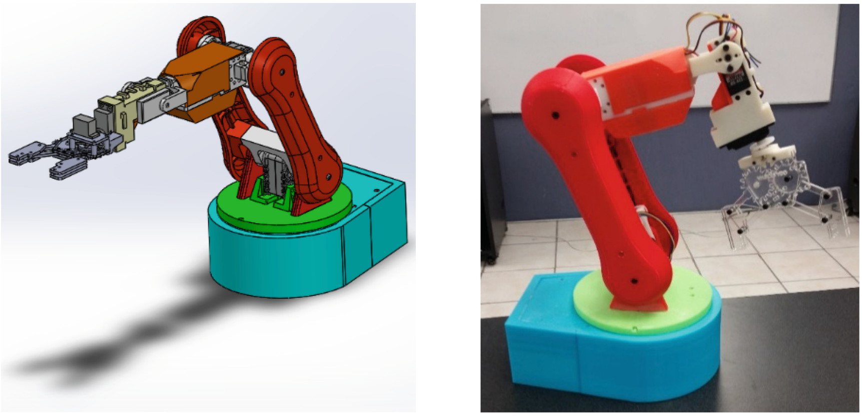
With the simulations, the movement capabilities of the robots can be observed in order to determine the validity of the mathematical models and then continue to the next stage in the proposed industrial applications.

For a more detailed analysis of this stage, consult the article presented at the 8th Multidisciplinary Scientific Research Congress 2016 [3].



a) 3D Model b) Prototype

Fig. 2. Design and construction of the SCARA robot.

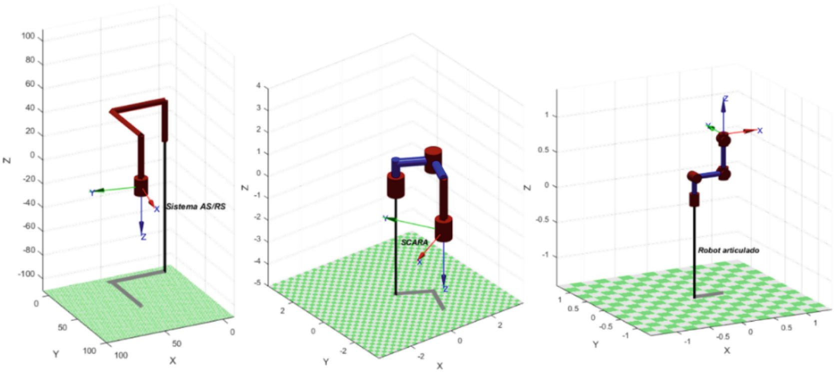


a) 3D Model b) Prototype

Fig. 3. Design and construction of the articulated robot.

Phase 3. Innovation and Process Improvements

Stage 3 was developed based on the observation of real industry tasks and their adaptation to the workspace of the robots, with the help of computer vision tools for the identification of objects by color, size, and location. Figure 5 shows the presentation of the final projects with the industrial applications. From left to right, the AR/RS system was programmed to distribute materials into the storing spaces, the SCARA to perform pick and place tasks, and the articulated robot to identify the position, color and size or certain elements to classify them into specific containers.



a) AS/RS system b) SCARA robot c) Articulated robot

Fig. 4. Simulation in Matlab.

Fig. 5. Presentation of the final projects.

2.4 Evaluation of Results

Table 2 presents a comparison between the periods August-December 2017, when the methodology was not implemented, and August–December 2018, which had the implementation of the methodology. Although the average performance of the group shows that it benefited from the methodology, the satisfaction surveys show even stronger results from a qualitative viewpoint.

Table 2. Comparison of overall average in the two periods.

Overall average of the industrial robotics subject	
August–December semester 2017	August–December semester 2018
83	89

The documentation in all three stages was evaluated according to technical reporting standards, taking into account content, spelling, the correct format in APA, and personal conclusions.

Below are shown the results of the surveys applied to the group of 24 students in the Industrial Robotics class.

In stage 1, a brief preliminary survey was applied to know the degree of knowledge the students had regarding the topics that would be developed during the project. The questions are shown in Table 3.

Table 3. Preliminary survey.

Question	Choice	
	Yes	No
Have you worked on prototype designs?	5	19
Have you used 3D printers?	10	14
Do you know the mathematical fundamentals of an industrial robot?	0	24
Do you think experiential learning is important?	24	0
Have you designed in 3D?	24	0
Have you asked your professor, "And how is this going to help me?	20	4
Do you feel motivated by the project?	22	2

The preliminary survey shows that for most of the students, the activity of building prototypes was new, but they did have knowledge about CAD design; only some had used a 3D printer. In their entirety, they believed that learning should be related to practice. None knew the mathematical fundamentals of an industrial robot. The intention of the question "And how is this going to help me?" was to prepare the student for a paradigm shift where mathematical knowledge is required for real-life problems with appreciable application. And, finally, one could observe high motivation for the project.

Stage two related to scientific development, this focused on the implementation of mathematical tools and the topics of computer vision. A short survey was conducted again, shown in Table 4, to poll the development of the class. Each question was based on a scale of 1 to 5, where 1 is the lowest level, and 5 is the highest.

Figure 6 shows the results of the survey, using the proposed valuation scale. Each question was answered by the 24 students about their current state of satisfaction and learning with respect to the development of the project.

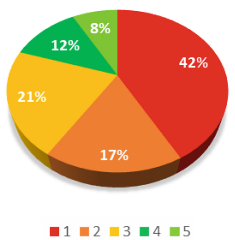
The answers given by students managed to give a picture of the students' perception of the challenge shown in the design and construction of the prototype, where it was noted that the majority considered it complex in all the sections, mechanical, electronic, and mathematical.

The great majority considered the use of the simulator relevant for the design of the robot because it facilitated the understanding of the mechanism and the mathematical implications.

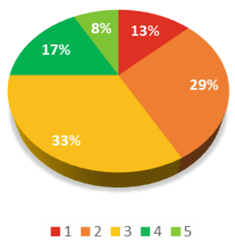
One important result to highlight is that, although the level of frustration was high for some students, most had a high level of satisfaction as well.

Table 4. Second stage survey.

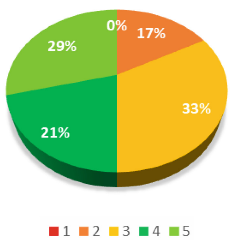
	Question
1	How complex was it to build the prototype?
2	How complex was it to perform the mathematical analysis?
3	What level of difficulty do you think the electronic design has?
4	Is the use of a simulator pertinent?
5	What is your level of frustration so far?
6	What is your level of satisfaction so far?



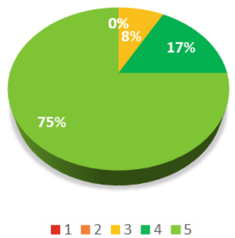
Question 1.



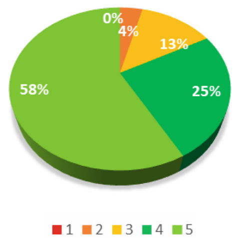
Question 2.



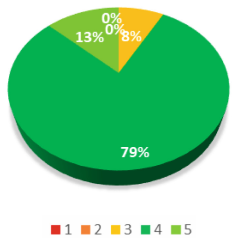
Question 3.



Question 4.



Question 5.



Question 6.

Fig. 6. Table 4 survey results.

The final survey of the project was focused on knowing the degree of learning and student satisfaction they had in carrying out an integrated project, where they were able to put the knowledge of the subject into practice in a real situation with the tasks of a modern manufacturing system. The survey is shown in Table 5. Each question is based on a scale of 1 to 5, where 1 is the lowest level, and 5 is the highest.

Figure 7 shows the results of the final survey, where a high degree of student satisfaction is observed, also indicated by additional comments made by students that are

Table 5. Final survey.

	Question
1	The content of the subject matter was better assimilated due to performing the project
2	What is your level of satisfaction for the development of the project?
3	The development of projects of this type would improve other areas
4	At what level do you know the functioning of an industrial robot after carrying out the project?
5	The knowledge acquired could be applied in real-life challenges

not attached, such as, "This is one of the few projects that have been done with real application, from scratch, and with satisfactory results."

In the opinion of the students, they had better learning because the subject contents were directly applied in a project, where the degree of satisfaction is evidentially high, and the acceptance of the strategy is such that they would like to apply it in other subjects. Most students trust the knowledge acquired because they assimilated it better by applying it directly to functional prototypes. Finally, all the students believed that they had applied the knowledge acquired in a real-life situation.

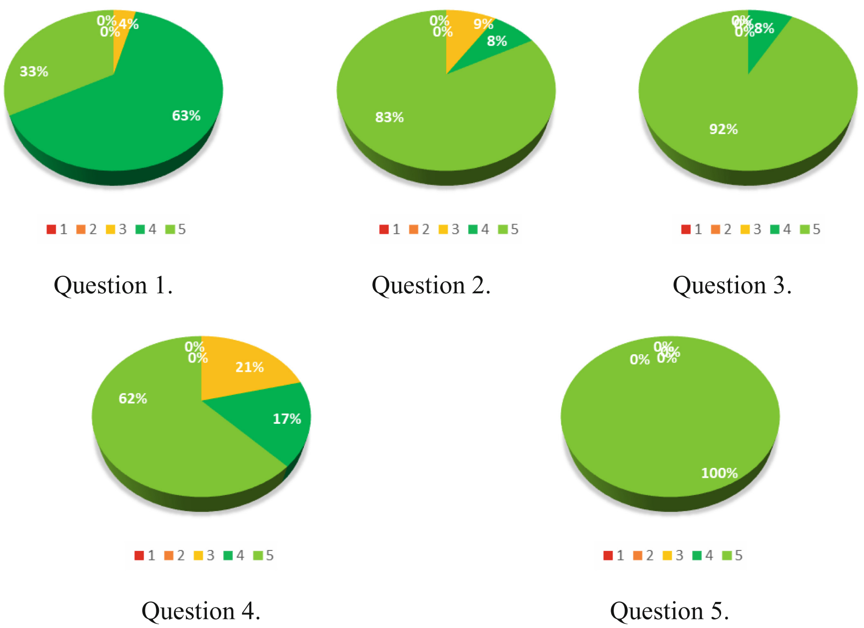


Fig. 7. Results of the final survey.

3 Conclusions

This project is strategically aligned to the Tec 21 Educational Model of Tecnologico de Monterrey, where the student is exposed to real problems, allowing the development of competencies that make the student more competitive worldwide. This educational innovation is experiential, collaborative, and knowledge integrator; it generates motivation in the students and a sense of achievement. This innovative space gives flexibility in student learning experiences.

The results assessment shows that students are more committed and motivated with their own learning. The overall average evaluation of the course was improved by using the methodology of this project.

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References

1. Valera, A., Soriano, A., Vallés, M.: Plataformas de Bajo Coste para la Realización de Trabajos Prácticos de Mecatrónica y Robótica, Revista Iberoamericana de Automática e Informática Industrial RIAI, vol. 11, no. 4, pp. 363–376. Elsevier (2014). ISSN 1697-7912
2. Corke, P.I.: Robotics, Vision and Control: Fundamental Algorithms in MATLAB. Springer, Berlin (2013)
3. Hernández-Rodriguez, F., Benavidez-Téllez, E.: Diseño y análisis de prototipos funcionales para el estudio de cinemática directa en robótica industrial. 8° Congreso Internacional de Investigación Multisciplinaria 2016, vol. 4, pp. 4–19 (2016). ISSN 2395–9711
4. Barrera, N.: Uso de la robótica educativa como estrategia didáctica en el aula. Praxis & Saber, Revista de investigación y pedagogía, vol. 6, no. 11, pp. 215–234, Uptc (2015)
5. Manzoor, S., Islam, R.U., Khalid, A., Samad, A., Iqbal, J.: An open-source multi-DOF articulated robotic educational platform for autonomous object manipulation. Robot. Comput. Integr. Manuf. **30**(3), 351–362 (2014). ISSN 0736-5845
6. de Monterrey, T.: Modelo educativo Tec21, Manual. Tecnológico de Monterrey (2016). https://modelotec21.itesm.mx/files/folletomodelotec21.pdf

Teaching Daily Life Skills in Autism Spectrum Disorder (ASD) Interventions Using the Social Robot Pepper

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Abstract. Advances in robot capabilities over the last few years have resulted in the introduction of robots in many disciplines. Amongst them, the field of *special* education attracts scientific attention, towards studying the effect of social robots in the treatment of children with Autism Spectrum Disorder (ASD). This paper presents a pilot study in a real therapeutic setting, using the social robot Pepper to interact with three children with ASD in specially designed educational scenarios regarding monetary transactions. The goal of these scenarios is to enhance short-term and long-term memory, as well as communication and social skills, through exercises involving coins and banknotes. Ultimately, these exercises will be part of a broader effort to help children with autism acquire daily life skills and self-reliance. The pilot study was evaluated using observation sheets completed by the therapist, which were then used to qualitatively assess the effectiveness of the proposed approach. The preliminary results show that the intervention results in increasing engagement and the motivation in communicating.

Keywords: Social robots · Special education applications · Autism spectrum disorder (ASD) intervention · Child-robot interaction

1 Introduction

The increasing number of studies that investigate the use of robots for educational purposes is indicative of the recognition of the benefits that robots bring into this field. In the case of special education in particular, robots have been found to be useful for a variety of conditions such as Autism Spectrum Disorder (ASD), learning disabilities, behavioral disorders and developmental disabilities. Eliciting child response and maintaining

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a high degree of engagement are some of the aspects that robots can offer towards the successful treatment of the aforementioned conditions. It is universally accepted that Socially Assistive Robots (SARs) have a significant role to play as pedagogical rehabilitation tools [1], especially when the educational objectives are strongly related with the acquisition and/or improvement of social skills.

Most of the work that can be found in the literature regarding robots in special education deals with ASD treatment [2–5]. Autism, estimated to affect one of every eighty eight children, is marked by the presence of impairments along a triad of dimensions: social interaction, communication, and imagination [6, 7]. A variety of approaches has been proposed, each designed to address a different aspect of ASD. For example, the promotion of social behaviors and communication skills resulting via engaging in game scenarios is the main goal of collaborative games [8], theatrical plays [9], or individual activities in the form of games such as cooking [10], storytelling [11] and imitation games [12]. Other studies are focused on increasing body awareness and teaching body parts identification by robot-assisted play [13] or by using imitation games and dance therapy [14]. The promotion of joint attention has also been the main theme of some studies, which exploit the attractive appearance of the robot and its ability to produce visual stimuli that capture the attention of children [15, 16]. Previous work by the authors has focused on the aspect of human-robot interaction and engagement measurement [17]. In a recent study, a series of interaction games using the NAO robot, designed for children with autism have been proposed in [18]. The proposed games aim at improving skills such as social interactions, memory association and motor response. In [19], a system for emotional state recognition and behavior selection is described.

The work presented in this paper aims at the development of social robot-based therapeutic interventions in order to deal with certain types of autism, and the application of these interventions in a real-world setting at the Novel Therapeutic and Consulting Unit Praxis in Kavala, Greece. Although the majority of similar studies have employed the NAO robot as mentioned above, in this study the educational activities are conducted with the social robot Pepper, so that different aspects, such as the effect of the robot's appearance, are also investigated. The activities that have been designed are focused on developing children's daily life skills and specifically to teach them about money and how to handle simple monetary transactions. They include activities such as free play, memory games, identification games and others, and were divided into six sessions. In the present paper, the suitability of these activities is evaluated through pilot studies with three children with autism. Evaluation takes place using observations sheets investigating behavioral aspects such as speech (duration, number of words etc.), eye contact, gestures, communication, etc. so that it can be determined whether the proposed activities are accepted and can keep children engaged.

The present paper is structured as follows: Sect. 2 presents the technical implementation details and the intervention protocol. In Sect. 3, the results of the intervention are presented and discussed. Finally, in Sect. 4 the conclusions of the study are summarized and future steps in the research are outlined.

2 Materials and Methods

In this section, the social robot Pepper, the implementation details and the training protocol are described.

2.1 The Social Robot Pepper

The social robot Pepper is a wheeled humanoid robot designed for extended human-robot interaction. Although the NAO robot has been used extensively in earlier robot-assisted ASD therapy studies (see for example [20]), and apart from differences in appearance and size, there have only been a few studies where the Pepper robot has been featured, even though it presents some advantages. More significantly, it has the additional advantage of being equipped with a tablet, which increases the child-robot interaction modalities. On one hand, the tablet can display content such as videos and images and generate additional visual stimuli, not otherwise available. On the other hand, the child can also interact with the Pepper robot and convey information using the touch screen. Also, another advantage of the Pepper robot is its increased energy autonomy compared to the NAO robot, which allows for longer child-robot interaction sessions.

A number of the Pepper's capabilities have been used for the implementation of the designed intervention. More specifically, the built-in speech recognition and text-to-speech engines have been used for verbal communication to and from the robot. During speech, Pepper is set to move its hands and torso so that it is given a more human-like behavior, and improve the child's experience. Pepper's LEDs in the eyes and body as well as Pepper's speakers are used to give visual and auditory feedback depending on the child's performance in each exercise. At all times, the robot uses of its top camera in order to track the child's face. During tracking, the Pepper robot turns its head to the direction of the child for the purposes of establishing eye contact, and therefore contribute towards maximizing the engagement. Pepper's cameras are also used to recognize predefined objects. In order for Pepper to be able to recognize the objects that are used in the corresponding exercises, an image dataset containing these objects has been created beforehand. Finally, a Graphical User Interface (GUI) was implemented on the tablet, from which the child as well as the therapist have access to the various exercises, as will be described in the next section.

2.2 Methodology

The intervention is divided into the six sessions outlined in Table 1. The duration of each session is 45 min, and they take place twice per week. No special technical knowledge is required by the therapist to operate the robot, only simple instructions to initialize the software from a laptop computer.

At the beginning of the first session, the therapist accompanies the child towards the robot, makes the introduction and points out the necessary rules, such as to tackle the activities in order, not to rush the completion of the activities, and to notify the therapist if the child is tired or bored. Also, instructions are given on the proper use of the robot, i.e. to keep a distance from the robot, to speak directly to the robot, to allow time for the robot to answer and to touch its screen softly. It is made clear to the child that the session

Table 1. Summary of the games in each of the six sessions

Session number	Activities
Session 1	1a. Introduction to the robot and its capabilities 1b. Memory game
Session 2	2a. Game for teaching coins 2b. Coin recognition game 2c. Memory game
Session 3	3a. Game for teaching banknotes 3b. Banknote recognition game 3c. Memory game
Session 4	4a. Learning coin value 4b. Recognition game with coins
Session 5	5a. Learning banknote value 5b. Recognition game with banknotes
Session 6	6a. Familiarization with monetary transactions 6b. Practice on monetary transactions

can stop anytime if it needs a break. The first contact of the children with Pepper is a short demonstration of the robot's most important functions, both visual and auditory, such as robot movements, tablet usage, music playback, pictures of images, etc. Children with ASD have difficulty in social interaction due to its unpredictable and critical nature [21]. Therefore, it is suggested that the main purpose of the first free-play session is to give each child the opportunity to get to know the robot and its functionalities. Therefore, the child can gain a better sense of the robot that he/she interacts with and hopefully can feel less anxious. Free play can be repeated more than once if needed or as a reward at the end of subsequent scheduled sessions. After the brief introduction, a memory game follows. Three objects are displayed for a few seconds on the tablet screen, while the robot is giving instructions. Then, the screen displays the same objects in random order among seven other objects. Figure 1 illustrates this screen. The child is asked by the robot to recall and tap on all three objects that were initially shown. In the event of a wrong answer, the robot urges the child to retry. If the answer is correct, the robot congratulates the child, a clapping sound is played and the eye and head LEDs of the robot are blinking in various colors for a few seconds. For each task, two attempts are allowed before the child proceeds with the next task. This scheme for rewarding correct answers is followed throughout the intervention, since the combination of visual cues and enticing activity types could help motivate children with ASD and encourage flexible thinking [22].

The therapist also asks the child various questions about these objects such as the price, the utility and personal experience of the individual with these objects. Studies have shown that when the recollections are associated with personally experienced events, these are remembered more concretely. Consequently, the way that things are paired with experienced memories creates a very specific pattern in the brain and the way that memory recognizes the stimuli [23].

Fig. 1. Screenshot of the memory game of the first session

The second session consists of three games. It starts with a sliding display of all available coins on the tablet. Once the child has been taught and is able to recognize each coin, it slides to the right to see the next one. The lack of concentration of autistic children on a particular subject is very common. Studies have shown that concentration is better when associated with interactive computer games [24]. Therefore, the therapist, who is next to the child, keeps on adding further aspects to the procedure such as what can be bought with this amount of money etc. in order to make it more interesting. For the second game, two coins appear on the tablet screen for a certain amount of time and the child is asked to identify and remember them. The coins then disappear and the child is asked to answer recall the coins that appeared on the screen. If it gives the right answer it is rewarded, but if the wrong answer is given, it is asked to try again. The third game of the second session is a classic memory game, where there is a board of tiles which the child has to flip and find pairs of identical coins. Every time a pair is revealed, the robot congratulates the child. The purpose of the memory games is to achieve the recognition of coins but also to improve the recollection ability. Understanding memory in ASD is crucial, because memory abilities can influence the way the individual is learning in general [25]. Figure 2 illustrates the games in the second session. Similarly, the games of the third session are the same as the second session's, only in this case instead of coins, banknotes are used.

The fourth session consists of two games. The first game aims at teaching coin denominations. Initially, all coins appear on the screen. When the child taps on one of the coins, the robot says which coin it is, and also displays all its denominations. For example, when the 10-cent coin is tapped, ten 1-cent coins, five 2-cent coins and two 5-cent coins appear on the screen. The therapist also helps the child understand the concept of value. The second game of this session addresses the tendency of children's with ASD to memorize patterns related to numbers and sequences [26] and the difficulty to recognize coins if picked randomly. Coins appear on the tablet screen except for the 2€ coin. The child needs to select coins in sequence that amount to 2€. Every time a coin is selected, the remaining amount is displayed on the screen and also spoken by the robot. Figure 3 shows the games of the fourth sessions. Session 5 is identical to the fourth session except in this case banknotes are used.

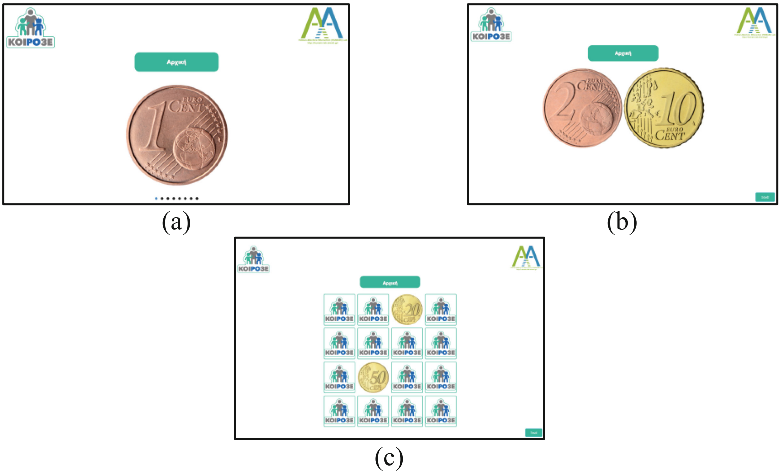

Fig. 2. Screenshots of the games in the second session: a) teaching coins, b) coin recognition and c) memory game

Fig. 3. Screenshots of the games in the fourth session: a) coin denominations, and b) coin addition

Finally, the sixth session deals with familiarizing children with buying items and at the same time keeping them visually engaged. People with ASD often have trouble with generalization. It is not easily understandable that different products can be bought with the same amount of money [26]. In the first game of the sixth session, Pepper acts as a cashier and asks the child which of four items it would like to buy. At the same time, the items (doll, board game, ball, chocolate) are displayed on the screen, as shown in Fig. 4. The objects are also available in physical form in the room, on a table next to the child, together with printed banknotes. The child chooses the item and shows it to Pepper. Pepper then recognizes the item and announces its price. Next, the child is asked by the robot to choose the banknote that is needed in order to buy the selected product and show it to the robot. If the right banknote is chosen, then Pepper congratulates the child. If the wrong banknote is picked, then Pepper encourages the child to try again.

Fig. 4. Main screen for the games of the sixth session

The second game of session 6 is similar to the first, only this time the prices of the items do not correspond exactly to the available banknotes, which means that after the selection of the banknote, there will be change. The robot computes the change and asks the child if it is correct. Depending on the child's answer, the robot congratulates the child or asks it to try again.

2.3 Evaluation

To evaluate the various behavioral aspects of the children during the pilot study, the evaluation sheet with the measures presented in Table 2 was used. The evaluation sheet was filled out by the therapist immediately after the end of each session.

Table 2. Measures included in the evaluation sheet

Measure	Possible values
Eye Contact	None/Medium/Satisfactory
Speech	None/Medium/Satisfactory
Voice Volume	Low/Medium/Satisfactory
Unprompted Communication	None/Medium/Satisfactory
Gesture communication	Yes/No/Sometimes
Focus on Tasks	None/Limited/Satisfactory
Word number	<20/20–50/>50
Unprompted imitations	<5/5–10/>10
Incorrect attempts/Answers	<5/5–10/>10

3 Application and Results

The pilot study took place with the participation of three children with ASD in the facilities of the Novel Therapeutic and Consulting Unit "Praxis" in Kavala, Greece. All the children were male from 6 to 12 years old, all of them with verbal abilities.

Fig. 5. Child interacting with the robot Pepper under the supervision of the therapist

Before selection, parental consent was obtained for all children. Figure 5 shows the child together with the robot and the therapist in one of the sessions.

Apart from the evaluation sheet presented in the previous section, notes were also kept for each child separately. The first child, S. H., age 9, is hyperactive and impulsive. His level of cognitive ability is higher compared to other children of his age. He already knew how to use money and he enjoyed the sessions. Given his observed excitement to sit opposite a robot, it was hard for him to control himself and the therapist frequently attempted to slow him down and follow the prescribed order of the activities. It was impressive that he tried to respond slowly in order to give Pepper the time to ask the next question. According to his usual therapist, the realization of this type of interaction was one of the most important goals for the particular child, and the therapist claims that this session was a small step towards this goal.

The second child was T.D., age 6. He has a constant need of communicating and speaking a lot, he is very social and he never used money before. The positive outcome of the session was that he learned the value of the various coins very quickly. He was very interested in the activities and especially those displayed by Pepper's screen. The child tried to speak less in order to hear the robot clearly. He was excited when Pepper congratulated him. When Pepper turned his head in another direction focusing briefly on the therapist, T.D. kindly asked why Pepper is not looking at him. His therapist observed that it was strange for that he noticed the lack of attention by the robot. When Pepper turned his head towards him again T.D. was very happy and said that they are friends now.

The last child was K.S., age 12. Although K.S. was the oldest of the three children, he did not know how to use money, nor he had knowledge of basic math like addition or subtraction. He was very happy to meet Pepper. He engaged in echolalia and constantly repeated what Pepper was asking. He was quite impulsive and had a difficult time following the rules set by the therapist or following the instructions given by the robot. He had trouble distinguishing between coins and banknotes. Despite the objective difficulties, K.S. completed the session without complaining and without raising his voice. His therapist finds it very positive that he engaged in a complex subject that he did not want to learn before.

Table 3 and 4 summarize the observed behaviors for the three children, for each of the selected measures per game category.

Table 3. Evaluation sheet results for the three children (1)

		Eye Contact	Speech	Voice Volume	Unprompted Communication	Gesture communication
Introductory Game	**C1**	Medium	Medium	Satisfactory	Medium	Sometimes
	C2	Medium	Medium	Satisfactory	None	No
	C3	Medium	Medium	Low	None	Sometimes
Memory Game	**C1**	Medium	Satisfactory	Medium	Medium	Sometimes
	C2	None	Satisfactory	Medium	None	No
	C3	Medium	Medium	Low	None	Sometimes
Teaching Coins	**C1**	Medium	Satisfactory	Medium	None	No
	C2	Medium	Satisfactory	Medium	None	No
	C3	None	Medium	Low	None	Sometimes
Recognizing coins	**C1**	Medium	Satisfactory	Medium	None	No
	C2	Medium	Satisfactory	Medium	None	No
	C3	Medium	Medium	Low	None	Sometimes
Coin Memo	**C1**	Medium	Satisfactory	Medium	Medium	Sometimes
	C2	None	Satisfactory	Medium	None	No
	C3	Medium	Medium	Low	None	Sometimes

Based on the evaluation sheet and additional observations by the therapist, certain conclusions about the overall performance of the children during the sessions can be drawn. Firstly, the focus of the children in the activities has been increased, compared to previous observations regarding therapy sessions without the Pepper robot. They were also very motivated to find the correct answers to the various quizzes, by attempting to answer multiple times. Moreover, the volume of the children speech was relatively high, indicating that the children were keen to communicate with the robot. In addition, it is observed that the children were in general more prone to communicate with speech as well as gestures.

Table 4. Evaluation sheet results for the three children (2)

		Focus on Tasks	Word number	Unprompted imitations	Incorrect attempts/Answers
Introductory Game	**C1**	Satisfactory	20–50	<5	<5
	C2	Satisfactory	<20	<5	<5
	C3	Limited	<20	<5	5–10
Memory Game	**C1**	Satisfactory	<20	<5	<5
	C2	Satisfactory	<20	<5	<5
	C3	Limited	<20	<5	>10
Teaching Coins	**C1**	Satisfactory	<20	<5	5–10
	C2	Satisfactory	<20	<5	<5
	C3	Limited	<20	<5	>10
Recognizing coins	**C1**	Satisfactory	20–50	<5	5–10
	C2	Satisfactory	<20	<5	<5
	C3	Limited	<20	<5	>10
Coin Memo	**C1**	Satisfactory	20–50	<5	5–10
	C2	Satisfactory	<20	<5	<5
	C3	Limited	<20	<5	>10

4 Conclusions

ASD is a condition which presents with varying characteristics and challenges. Most people with ASD face difficulties in engaging with other people through social attention, thus making certain activities challenging. Monetary interaction constitutes a common human's day life activity as well as an essential skill for people to achieve (partial or complete) independence. The results of the three pilot sessions produced encouraging results regarding the suitability of the proposed intervention in teaching monetary interactions, and support the theory that a social robot can be a useful tool for professionals (therapist and teachers) when trying to teach social skills to children with ASD. The research is still in its initial stages and several questions need to be answered. For example, it has to be determined whether the intervention has long-term results and whether the level of engagement would be as high, if the intervention was to be repeated. The next step is to apply the intervention in a larger scale, and steer the research in the direction of comparing children's performance when the teaching is carried out with and without the presence of a social robot.

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References

1. Kaburlasos, V.G., Vrochidou, E.: Social robots for pedagogical rehabilitation: trends and novel modeling principles. In: Dimitrova, M., Wagatsuma, H. (eds.) Cyber-Physical Systems for Social Applications. Advances in Systems Analysis, Software Engineering, and High Performance Computing (ASASEHPC), pp. 1–21. IGI Global (2019). https://doi.org/10.4018/978-1-5225-7879-6.ch001
2. Lewis, L., Charron, N., Clamp, C., Craig, M.: Soft systems methodology as a tool to aid a pilot study in robot-assisted therapy. In: 2016-April ACM/IEEE International Conference on Human-Robot Interaction, pp. 467–468 (2016). https://doi.org/10.1109/HRI.2016.7451809
3. Pennisi, P., Tonacci, A., Tartarisco, G., Billeci, L., Ruta, L., Gangemi, S., Pioggia, G.: Autism and social robotics: a systematic review. Autism Res. **9**, 165–183 (2016). https://doi.org/10.1002/aur.1527
4. Pachidis, T., Vrochidou, E., Papadopoulou, C.I., Kaburlasos, V.G., Kostova, S., Bonković, M., Papić, V.: Integrating robotics in education and vice versa; shifting from blackboard to keyboard. Int. J. Mech. Control. **20**, 53–69 (2019)
5. Holeva, V., Nikopoulou, V.-A., Papadopoulou, M., Vrochidou, E., Papakostas, G.A., Kaburlasos, V.G.: Toward robot-assisted psychosocial intervention for children with Autism Spectrum Disorder (ASD). In: Salichs, M.A., Ge, S.S., Barakova, E.I., Cabibihan, J.-J., Wagner, A.R., Castro-González, Á., He, H. (eds.) ICSR 2019. LNCS (LNAI), vol. 11876, pp. 484–493. Springer, Cham (2019). https://doi.org/10.1007/978-3-030-35888-4_45
6. Bartoli, L., Garzotto, F., Gelsomini, M., Oliveto, L., Valoriani, M.: Designing and evaluating touchless playful interaction for ASD children. In: Proceedings of the 2014 Conference on Interaction Design and Children - IDC'14, pp. 17–26. ACM Press, New York, USA (2014). https://doi.org/10.1145/2593968.2593976
7. Dimitrova, M., Wagatsuma, H., Kaburlasos, V., Krastev, A., Kolev, I.: Towards social cognitive neuropsychology account of human-robot interaction. Complex Control Syst. **1**, 12–16 (2018)
8. Huskens, B., Palmen, A., Van der Werff, M., Lourens, T., Barakova, E.: Improving collaborative play between children with autism spectrum disorders and their siblings: the effectiveness of a robot-mediated intervention based on lego® therapy. J. Autism Dev. Disord. **45**(11), 3746–3755 (2014). https://doi.org/10.1007/s10803-014-2326-0
9. Jeon, M., Barnes, J., FakhrHosseini, M., Vasey, E., Duford, Z., Zheng, Z., Dare, E.: Robot Opera: a modularized afterschool program for STEAM education at local elementary school. In: 2017 14th International Conference on Ubiquitous Robots and Ambient Intelligence (URAI), pp. 935–936. IEEE (2017). https://doi.org/10.1109/URAI.2017.7992869
10. Simut, R.E., Vanderfaeillie, J., Peca, A., Van de Perre, G., Vanderborght, B.: Children with autism spectrum disorders make a fruit salad with probo, the social robot: an interaction study. J. Autism Dev. Disord. **46**(1), 113–126 (2015). https://doi.org/10.1007/s10803-015-2556-9
11. Dimitrova, M., Lekova, A., Chavdarov, I., Kostova, S., Krastev, A., Roumenin, C., Stancheva, V., Andreeva, A., Kaburlasos, V.G., Pachidis, T.: A multidisciplinary framework for blending robotics in education of children with special learning needs. In: Palalas, A., Norman, H. (eds.) Proceedings of the International Association for Blended Learning Conference (IABL 2016), pp. 152–155, Kavala, Greece (2016)
12. Tapus, A., Peca, A., Aly, A., Pop, C., Jisa, L., Pintea, S., Rusu, A.S., David, D.O., Hammouda, O., Borbély, G.: Children with autism social engagement in interaction with Nao, an imitative robot: a series of single case experiments. Interact. Stud. **13**, 315–347 (2012). https://doi.org/10.1075/is.13.3.01tap
13. Costa, S., Lehmann, H., Dautenhahn, K., Robins, B., Soares, F.: Using a humanoid robot to elicit body awareness and appropriate physical interaction in children with autism. Int. J. Soc. Robot. **7**(2), 265–278 (2014). https://doi.org/10.1007/s12369-014-0250-2

14. Suzuki, R., Lee, J., Rudovic, O.: NAO-dance therapy for children with ASD. In: Proceedings of the Companion of the 2017 ACM/IEEE International Conference on Human-Robot Interaction - HRI'17, pp. 295–296 (2017). https://doi.org/10.1145/3029798.3038354
15. Breazeal, C., Dautenhahn, K., Kanda, T.: Social robotics. In: Siciliano, B., Khatib, O. (eds.) Springer Handbook of Robotics. LNCS (LNAI), pp. 1935–1972. Springer, Cham (2016). https://doi.org/10.1007/978-3-319-32552-1_72
16. Warren, Z.E., Zheng, Z., Swanson, A.R., Bekele, E., Zhang, L., Crittendon, J.A., Weitlauf, A.F., Sarkar, N.: Can robotic interaction improve joint attention skills? J. Autism Dev. Disord. **45**(11), 3726–3734 (2013). https://doi.org/10.1007/s10803-013-1918-4
17. Lytridis, C., Bazinas, C., Papakostas, G.A., Kaburlasos, V.: On measuring engagement level during child-robot interaction in education. In: Merdan, M., Lepuschitz, W., Koppensteiner, G., Balogh, R., Obdržálek, D. (eds.) RiE 2019. AISC, vol. 1023, pp. 3–13. Springer, Cham (2020). https://doi.org/10.1007/978-3-030-26945-6_1
18. Lytridis, C., Vrochidou, E., Chatzistamatis, S., Kaburlasos, V.: Social engagement interaction games between children with autism and humanoid robot NAO. In: Graña, M., López-Guede, J.M., Etxaniz, O., Herrero, Á., Sáez, J.A., Quintián, H., Corchado, E. (eds.) SOCO'18-CISIS'18-ICEUTE'18 2018. AISC, vol. 771, pp. 562–570. Springer, Cham (2019). https://doi.org/10.1007/978-3-319-94120-2_55
19. Lytridis, C., Vrochidou, E., Kaburlasos, V.G.: Emotional speech recognition toward modulating the behavior of a social robot. In: The Proceedings of JSME Annual Conference on Robotics and Mechatronics 2018, pp. 1A1–B14 (2018). https://doi.org/10.1299/jsmermd.2018.1A1-B14
20. Qidwai, U., Kashem, S.B.A., Conor, O.: Humanoid robot as a teacher's assistant: helping children with autism to learn social and academic skills. Journal of Intelligent and Robotic Systems (2019). https://doi.org/10.1007/s10846-019-01075-1
21. Bernardini, S., Porayska-Pomsta, K., Smith, T.J.: ECHOES: an intelligent serious game for fostering social communication in children with autism. Inf. Sci. (Ny) **264**, 41–60 (2014). https://doi.org/10.1016/j.ins.2013.10.027
22. Doyle, T., Arnedillo-Sánchez, I.: Using multimedia to reveal the hidden code of everyday behaviour to children with autistic spectrum disorders (ASDs). Comput. Educ. **56**, 357–369 (2011). https://doi.org/10.1016/j.compedu.2010.08.016
23. Bowler, D.M., Gaigg, S.B.: Memory in ASD: enduring themes and future prospects. In: Boucher, J., Bowler, D. (eds.) Memory in Autism, pp. 330–349. Cambridge University Press, Cambridge (2008). https://doi.org/10.1017/CBO9780511490101.019
24. Rahman, M., Ferdous, S.M., Ishtiaque Ahmed, S., Anwar, A.: Speech development of autistic children by interactive computer games. Interact. Technol. Smart Educ. **8**, 208–223 (2011). https://doi.org/10.1108/17415651111189450
25. Boucher, J., Mayes, A.: Memory in ASD: have we been barking up the wrong tree? Autism **16**, 603–611 (2012). https://doi.org/10.1177/1362361311417738
26. Hassan, A.Z., Zahed, B.T., Zohora, F.T., Moosa, J.M., Salam, T., Rahman, M.M., Ferdous, H.S., Ahmed, S.I.: Developing the concept of money by interactive computer games for autistic children. In: 2011 IEEE International Symposium on Multimedia, pp. 559–564. IEEE (2011). https://doi.org/10.1109/ISM.2011.99

Synergy of Intelligent Algorithms for Efficient Child-Robot Interaction in Special Education: A Feasibility Study

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Abstract. In this paper the problem of algorithms' interoperability in the context of an intelligent child-robot interaction for special education is studied. Given a technically demanding intervention scenario designed by experts, the set of algorithms that needed to implement the scenario are defined explicitly. Following a test case implementation involving a NAO robot, a feasibility analysis of the algorithms' synergy, with respect to the adopted architecture consisting of the robot, its sensory modules and the timing performance of the incorporated algorithms is presented. The developed algorithms have been tested both in laboratory conditions as well as in a pilot study involving three children. The experiments reveal the hardware and software requirements for the implementation of such an intervention scenario with high intelligent child-robot interaction capabilities and highlight the need for an alternative system architecture.

Keywords: Child-robot interaction · Intelligent algorithms · Special education

1 Introduction

Nowadays, we are experiencing the rapid technology development etc., robots have moved from the automation and industrial use to the day life use. This is partly due to the phenomenon of the fourth industrial revolution [1], which is characterized by cyber-physical systems, IoT, cloud computing and robots interacting with humans in the context of a smart city. The robots that interact with humans are called *social robots* and are currently being used in different application fields with varied purposes. For

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example, social robots have been used for domestic applications, elderly assistance, museum guides, typical and special education, etc.

Due to this continuous development of the technology and social robots, their potential is becoming understandable as effective add-ons to learning [2]. Robots can be an entertaining platform for different fields e.g. languages teaching, with results showing that young children performed better on post-learning examinations and generated more interest with the help of a robot compared to audiotapes and books [3]. Similarly, their potential has also been demonstrated in special education. Social robots have been used during the diagnostic process and also to improve specific impairments of children [4], such as physical disabilities, social skills etc. For example, the social robot NAO was used to improve the social and attention skills of the children [5].

In this context, human-robot interaction needs to be as natural as possible. This work examines the technical requirements of an intelligent child-robot interaction in special education through the synergy of collaborating intelligent algorithms. For this purpose, a typical intervention scenario in special education has been considered.

This paper is organized as follows: a brief survey regarding the use of social robots in special education is presented in Sect. 2. Section 3 presents the feasibility analysis of executing the required intelligent algorithms towards implementing the predefined intervention scenario. In Sect. 4, the experimental results are presented and finally, Sect. 5 summarizes the conclusions and recommendations for future work.

2 Social Robots in Special Education

Socially Assistive Robots (SARs) are widely used in special education [6] with related studies to deal with a variety of conditions such as learning disabilities, behavioral disorders and developmental disabilities. The role of the robot in each study depends on the type of the interaction and the educational objective. The most common way of incorporating a robot to the educational procedure, is using it as a tutor or a teacher (usually as a teaching assistant). For example, in [7] a humanoid social robot is used to systematically teach music to children with autism. In [5], three different studies occurred dealing attention and joint attention, imitation, turn-taking and initiative by providing some behavior examples to children. An interaction based sign language game is used in [8], where a non-verbal game for children with hearing disabilities is proposed.

In other studies, robot is used as a peer instead. A peer has the potential of being less intimidating than a tutor or teacher, and also, peer-to-peer interactions can have significant advantages over tutor-to-student interactions. A teaching-through-playing method is proposed in [9], where children play some imitation games, memory games, and dancing. As noted by researchers, there is a significant increase of studies engaging social robots with children with impairments [10]. The dropping prices of the social robots and their increased functionality [11, 12] are converting the robots to affordable and efficient solutions gaining more and more acceptance by teachers and parents [13].

3 Feasibility Analysis

The main purpose of this study is to investigate how intelligent algorithms can be used effectively in a robot-based special education scenario given common computational and sensory limitations, and how these algorithms can collaborate towards establishing a real child-robot interaction. To achieve this, the synergy of different types of algorithms is essential.

For this purpose, our multi-disciplinary team has developed a test case educational scenario. In the context of this scenario, the child has to imitate the robot's movements when instructed to do so by the robot. Table 1 shows the different steps the scenario has and the actions each step includes for the child to imitate, while Fig. 1 shows the flowchart of this scenario.

Table 1. Actions for each set in the test case scenario.

Set 1	Set 2	Set 3
Nose touch	Elevator (raise both arms up and then lower them both simultaneously)	"Hello", "Come"
Raise right arm		Close eyes
Raise left arm		Thumbs up/down
		Head motion yes/no

According to the above scenario, the need for intelligent algorithms arises for analyzing the visual and audio data have to be used. Table 2 shows the requirements as dictated by the scenario and the corresponding algorithm that has to be used to satisfy each one of them.

Table 2. Algorithms needed for each scenario requirement.

Scenario requirement	Algorithm needed
Recognize keyword commands	Word recognition
Total time of verbal interaction, pauses between sentences or words, average & max speech volume	Sound detection
Track child (via sound)	Sound tracking
Track child (visually)	Face tracking
Arm detection (Raise of hand, "Hello", "Come", Head motion)	Pose estimation
Closed eyes detection	Facial landmark detection
Thumbs up/down detection	Hand keypoint detection

Table 2 reveals that several algorithms have to be applied in order to satisfy the scenario's requirements. For the requirement of *keyword commands* recognition, the NAO Speech recognition module (provided by Nuance) was used.

The recording of the *total time* of the child's speech, the *time of pauses* in between the sentences or words, and the calculation of *average and max volume* of the verbal interaction, measurements needed for interaction quality assessment, are performed by using the NAO microphone energy computation module.

The robot also needs to keep facing the child at all times. This functionality is needed, as the robot speech recognition works much better if the microphones are oriented to the source of the sound [14]. Maintaining eye contact also creates a more realistic interaction and improves engagement. To achieve this, the Audio Source Localization function of the NAO robot is used.

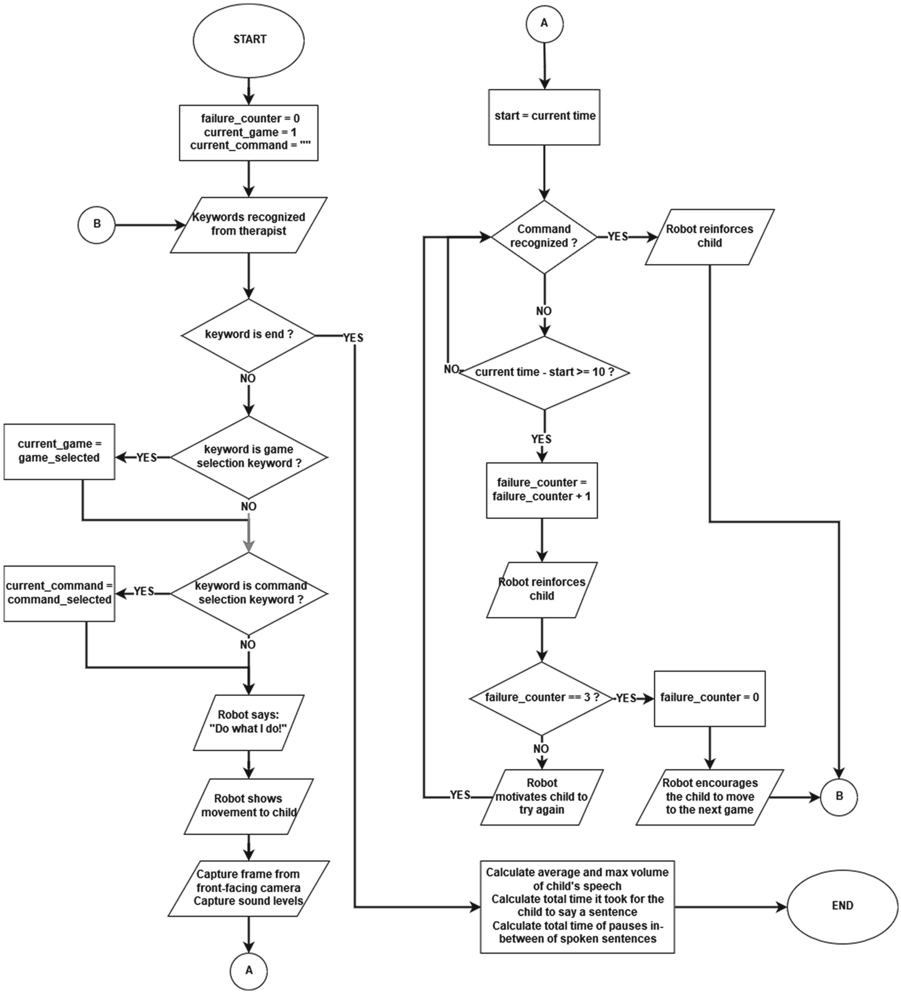

Fig. 1. Flowchart of the test case scenario.

Using this algorithm, the robot turns its head automatically to the source of the sound. Moreover, for the face tracking, the NAO robot's tracking module has been used to track the child's face.

In addition to the above, a pose estimation algorithm has to be deployed, to detect the 2D *human pose* keypoints and therefore the corresponding action. The reasoning behind the choice of a pose estimation algorithm instead of others is due to the fact that using just the detected body keypoints in combination with a heuristic method can be robust. This way, the actions can be recognized more easily in comparison to other techniques, such as wearable devices [15], which are prohibitive in special education because they can make the child feel uncomfortable.

In addition to pose estimation, the actions that have to be recognized in the scenario require the detection of *hand keypoints* and *facial landmarks*. Taking into account all of the above, the OpenPose library [16] was chosen, as it provides robust models for the keypoint detection and the installation process allows for rapid prototyping compared to other similar libraries.

Next, the recognition of the demanded actions has to be implemented. For example, to check if the nose was touched by the child, we used the keypoints of the fingers, the keypoint of the nose and the distance between them. To detect if the eyes are closed, the method proposed by Soukupová and Čech [17] is adopted. A similar approach was used to recognize the thumbs up/down action, by calculating the aspect ratio of the index, middle and pinky fingers. For the detection of the arm being raised or not, the keypoints of the elbows, the shoulders and the wrists were checked.

On the other hand, the recognition of the "yes" or "no" head motion and the elevator movement, although it requires the analysis of the flow of keypoints, it is quite simple. For the "yes" head motion, the only check that has to be done is if the head is going up and down and for the "no" head motion if it is going left and right. For the elevator motion, it was recognized by checking, for a sequence of keypoints (5 frames), if the hands went from being up to down.

Lastly, the recognition of the "hello" and "come" gestures was performed by using a simple kNN classifier. The dataset for each action was created by recording roughly 3 min of doing the specific action. Then, for each video, the pose estimation algorithm was run and the keypoints were extracted. Using these keypoints, the angle between the three points (wrist, elbow and shoulder) was calculated and used as a feature for the kNN algorithm, along with the points themselves making a total of 7 features per frame. For the training, the entirety of the action keypoints and angles was used as the features. The duration of each action was set to 5 frames, meaning that a total of 35 (5 frames x 7 features) features were used for each action. It is worth noting that in a more unstructured environment more sophisticated classifiers e.g. SVM, RF need to be applied, but making the entire system more computationally demanding.

4 Experiments

As can be seen from the previous section, the educational scenario requires a number of complex algorithms to be deployed. Moreover, these algorithms need to be operating concurrently. Two system architectures are examined herein: (1) the NAO processes the collected data by itself and (2) the NAO robot collects data from its sensors, and then transfers them to a remote computer for processing. The main advantage of the second architecture is that by having an external processing unit, the majority of the algorithms needed can be applied successfully. Nevertheless, some drawbacks can be noted. Using an external unit makes the system lose its compaction since two units are used instead of one. It also converts the NAO robot to an aggregation of sensors at most parts of the first phase, and a "puppet" at the final phase where it only waits for some commands from the computer since no decision making occurs on the robot itself. However, the most important disadvantage of this architecture is the data transfer limitations.

In order to analyze the two abovementioned architectures during the scenario execution, a pilot study with three children with autism was conducted. For the sake of the experiments, the video capturing resolution was set to 640x480 pixels for best results. As noted in NAO's documentation [18] the limit for transferring images of this size is 2.5fps wirelessly. The use of a wired connection was also tested but there were no significant improvements.

According to the selected system architecture, a laptop computer was added to the system, with the following specifications: Intel i7-6700HQ CPU, GTX 960 M GPU and 8 GB of DDR4 RAM. The connection between the NAO robot and the computing unit was established via a router, to which both of them were connected wirelessly.

To measure the loss in performance due to the video transmission overhead from the robot to the computing unit, we performed an additional test using the laptop's built-in camera. Table 3 summarizes the results, showing the average Frames Per Second (FPS) of the system during the scenario in each test for three repetitions of each test case.

Table 3. Comparative simulation results.

Algorithms	Average FPS (Laptop's camera)	Average FPS (NAO's camera)
Word recognition & Pose estimation	9.58	1.85
Sound detection	8.27	1.77
Sound tracker	7.82	1.77
Facial landmark detection	3.62	1.35
Hand keypoint detection	2.24	0.99
Face tracking	2.22	1.25

It should be noted that during each test, the algorithms were added incrementally, meaning that in each step the algorithms collaborating up to the time step, were tested together. For example, the Sound Detection test, included the Word recognition and Pose estimation algorithms. Additionally, each algorithm test case was applied on the parts of the scenario that they were applicable. For example, the first algorithm test case was applied only on the arm raise, elevator, "hello" and "come" actions.

It is obvious that the image transmission limits the overall system timing performance. Using only the word recognition and the pose estimation algorithms there is a vast difference (about 5 times slower) between the two examined cases.

Finally, it is worth noting that for each algorithm that was added to the system, its timing performance was dropping, with the biggest drop occurring when the facial landmark detection algorithm was added. Eventually, by adding more and more algorithms, the timing performance between the two cases converged, showing that both of these architectures are limited by the hardware requirements of the algorithms.

Besides the observation of the gradually decreasing of the real-time performance of the algorithms' synergy, which in some sense it was expected due to the algorithm stacking, this study reveals the very low response time of both cases. The low FPS performance (2.22 and 1.25), constitutes a barrier in highly changing intervention environments where hyperactive children interact with the robot.

5 Conclusion and Future Work

A detailed feasibility analysis of implementing intervention scenarios by applying multiple intelligent algorithms towards achieving a high degree of intelligent child-robot interaction was presented in the previous sections. The analysis was conducted towards two different system architectures: one concerning the processing capabilities required for a given intervention scenario and another one that concerns its data transmission performance. The experiments showed that the former architecture needs fast intelligent algorithms, and the latter is faced with the bottleneck occurring during data transfer from the robot to a remote processing unit. A possible solution is the use of an external processing unit and sensors (microphones, cameras) so that the needs for data acquisition and processing by the robot are reduced. However, such an architecture increases the dependency of the robot on out-of-the-system resources and therefore reducing its capacity of operating autonomously.

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References

1. Hermann, M., Pentek, T., Otto, B.: Design principles for industrie 4.0 scenarios: a literature review. In: 49th Hawaii International Conference on System Sciences (HICSS). IEEE. pp. 3928–3937 (2016). https://doi.org/10.1109/HICSS.2016.488
2. Mubin, O., Stevens, C.J., Shahid, S., Mahmud, A., Al, Dong, J.-J.: A review of the applicability of robots in education. Technol. Educ. Learn. **1** (2013). https://doi.org/10.2316/Journal.209.2013.1.209-0015
3. Han, J.-H., Jo, M.-H., Jones, V., Jo, J.-H.: Comparative study on the educational use of home robots for children. J. Inf. Process. Syst. **4**, 159–168 (2008). https://doi.org/10.3745/JIPS.2008.4.4.159
4. Holeva, V., Nikopoulou, V.-A., Papadopoulou, M., Vrochidou, E., Papakostas, G.A., Kaburlasos, V.G.: Toward robot-assisted psychosocial intervention for children with autism spectrum disorder (ASD). In: Salichs, M.A., Ge, S.S., Barakova, E.I., Cabibihan, J.-J., Wagner, A.R., Castro-González, Á., He, H. (eds.) ICSR 2019. LNCS (LNAI), vol. 11876, pp. 484–493. Springer, Cham (2019). https://doi.org/10.1007/978-3-030-35888-4_45
5. Lewis, L., Charron, N., Clamp, C., Craig, M.: Co-robot therapy to foster social skills in special need learners : three pilot studies, pp. 131–139. https://doi.org/10.1007/978-3-319-40165-2

6. Kaburlasos, V., Vrochidou, E.: Social robots for pedagogical rehabilitation : trends and novel modeling principles. In: Dimitrova, M. and Wagatsuma, H. (eds.) Cyber-Physical Systems for Social Applications. Advances in Systems Analysis, Software Engineering, and High Performance Computing (ASASEHPC), pp. 1–21. IGI Global (2019)
7. Taheri, A., Meghdari, A., Alemi, M., Pouretemad, H.: Teaching music to children with autism: a social robotics challenge. Sci. Iran. **26**, 40–58 (2019). https://doi.org/10.24200/sci.2017.4608
8. Akalin, N., Uluer, P., Kose, H., Ince, G.: Humanoid robots communication with participants using sign language: An interaction based sign language game. In: Proceedings of IEEE Workshop on Advanced Robotics and its Social Impacts, ARSO, pp. 181–186 (2013). https://doi.org/10.1109/ARSO.2013.6705526
9. Lytridis, C., Vrochidou, E., Chatzistamatis, S.: Social engagement interaction games between children with autism and humanoid robot NAO, p. 771 (2019). https://doi.org/10.1007/978-3-319-94120-2
10. Papakostas, G.A., Sidiropoulos, G., Bella, M., Kaburlasos, V.G.: Social robots in special education: current status and future challenges. In: Proceedings of JSME Annual Conference Robotics Mechatronics. 2018, 1P1-A15 (2018). https://doi.org/10.1299/jsmermd.2018.1P1-A15
11. Pachidis, T., Vrochidou, E., Kaburlasos, V.G., Kostova, S., Bonković, M., Papić, V.: Social robotics in education: state-of-the-art and directions. In: Aspragathos, N.A., Koustoumpardis, P.N., Moulianitis, V.C. (eds.) RAAD 2018. MMS, vol. 67, pp. 689–700. Springer, Cham (2019). https://doi.org/10.1007/978-3-030-00232-9_72
12. Papakostas, G.A., Strolis, A.K., Panagiotopoulos, F., Aitsidis, C.N.: Social robot selection: a case study in education. In: 26th International Conference on Software, Telecommunications and Computer Networks (SoftCOM), Split, pp. 1–4 (2018). https://doi.org/10.23919/SOFTCOM.2018.8555844
13. Fridin, M., Belokopytov, M.: Acceptance of socially assistive humanoid robot by preschool and elementary school teachers. Comput. Human Behav. (2014). https://doi.org/10.1016/j.chb.2013.12.016
14. Kennedy, J., Lemaignan, S., Montassier, C., Lavalade, P., Irfan, B., Papadopoulos, F., Senft, E., Belpaeme, T.: Child speech recognition in human-robot interaction: evaluations and recommendations. Proc. ACM/IEEE Int. Conf. Human-Robot Interact. (2017). https://doi.org/10.1145/2909824.3020229
15. Lara, O.D., Labrador, M.A.: A survey on human activity recognition using wearable sensors. IEEE Commun. Surv. Tutorials. **15**, 1192–1209 (2013). https://doi.org/10.1109/SURV.2012.110112.00192
16. Cao, Z., Simon, T., Wei, S.-E., Sheikh, Y.: Realtime multi-person 2D pose estimation using part affinity fields. In: 2017 IEEE Conference on Computer Vision and Pattern Recognition (CVPR), pp. 1302–1310. IEEE (2017). https://doi.org/10.1109/CVPR.2017.143
17. Soukupová, T., Cech, J.: Real-time eye blink detection using facial landmarks. In: Cehovin, L., Mandeljc, R., Struc, V. (eds.) 21st Computer Vision Winter Workshop, pp. 1–8. Rimske Toplice, Slovenia (2016)

DOPPLER Project: Inspiring A New Generation in STEM

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Abstract. sDOPPLER is a funded project aimed to provide training in STEM for students and teachers, using robotics in non-formal education. In the Mozambican context, it also works as a lobby in order to accelerate important curricula changes that must be achieved, so that schools can put aside the theoretical approach they use and adopt new forms of teaching, practical and dynamic, suited to the needs of the future. Osuwela is one of the Mozambican partners in DOPLLER, who took as its mission the training in STEM, using robotics to help students acquire the necessary skills and teachers to be the leaders of the mandatory changes, so important for the country's development.

Activities are set up so that students and teachers can integrate robotics with subjects such as math and physics. Teams of students must complete certain tasks and then go through a competition with other teams – as it has been claimed in some studies that competition is the most effective way to integrate different disciplines into one challenge. With DOPPLER project, Osuwela intends to inspire a whole generation of young people to work in robotics, engineering and other STEM jobs, fulfilling the country's needs.

Keywords: Science communication · STEM · Robotics · Mozambique

1 Context

The growing importance of innovation in modern societies [1] has resulted in pressure on schools to develop innovative skills in their students. Along with technology development, researchers and educators in many countries have been using robots to support education [2], since robotics has proved to have a significant impact on developing students' 21st century skills such communication, collaboration, problem-solving skills, creativity and critical thinking [3].

Education in Mozambique is experiencing an unprecedented crisis, with over a million students entering the education system every year, the lack of funding and the need

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to put into practice curricular reforms that go from classical teaching to teaching based on experimentation and fieldwork. The country faces a bigger problem, as both initial teacher training and on-the-job teacher training are very theoretical and leaves no space for teachers to develop their creativity.

The need to have training that works in a practical way on STEM subjects - in fact, the only possible way to work on STEM, combined with the market needs that demand professionals with the capacity and skills to work in the emerging oil and gas industries in Mozambique, leaves universities under pressure. The central idea of Osuwela's work is to start in secondary school with non-formal education programs encouraging young people to learn STEM while making the necessary changes in higher education through specially designed programs (like MozSkills[1]).

2 The DOPPLER Project

The International Astronomical Union, through its "Astronomy for Development" strategic plan, actively promotes the use of astronomy as a tool for development, mobilizing human and financial resources to connect science to economic growth and cultural changes in society. DOPPLER (DevelOpment of PaloP knowLEdge in Radioastronomy) is a partnership between Portuguese and Mozambican institutions to promote continuous collaborations in areas such as Radio Astronomy, Earth Observation, Big Data and STEM.

DOPPLER includes initiatives to promote advanced training in areas related to biodiversity, food security and robotics. The DOPPLER project is an opportunity to create broad understanding and work platforms among scientific and business communities supported by Science. For Education, it is an opportunity to promote the STEM curriculum, from primary to higher education, through experiences that induce significant changes in teaching and learning.

Doppler is an exemplary project in the way of approaching new skills, exploring various engineering and science topics for better qualification of teachers and students for real problems[2].

DOPPLER can be an exemplary project in the form of approaching new competences, exploring various engineering and science topics for a better qualification of teachers and students for real problems that can be faced with knowledge acquired in schools and universities. The aim is to promote the development of the Mozambican society through innovative educational approaches and bring the research to real and daily life issues. DOPPLER aims to go beyond teaching, with real learning that develops competencies for a real daily life practical problem solving.

The Doppler project is an opportunity to create broad understanding and working platforms between the business and science communities. In Mozambique, it is also an opportunity to promote a curriculum in STEM, from secondary school to higher education through significant changes in teaching and learning.

[1] https://www.mctestp.gov.mz/por/O-Ministerio/Programas/MozSkills, visited on 30 January 2020.

[2] DOPPLER is financed by the Aga Khan Development Network and the Portuguese Science and Technology Foundation, reference of project nº. 333197717.

Osuwela has been lobbying for reforms in the secondary and higher education curricula, as well as in teacher training, in order to accommodate new imminently experimental approaches to teaching and learning STEM.

3 The Danger of Imitation

As can be read in [4] "The vast majority of African universities and other higher education institutions imitate with a high degree of exactitude Western universities' academic curricula objectives, content, assessment approaches and learning materials. The imitation occurs in all academic disciplines, including the natural sciences, social sciences, humanities, business and technology. It is not only the pioneering universities established by African former colonial masters that are guilty of academic imitation. Post-colonial African universities are equally guilty."

We need to prepare universities for a new era of development in line with the country's needs. This is a long process and it will depend on the policies defined for higher education. The job to be done has to do with the creation of an adequate model for STEM and not copying universities from very different backgrounds, whose students are very different, come from societies with a greater scientific culture and teachers trained for the challenges of the society and the labor market in which they operate. Adapting a model from a western university would be academic suicide.

In Mozambique, there are only four public universities, with many students, with the potential to change curricula and develop STEM activities. The remaining are private and dedicated to the so-called "paper and pencil" courses.

DOPPLER's approach is to create a set of non-formal education activities that, even in secondary school, start by showing the potential of STEM as an inducer for new skills. Some studies demonstrated that robotics competitions provide engaging contexts for learning STEM subjects and promote students' interests toward STEM-related fields [5]. Other studies indicate that it also has positive effects on students' attitudes towards teamwork and collaborative problem solving [6, 9].

Mozambique participated for the first time in 2017 in an international robotics competition - First Global - which took place in the United States, the following year it was in Mexico and, last year, in Dubai. The results obtained by our students have always been encouraging and lead to the need to make a better use of competition as a way of exploring Robotics and learn STEM.

4 Robotics in Science Education in Africa

The world is undergoing a technological revolution that is fundamentally altering the way we live, work, and relate to one another. In its scale, scope, and complexity, the transformation is unlike anything humankind has experienced before. This has been dubbed 'The Fourth Industrial Revolution' and it is characterized by a fusion of technologies that is blurring the lines between the physical, digital, and biological spheres.

Robotics and programming are critical aspects of this revolution and Africa needs to teach her children and teachers these skills so that they can be functional in an increasingly digital world [7].

When used properly in school's robotics forms the basis of a cross curriculum activity, an ideal resource that can be used to teach:

– Mathematics;
– Scientific principles;
– Design and Technology;
– ICT (algorithms and computer programming).

Unfortunately, a look at schools in Mozambique will show that the bulk of them are not ready to teach children these skills. The teaching and learning of robotics and programming require specialized material, a very effective teacher training and, above all, the type of training that values the practice in detriment of the theory. This provocative phrase has a special meaning in the African context where, for various reasons - such as a large number of students in the classroom and little time for long curricula - teaching is expository and without space for practical activities.

In order to teach such practical concepts successfully, the right equipment is necessary. This is one gap that Osuwela seeks to address. The educational materials needed for teaching and learning robotics and programming are very expensive but not facing this situation now will cause serious problems in the future.

Since robotics and programming are relatively new on the African education scene, introducing them in a school's curriculum may not be straightforward. However, the successful introduction of an educational innovation in school settings is not just a matter of access to new technologies. Appropriate educational philosophy, curriculum and learning environment are some of the important factors leading any educational innovation to success. The robot is just another tool, and it is the educational theory that will determine the learning impact coming from robotic applications.

The use of robots in the classroom introduces students to possible career paths they may have never considered. In addition, robotics is a perfect way to show students that engineering and IT can be fun, by making abstract knowledge concrete. Working with robots enhances creative problem-solving techniques and encourages the development of basic communication and interpersonal skills as well as the ability to collaborate and convey complex ideas to a fellow students or colleagues.

5 DOPPLER Experience in Robotics

It has been claimed in some studies that competition is the most effective way to integrate robotics into subjects such as math and physics [8].

5.1 Activity I - Robot Farmer

The robot has 5 points (vessels) referenced through the color sensor/follows the line. Every day the robot must measure soil moisture (sensor simulated using a push button). Test whether there is humidity or not, and if not, irrigate that vessel (action simulated by a touch sensor/LED (blue color when simulating watering and red for inactivity) and a timer. After going through the 5 points must return to the starting point (charging station).

5.2 Activity II - Math DrawerBot

The robot has a set of geometric figures programmed in its controller and, by user selection, the selected geometric figure must be drawn on a sheet of paper. For this procedure, the robot must pick up the pen for the purpose and move to the starting point of the drawing and start the process of drawing the geometric figure. This exercise can be extended to several mathematical themes, such as, numbering, hours, etc.

5.3 Activity III - Physical Robot

The robot must be challenged by a test track created specifically to test the robot in terms of friction, inclinations, moments, among other topics in physics. This exercise should allow you to test different surfaces so that students can test different behaviors at different frictional forces. Inclinations to address the theme of the robot's center of mass and the different behaviors towards different ascents, descents, different reliefs… Etc. Different types of claw structures can be created in order to study the different behaviors for different moments of forces. This activity serves to verify that physics is in everything we do.

5.4 Training Teachers and Students

The idea is to train teachers and students in STEM and robotics activities, for that purpose teacher training activities and workshops with students in radio robotics are underway. These trainings and workshops are guided by Problem Solving methodologies and are always worked in groups. Osuwela trainers take a position as advisors and facilitators, always proposing a discussion and always stimulating critical spirit as a way of approaching problems. The main objective of these activities for students is to win the final competition that takes place at the end of the year (Fig. 1).

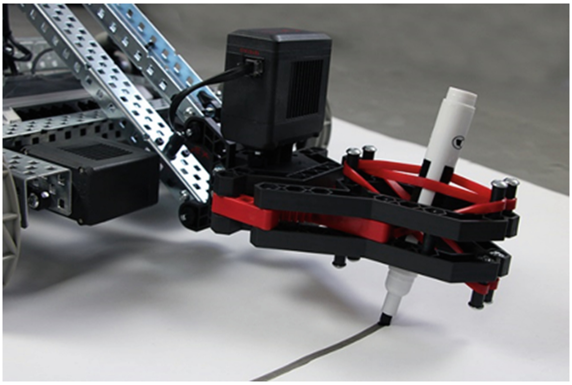

Fig. 1. MathRobot - The robot has a set of geometric figures programmed in its controller and, by user selection, the selected geometric figure must be drawn on a sheet of paper.

Regarding project DOPPLER, first Workshop for Robotics Initiation took place, with 60 pupils of six secondary schools attending a 3-day course. Robot design for different goals and perform different tasks was the main subject, aggregating subjects like physics, mechanics and mathematics in a problem-solving approach. In order to solve a problem, groups must decide on the better options for their robot – in dimensions, functions, sensors, and other possibilities – and make sure it is doable taking in consideration the laws of physics and mechanics. School groups were accompanied by one science teacher, who also benefit from the training. Together, they worked to have a functional robot that could perform the indicated tasks. Light programming was also addressed, as well as an overview of the possibilities in Robotics and Radio astronomy.

6 Conclusion

Schools in Mozambique [10] are not prepared to provide their students proper STEM training, neither through robotics. Teachers haven't received the necessary training and schools do not have the equipment. Both students and teachers are, however, eager to learn more.

Osuwela, whose mission at DOPPLER is to ensure science communication in STEM, has set as its goal to engage young people in secondary schools in STEM. We are not able to take robotics to all 800 secondary schools in the country, but through short steps we have been offering equipment and training for some schools, creating Robotics Clubs and inspiring students and teachers through activities and competitions set to place them at the same level as students attending similar competitions in many other countries.

As the project grows, we believe to be inspiring a whole generation of young people to work in robotics, engineering and other STEM jobs. As for the teachers, those who attend DOPPLER actions will certainly be the leaders of a mission that aims to deeply transform curricula so that STEM can be a reality in Mozambique in a few years.

References

1. OECD (Organization for Economic Cooperation and Development): The OECD Innovation Strategy: Getting a head start on tomorrow (2010)
2. Han, J.: Emerging technologies: robot assisted language learning. Lang. Learn. Technol. **16**(3), 1–9 (2012)
3. Chalmers, C.: Learning with FIRST LEGO League. In: Society for Information Technology and Teacher Education (SITE) Conference, March 2013
4. Fredua-Kwarteng, E.: University World News. African universities – Imitation or adaptation? 12 December 2019
5. Fike, H., Barnhart, P., Brevik, C.E., Brevik, E.: Using a robotics competition to teach about and stimulate enthusiasm for earth science and other STEM topics. EGU General Assembly (2016)
6. Goodman Research Group: Final report to FIRST. Cambridge, MA (2000)
7. Jenlink, P.M., Jenlink, K.E.: The next generation of stem teachers: an interdisciplinary approach to meet the needs of the future. s. l. Rowman & Littlefield (2019)
8. Khanlari, A.: Knowledge building, innovation networks, and robotics in math education. Graduate Department of Curriculum, Teaching, and Learning, University of Toronto: s.n. (2020)
9. World Bank: Studying the hurdles for improved teaching of Mathematics and Science subjects in secondary education in Mozambique (2017)
10. Davies, E.: Robotics the future of STEM Education (2017). https://www.edureporter.com.au/robotics-the-future-of-stem-education/

Geriatronics - A Student Workshop on Senior Citizens, Robotics and Ethical Issues

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Abstract. The term geriatronics refers to the use of robotics, mechatronics and information technology in geriatrics, gerontology and medical care. The Munich School of Robotics and Machine Intelligence (TU Munich), together with several partners from industry, is currently running the first lighthouse initiative geriatronics with the aim to allow elder people a longer self-determined life at home. The main research focus lies on the development of a humanoid assistance robot (GARMI) that supports elderly within their home environment as well as nursing and medical staff in physically demanding situations. Within this research initiative, the Deutsches Museum in Munich is developing a training program for multipliers, that shall not only be capable of using the developed robotic systems but also to teach medical staff how to use it in their everyday work. To create a suitable education program, the first step is to carry out workshops and training programs with students and thereby form a basis for further development. This article presents a tried and tested workshop for students, highlighting the interplay of robotics and ethics in the field of geriatronics.

Keywords: Geriatronics · Robots · Education · Robotics and ethics · Geriatrics · Workshop

1 Introduction

Due to demographic change and the decreasing number of nursing staff, life is becoming increasingly difficult for elder people. Geriatronics refers to the use of robotics, mechatronics and information technology, in particular machine intelligence and 3D technology, in geriatrics, gerontology and medical care. On one hand maintenance of mobility, interpersonal interaction and communication in old age is given and on the other hand independence through technical and intuitively operated, adaptive and thus personalized assistance systems. In addition, geriatrionics is to support and relieve caregivers, particularly in non-maintenance tasks and non-ergonomic activities, which in the long term have a detrimental

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effect on their health. There are several motivations for developing a geriatronic systems: Many seniors are not able to cope with their everyday life due to minor physical limitations and then, contrary to their wishes, are often no longer able to live in their own home. At the same time, there is a large number of people who live in elder care homes or nursing homes due to various health impairments and do not receive sufficient support there to lead a self-determined life [1,2].

Within this research initiative, the Deutsches Museum carries out public outreach initiatives and ensures that the main idea of geriatronics is conveyed in appropriate form. Furthermore, new concepts for training and education systems for nursing and medical staff are going to be developed, tested and sustainably implemented. In order to create a robot that is useful in everyday lives of seniors, the research process involves the inputs of the stakeholders - giving the answer to the question: What are actually the difficulties in everyday life where help is needed?

The student workshop presented below is centered around a professional, industrial robot arm, the Franka Emika Panda. This single robotic arm symbolizes one of the arms of the personalized assistance robot GARMI, which is being developed as part of the geriatronics project. In order to design a robot that is actually able to assist in tasks that are required in everyday life situations it is important to know the actual needs of the society. Additionally possible feeling of fear and prejudice of robots have to be addressed right from the beginning. Hence, the idea is to integrate a robotic system like the Panda into the educational concepts right from the start to provide a faster acceptance of robotic systems in society. In order to do so, the Deutsches Museum is running workshops for students. Because of the width range this project covers, this proposed workshop concept deals intensively with three topic areas: Robotics, Ethics and Geriatrics (gerontology). To cover all these areas, but at the same time maintaining the motivation and interest of the students, workstations have been conceptualized. The workshop is designed for groups up to 24 students. At 3 different stations, students learn and explore the basics of mobile robots, work with an real industrial robotic system and develop and discuss ethical issues and fields of application.

2 Robots in Comparison

The first station contains two different robotic systems. The students learn how to handle the Panda robot and what properties such robot systems have. In order to provide a comparison, a LEGO Robot is used as an additional robotic system, which should be programmed to perform a thematically related task and thereby demonstrate how such systems could be used for solving a common problem in everyday life tasks. The students will be able to identify advantages and disadvantages of both robotic systems. By working parallel with a system like a LEGO robot, the students recognize disadvantages and obstacles of the development and enforcement of certain regulations on a robot. They will also gain a better understanding of the complexity of a robotic system and understand what it takes to build a robotic system.

2.1 The Franka Emika Panda

This station consists of two parts: the robot itself and a laptop or a screen with the corresponding app based user interface. For the time being, the students are supposed to make first contact with the robot by moving the robot arm independently in order to sense how the robot is to be operated. Through this first contact a possible feeling of fear and prejudice can be overcome.

The next step is a demonstration of an easy task that shows how the system works as a whole. Thereby it is important to explain the user interface and the apps that are needed for this task. In this step it is also important to explain how to switch from robot to desktop interface control. The user stop button should be turned on and off once by every student before starting with their given task to ensure that the students know how to use it. During the proceedings at this station it can also happen that the students move the Panda into a self-lock position. This has the advantage that the students recognize the limits of the system and thereby also generate questions that are related to the mechanical properties of the system. After the students have carried out their first test run, they can program an own task using different apps. Those tasks can for instance be: Grasp a bottle, position it over a glass and pour water into the glass. An important note here, each student should have the opportunity to use both, the robot and the desktop interface. This ensures that every student who has worked at this station can also teach the robot to do something.

By questioning, the workshop leader triggers a discussion. Common student questions at this station are: how is such a system supposed to be easier for these people to use, if they are even afraid to switch to a computer? How are they suppose to control a robot with a computer control? For these and other reasons it is therefore important to explain to the students in detail, that geriatronics is a project that is in its infancy. The systems available right now are first prototypes of GARMI and not the end product. It needs to be clear to the students that their feedback is highly appreciated and that by participating in workshops like this, they become a part of the project as well.

2.2 The LEGO Robot

The LEGO Mindstorms robot is rather known to most students. As an already spread and implemented system, there is no need for detailed explanation. Two possible events, however, that should be considered to happen: first possibility - the students are familiar with sensors and have learned about them and are able to handle them; second possibility - they are not familiar with them at all. If the second case occurs, the Lego robot is well suited for explaining sensors, as the individual components are clearly visible on the robot. Furthermore, simple examples can be used to show how contact or light sensors work in operation.

At this station, students program the Lego robot to solve a concrete problem that can occur in the everyday life of a senior. The following scenario represents only an example: Ms. Jones wishes a drink to be delivered to her bed. Students task is now to program the robot to pick up an object and follow a given path between the ‘kitchen’ and the ‘bedroom’. This station comprises a laptop or computer, a Lego robot and a tape to mark the path on the ground, that the robot should follow. The students first learn how to program the robot using simple basic functions. Then they gradually program the functions that the robot needs for its delivery service. To do so, the robot should know where the pick-up should take place. A floor plan designed with the tape serves as orientation, because the robot also needs to know where to take the deliverance. In this process, it is also necessary to specify or program how long the robot needs to wait or according to which information the robot knows that the loading can take place. Depending on whether the students have founded experience or not, they will need a helping hand on this exercise, especially, because they are limited in time.

The advantage of this station is that the students realize that there are many factors which need to be taken into account to provide a perfect performing of a robot.

3 Robots and Ethics

To create a productive workshop with students in context of ethics in robotic science, we start with the proposal of Manzeschke’s model for the ethical evaluation of social-technical arrangements (MEESTAR). MEESTAR helps in a structured way, on the basis of seven assessment dimensions, to identify ethically problematic effects and, building on this, to develop ways of solving them. The seven dimensions are: Care, self-determination, security, justice, privacy, participation and self-conception. In order to give an overview of those seven dimensions, they should be at least in form of questions be explained to the students. Example of those questions are: At what point does a technically supported care for people in need become problematic, because it changes the self relationship and the world relationship of these people in a way that they themselves do not want or that we others should not want in view of these people? How can people be supported in living their right to self-determination - in accordance with a practice, oriented towards the right to self-determination of the individual [3]?

The ethics station consists of two groups of 4 students arguing in a debate about whether GARMI should be implemented into home environments of the elder people or not. The debate is structured in three phases: the first phase is the research phase. The students have a defined time limit in which they should learn more about ethical questions during the development of a robotic system. Depending on how much time is available for the workshop, the students can conduct research in a real library, in the internet or in preselected resources, e.g. newspaper articles, magazines or books. Help can be offered by supporting cards with ethical guidlines proposed by the MEESTAR model. After their research every group should have supportive arguments for their ethical point of view to convince an objective, not involved person to get or not to get a GARMI system. The group who succeeds in the convincing - wins. The second phase is scientifically presenting their arguments. Using supportive references they have found, they need to present why their opinion is right. In the third phase the students argue and discuss about questions asked by a host of the debate. The content of these questions depends on the students presentations. They need to answer these questions with arguments and thereby defend their point of view.

As the research initiative geriatronics aims to involve the public in fundamental discussion we find it important to start with involving the topic of ethics in the workshops with students. The younger population has a different path to argue problematic questions regarding new technology. There are several reasons for that: first, they believe in a more technological way of life and they want to live it. Second, a part of them is still innocent and creative enough, that they might come faster to a solution, that would be appropriate for this special research field. Third, the social thinking is more dominant than the economic thinking. By implementing a station like this, it is ensured that the students will know, that not only experimenting and exploring is important in a research, but approval of the society as well.

4 Geriatrics

Since the needs of elderly people are neither a subject in school curricula nor necessarily present in younger peoples everyday life, it is important to rise awareness for this topic in more detail. It is possible that students involve stories about their grandparents or other relatives that have to cope with certain difficulties that keep them from living a self-determined life at home. This kind of experiences should be addressed and discussed before the students get the instruction of the workstation. Such discussions can help the students to feel more related to the issues seniors encounter in their everyday life and thus enables them to better understand the need for geriatronics research.

This station is designed as a game. At least two whiteboards are needed, which should be placed in a way, that the groups working at the station cannot see what the opponent group is writing. On the board a drawn or pictured floor plan of an apartment is displayed. In the first step of this game the students write down possible scenarios, in which elderly people can find themselves because of health or age related impairments. The developed scenarios should be written down on Post-Its and be sticked onto the corresponding rooms on their floor plan. It has been shown that it makes sense to implement a floor plan with numerous rooms to enable the students to create more ideas through a visual perception. In this workshop the students have 15 min to write down as many scenarios as possible. When these 15 min are over, the groups rotate and the given task changes to finding a solution for the given scenarios written down by the opponent group. However, the students are not allowed to integrate the help of other humans in their solution scenarios. Either they solve the given situation by using a robotic or other technological assistance system or by implementing senior appropriate furniture. The group that manages to achieve the greater ratio of solutions to the given scenarios - wins. The possibility of a tied is very low in this task. If, however it happens, then one scenario can be chosen and the groups try to debate about a meaningful solution. Whoever has better arguments to solve the given problem - wins.

5 Conclusion

The described student workshop is the first public outreach activity developed in the research project to reach out to younger people in order to make the topic of geriatronics tangible and accessible in an interesting and meaningful way. In the longer run, it is creating the basis for further training and education programs for other target groups, like nursing staff and senior citizens. We do believe that workshops and trainings with relevant user groups are a great opportunity to early identify possible problems from the perspective of society in human centred research approaches. Within the lighthouse initiative geriatronics these activities provide the basis for the development of beneficial and sustainable solutions strategies in order to create a robotic system that is accepted and accessible by seniors and other stakeholders. It is aspired that the society and the stakeholders can play not only as users an important role, but also in terms of setting agendas and exploring desirable futures to be achieved through research and innovations.

After completing the geriatronics student workshop every student should be able to understand the challenges of senior citizens, discuss them and express them in their own words. Further, they should have acquired the basics of robotics, as well as operating and programming a robot system. By doing so, they should be able to understand and interconnect the topics and develop questions. This, the main learning goals of the student workshop are:

- That in general a nursing care problem exists, what are the reasons and where the difficulties lie in solving this problem.
- That the future of care for the elderly is uncertain and that there are more solutions than retirement and nursing homes.
- That robotic systems will have a major role in the future.
- That it is important to develop easy to use robotic systems for all people.
- To operate different robotic systems, even professional industry standard systems.
- To know the importance of other segments of research, not just exploring and experimenting.

References

1. Medizin, S.: Roboter in der Pflege – Ein Ausweg aus dem Personalnotstand? Geriatr. Rep. **14**(2), 6–7 (2019)
2. Manzeschke, A., Weber, K., Rother, E., Fangerau, H.: Ergebnisse der Studie: Ethische Fragen im Bereich Altersgerechter Assistenzsysteme. VDI/VDE Innovation + Technik GmbH, Januar 2013
3. Veruggio, G., Operto, F.: Roboethics: a bottom-up interdisciplinary discours in the field of applied ethics in robotics. In: Capurro, K.W.R., Hausmanninger, T., Weil, F. (eds.) Ethics in Robotics, IRIE, vol.6, p. 6. (2011)

Integrating Robotics with School Subjects

Teachers' Perceptions of Bee-Bot Robotic Toy and Their Ability to Integrate It in Their Teaching

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Abstract. Robotic toys provide opportunities for learning across different areas of the curriculum. This paper investigates teachers' perceptions of robotic toys and their ability to integrate the Bee-bot robotic toy in their teaching of English as a foreign language. For the purpose of this research, a training session specialized for teachers of English was held in an informal educational institution in Greece while, a year later a follow-up session took place at the same institution with the aim to reexamine teachers' perceptions and study their ability to integrate the Bee-bot robotic toy in teaching. In this study, we have followed a qualitative approach and collected qualitative data by carrying out two interviews with the teachers (in the end of the training and in the follow-up session) and by examining their lesson plans. The results show that teachers after receiving training, feel confident and eager to use robotic toys in their teaching and view that that there are multiple applications of this technology in foreign language instruction. After having the opportunity to use robotic toys in their teaching practice, teachers' perceptions remain positive despite the few challenges they faced in the implementation. The results of the follow-up session indicate that teachers participating in the training were able to integrate the Bee-bot robotic toy in their teaching of English as a foreign language.

Keywords: Educational Robotics · Robotic toys · Teacher training

1 Introduction

In the framework of Educational Robotics (ER), robotic toys have emerged as ER resources specialized for younger children. Although in current literature a clear definition of robotic toys has not been formulated, there is reference to their characteristics; Robotic toys are tangible devices that interact with their surroundings that are employed for children's leisure activities such as play, creativity, playful learning, entertainment, and relaxation [1]. Robotic toys look like social robots, however, they are of lower-level technology [2]. Despite the fact that robotic toys cannot be modified or reconstructed as other ER resources [2], they are used in various areas of studies as documented in literature presented in the theoretical framework section.

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Robotic toys are applied in several educational and research contexts; more precisely, the robotic toy called Bee-bot which is very popular among students and teachers [3] is widely spread across different areas of studies at preschool and primary school level. The Bee-bot is easy to use and appealing to young children. It is also a non-screen robot, meaning that it is physically manipulated by the users with buttons, without any kind of screen. On its top part there are buttons that program movement and delete, pause and start the inputted program. One of the most important advantages of the Bee-Bot robotic toy is that it does not break easily and this makes it particularly suitable for young children [4].

In the next section, the potential of the Bee-bot in different areas of studies will be presented based on previous studies carried out in the field. In order to enable teachers to make an appropriate use of the Bee-bot resource in their teaching, teachers need to receive specialized training. This paper will discuss the potential of Bee-bot across disciplines and teacher training in the field.

2 Theoretical Framework

2.1 Bee-Bot Robotic Toy Across Disciplines

Throughout current literature, the robotic toys are applied in several different disciplines, extending from science to foreign language learning, and different educational levels. To be more precise, regarding the Bee-bot robotic toy, most often in present literature it is applied in the preschool education [5–8], and early primary school classroom [9–11]. Current literature suggests that children when learning to program a robot, they do not only acquire knowledge relevant to technology and engineering, but they also the learn foundational math, literacy, and arts concepts [12]. Literature referring to the interdisciplinary use of robotic toys will be further examined below;

First of all, authors view that the Bee-bot robotic toy can teach young children important skills as logical thinking and problem solving [4]. Additionally, the use of Bee-bot contributes to enhancing young children's development of mathematical thinking [10, 13]. In particular, Bee-bot may have a positive impact on students' transformational (geometric) and measurement processes, problem-solving, semiotic processing [13] and metacognitive skills [10]. Apart from mathematics, teachers and researchers have also applied the Bee-bot robotic toy in science and in and particular in the areas of biology, botany, geometry and earth science [9]. Upon finalization of this multi-disciplinary project, researchers reported students' gains in science knowledge, problem solving, easiness to rapidly reach correct solutions and depth of the learning process [9].

Apart from familiarization with mathematical and scientific concepts, the robotic toys can be used to deliver content in arts and social sciences. For instance, in the framework of Erasmus+ KA2 program [5] the Bee-bot was employed in the kindergarten classroom through two different activities to deliver content in the area of history and music. The children by programming the Bee-bot acquired knowledge in the area of history and music respectively while enhancing their mathematical skills and computational thinking [5]. The robotic toys is also a powerful resource for language learning; in a recent research [11], it was suggested using the Blue-Bot robotic toy for introducing the alphabet, reinforcing spelling, playing word games, and teaching directions, numbers, and vocabulary in general. To support language learning, thematic mats can be created and then filled with relevant print-outs of letters, words or pictures [11].

Even though robotic toys cannot be modified or reconstructed [2], the abovementioned studies display that they can be used to teach, apart from programming concepts and processes, multidisciplinary content knowledge. As a result, the robotic toy is a powerful resource for teachers in kindergarten and early primary school, and through training, teachers can discover its potential and apply it in the school classroom.

2.2 Teacher Training in Educational Robotics and Robotic Toys

The role of teacher is of crucial importance when it comes to the successful introduction of robotics in classrooms, however, it is reported that only few studies have been carried out to train school teachers in using Educational Robotics [14, 15]. When it comes to robotic toys, very few studies have been encountered in literature focusing on training teachers in robotic toys [16, 17]. For example, in [16] preschool teachers received an one-day workshop in using the Bee-bot robotic toy in their classes. Additionally, in [18] pre-school, primary and secondary school teachers received a joint 32-h training in robotics and pedagogy with different ER resources one of which was the Bee-bot. In [19] preschool teachers together with primary school teachers were trained in using the Blue-Bot among other ER resources. Finally, in the research of [20], pre-service and in-service learning support teachers received training in using robotic toys and other ER resources, methodology and designing ER didactical units. Apart from the limited amount of the studies in teacher training, there is a lack of studies examining the role of the teachers in the introduction of ER technology in schools and their attitudes towards this technology [17]. An exception to this, is the study of [21] that looks into the use and acceptance of robots by teachers in classrooms and [20] that explores teachers' attitudes towards robotics. Based on the abovementioned problem, a need arises for further qualitative research in teacher training in robotic toys that would explore in depth, throughout a long period of time, teachers' attitudes towards this technology and their ability to integrate it in the school classroom.

The successful integration of robotics into the school classroom does not only depend on the robot itself, but also on the activities selected and on material designed. Regarding robotic toys, a combination of these toys and engaging tasks would have a positive impact on students' perseverance, motivation and responsiveness in the classroom activities [6]. The authors in [9] point out the importance of the teaching scenario; the robot is important, however, other elements play an important role, too, as the story, the realization of accessory artifacts, discussions within groups etc. In accordance with this, it is important to train teachers in the use of this technology, emphasizing both didactic and technical aspects, equally [22]. The importance of appropriately designed learning activities and supporting material is also pointed out in [23]. As far as robotic toys are concerned, in the research study of [10] three different types of tasks are proposed; structured tasks, exploratory and extended tasks. The authors underline that each task serves a different purpose; "exploratory and extended tasks provide opportunities for problem solving, whereas structured tasks focused on discrete skills required in the more advanced tasks" [10]. More precisely, when it comes to foreign language teaching through robotic toys, the R.O.S.A. framework has been developed to provide teachers with a criterion to assess the feasibility of the integration of the robots in their classes [11]. By applying the R.O.S.A framework, teachers assess the robotic toys based on their applications, cost, age appropriateness, operation and potential usage in the foreign language class.

As current literature suggests, research in teacher training in ER is not adequate, particularly when it comes to robotic toys for learning and teaching purposes. This qualitative study aims at contributing to current literature by providing more insight in teachers' attitudes towards learning and teaching with robotic toys and in particular with Bee-bot.

3 Methodology

Our qualitative and interpretative study explores teachers' perceptions of the Bee-bot robotic toy and teachers' ability to integrate it in their teaching of English as a foreign language in a language school in Greece. A multiple-case study was conducted, and the data collection took place in two stages; once in the end of the training session and a second time in the follow-up session, almost a year after the training session. The multiple-case design was chosen as it strengthens the findings and provides analytic benefits compared to single-case studies [24]. The research data was analyzed with a thematic analysis as it offers an accessible and theoretically flexible approach to analyzing qualitative data [25].

3.1 Research Questions

1. How do teachers initially perceive the Bee-bot after receiving training?
2. How do teachers perceive the Bee-bot after making use of it their teaching practice?
3. To what extent were teachers able to integrate the Bee-bot in their teaching practice?

Context, Sample and Research Instruments

The study was conducted throughout January–December of 2019 at a non-formal educational institution, located in Thessaloniki, Greece. The non-formal educational institution is specialized in teaching foreign languages and in particular English, German and French to children, teenagers and adults. Two foreign language teachers with no prior experience in ER, participated in the training session in January 2019 and later in the follow-up session in December 2019. In the meanwhile, they were using the Bee-bot in their teaching practice. Both teachers are teachers of English, female, and have more than 25 years of teaching experience.

For the purpose of this research, two semi-structured interviews took place; the first one in the end of the training session that lasted 20 min, and a second one, almost a year after, during the follow-up session that lasted 30 min. The interview questions were designed by the researchers and were related to teachers' perceptions of robotic toys; perceived usefulness of the Bee-bot, self-efficacy and eagerness to use Bee-bot in teaching, difficulties in the implementation of Bee-bot activities, students' reactions, Bee-bot suitability for formal education). Even though the scope of the two interviews was the same, the questions varied between the first and the second one; the first interview was prior to classroom use, while the second one was subsequent to classroom use and this consequently led to variations. The interviews were transcribed and the pattern matching analytic technique was implemented.

In the follow-up session, the teachers handed in a lesson plan they had previously implemented in their classes. After the follow-up session, the researchers assessed the lesson plans to evaluate teachers' ability to integrate the robotic toys in their teaching of English as a foreign language. The lesson plans were assessed according to an evaluation rubric, created by the researchers, based on [14] and adapted to the requirements of this context. The evaluation rubric examined the learning objectives, description of activities, teaching material design and interdisciplinarity of the lesson plan.

3.2 Training Session Description

The workshop lasted 2 h and took place on the premises of the institution. In the beginning of the workshop, the teachers were familiarized with the 21st century skills framework, basic programming concepts and computational thinking practices (Fig. 1). After that, the participants were instructed on how to use the Bee-bot robotic toy. The rest of the session was dedicated on how the Bee-bot can be applied in the particular context of the teachers that is teaching English as a foreign language; activities with present simple, daily routine verbs, time and numbers were presented to the participants. This part of the session aimed at enabling the teachers to understand how robotic toys can be integrated in their teaching and create their own teaching materials and lesson plans by making use of the Bee-bot at its full potential. T different types of tasks were proposed to be used in their teaching; structured tasks, exploratory and extended tasks [10]. Almost a year after the training session, a follow-up session took place, the participants discussed with the researchers the implementation of the Bee-bot in their teaching of English as a foreign language and their perceptions of this resource and handed in lesson plans that they had previously implemented in classes of 8 to 10 children.

Fig. 1. Teacher training and follow-up sessions 2019

4 Results

4.1 RQ1: How Do Teachers Initially Perceive the Bee-Bot After Receiving Training?

Teachers' initial perceptions of the Bee-bot are presented below per theme and are summarized in Table 1. The initials [T1] and [T2] are used to refer to Teacher 1 and 2.

Teachers Feel Self-Confident
The workshop participants reported that they did not face any particular difficulty with the robot nor the workshop. However, T1 reported that "it is a matter of familiarization and repetition to remember to press the delete button before starting the new program". Both teachers agreed that the workshop enabled them to feel confident when using the Bee-bot robotic toy. Interestingly, T2 explained that even though the workshop made them feel confident, they need to do further practice –this practice does not refer to using the robot, but rather, it has to do with the design of the Bee-Bot activities.

Usefulness of the Robotic Toys in the Foreign Language Instruction
Participants viewed that robotic toys will provide engagement and motivation for learning and stated that they anticipate that the learners will be enthusiastic and motivated by the robotic toys to carry out activities and exercises in the foreign language. The participants underlined that the workshop gave them insight on how to make use of robotic toys in the context of the foreign language classroom. Although initially the teachers felt that robotic toys were not relevant with the foreign language instruction, T1 underlined that "after the workshop, robotic toys seem to be simple to use and to have multiple applications in the foreign language classroom". The workshop participants view with enthusiasm the potential implementation of the Bee-bot robotic toy in foreign language instruction and they started brainstorming on how to apply it in the classroom.

Students' Skills Development Through Robotic Toys
Teachers positively perceive the development of skills through robotics toys. The teachers underlined that robotic toys provide learners with the opportunity to acquire skills through play. In particular T2 pointed out that "through play, children deal with challenges and consequently develop their problem-solving skills, for example, if you put bombs on the Bee-bot mat, students will need to program their robot to avoid the bombs". Teachers reported that through robotic toys learners may practice their teamwork skills [T2], critical thinking [T1] and mathematical thinking [T2].

4.2 RQ2: How Do Teachers Perceive the Bee-Bot After Making Use of It in Their Teaching Practice?

Teachers' perceptions of the Bee-bot after having the chance to use it their classes are presented below per theme and are summarized in Table 2. Both teachers consider the Bee-bot robotic toy a useful resource as that they have made extensive use of it throughout the school years 2018–2019 and 2019–2020 (3–5 times per semester) in various levels;

Table 1. Summary teachers' views – Research Question 1

Teachers' general perceptions of the Bee-bot:	Teachers' views on usefulness of the Bee-bot in foreign language:	Teachers' views on students' skills development through the Bee-bot:
Teachers are eager and confident to apply ER in their classroom practice [T1–T2]	There are multiple applications of the robotic toys in the foreign language instruction [T1–T2]	The Bee-bot will enhance students' problem-solving skills [T2], critical [T1], and mathematical thinking [T2]
Teachers need further practice with robotics activities design [T2]	The Bee-bot will engage the learners in foreign language instruction [T1–T2]	Through the Bee-bot use students enhance teamwork [T2]

T1 used the robot in junior classes (children from 7 to 9 years old) while T2 apart from junior classes, also used it to teach older children from 9 to 11 years old.

Teachers' Self-efficacy and Eagerness to Use the Bee-Bot and Other ER Resources
Both teachers feel confident when it comes to the Bee-bot robotic toy use and activities design. Teachers report that they are eager to continue using the Bee-bot and they are willing to try out other robots and learn more about Educational Robotics. Regarding the bee-bot activities creation they point out that it requires time, however, not more than any other game they create [T1]. T2 states that she would like to have access to a website that has ready to use material to adapt and use in her classes.

Difficulties in Bee-Bot Activities Implementation
Both teachers face difficulties with time-management and report that the activities with the Bee-bot are always very time consuming. T1 explains; "I implement the Bee-bot activities only at the end of the lesson, in order to control the time dedicated to this activity, it is difficult to control the children, when they like something they want to do it again and again…" Apart from time-management, T1 had difficulties with the mat creation; "once the mat is folded, it cannot be re-used". T2 agrees and points out that the mats cannot be made of paper, they need another material that is resistant and smooth and to solve this, she put stickers on the classroom floor. In addition, both teachers agree that the use of the Bee-bot may create classroom management problems, as children tend to get competitive and miss-behave.

Students' Reactions on the Bee-Bot Activities
Teachers report that all students, including the older ones [T2], were very enthusiastic about using the Bee-bot; "after bringing the Bee-bot in one class, students kept asking me to use it in the following lessons" T1 said. Students coped with the Bee-bot activities, however, teachers observed that their students faced the following difficulties in their first contact with the Bee-bot; programming the robot to turn, [T2], laterality [T2] sequencing [T2] and decomposing instructions [T1–T2].

Usefulness of the Robotic Toys in the Foreign Language Instruction
The teachers view that the Bee-bot can be implemented in various ways in the teaching of

English as a foreign language and provide examples of this implementation; T2 suggests that any kind of grammar or vocabulary exercise can be transferred to the Bee-bot mat. For example, a filling the gap exercise on verb tenses can be converted into a Bee-bot game. T2 also proposes that students can also put words in order to make a sentence on the Bee-bot mat, a story or a recipe. T1 mentions that she implemented various projects with the help of the Bee-bot, for example, she taught young learners the time, numbers and giving directions. T2 created a treasure hunt on the Bee-bot mat in order to teach students giving instructions in English. T2 said that she is planning on using the Bee-bot the following month to teach young learners the alphabet (6-year-old children), shops (7-year-old children) and simple past tense (8-year-old children).

Robotic Toys Have a Positive Effect on Children with Attention Deficit and Dyslexia
Both teachers observed that the robotic toys were particularly useful in the case of children with attention deficit and dyslexia. T1 explained; "throughout the Bee-bot activities, the students with attention deficit and/or dyslexia were very concentrated and did very well, in some cases much better than the rest of the students". T2 added that doing well in the Bee-bot activities, boosted their self-confidence and gave them a feeling of achievement.

Bee-Bot Activities Can Be Implemented in the Formal Education
When teachers were asked about the implementation of robotic-toy activities in the formal education, they were very positive and underlined its potential for multidisciplinary integration across the curriculum. Nevertheless, bringing the robotic toys into formal education would entail funding to purchase equipment [T1], hiring teaching assistants to deal with classroom management issues [T1], designing ready-to-use materials in different disciplines [T1] and holding training sessions for teachers [T2].

4.3 RQ3: To What Extent Were Teachers Able to Integrate the Bee-Bot in Their Teaching Practice?

The researchers assessed the lesson plans based on the evaluation rubric. The results demonstrated that the teachers were able to integrate successfully the Bee-bot robotic toys in their teaching of English as a foreign language. Their lesson plans made use of the robotic toys resources to deliver content in the foreign language and facilitate the objectives of the class. The lesson plans are discussed below. First of all, as far as the lesson plan of T1, the Bee-bot was used in a lesson related to giving directions. The learning objectives were targeting vocabulary and grammar in English together with 21st century skills as teamwork and problem-solving. The learning areas chosen were English, Technology and Geography (orientation). The teacher carried out her teaching with the usual resources (textbooks and interactive board) in the first and second part of the lesson – 'vocabulary and grammar presentation and practice'. The Bee-bot robot was used in the third part of the lesson at a language production activity on giving instructions. The students in pairs were giving each other directions and programming the Bee-bot to go to different locations around the village. Regarding the lesson plan of T2, the topic of the lesson was possessive adjectives in English and the objectives of the lesson was to familiarize students with the possessive adjectives and enhance

Table 2. Summary teachers' views – Research Question 1

Bee-bot implementation:	Students' reactions:	Usefulness in foreign language instruction:	Implementation in the formal education:
Useful resource for children of various ages (7 to 9 years old - T1) and (7 to 11 years old - T2)	Students were enthusiastic about using the Bee-bot in class [T1-T2]	Teachers used the Bee-bot in grammar, vocabulary and reading exercises [T1-T2]	Bee-bot can be integrated in different disciplines of the formal curriculum [T1-T2]
Teachers are confident, eager to continue using the Bee-bot and want to learn more about ER. They had difficulties time-management mat design and classroom management [T1-T2]	Students were able to do the Bee-bot activities. First, they had difficulty with programming the robot to turn, laterality, sequencing and decomposing in-structions [T1-T2]	Bee-bot activities were useful to children with attention deficit and dyslexia; they enhanced the concentration, achievement and self-confidence [T1-T2]	The implementation requires purchasing equipment [T1], hiring teaching assistants [T1], designing ready-to-use materials [T1] and teacher training [T2]

students' problem-solving skills. The students made use of the Bee-bot robotic toy in the second part of the lesson – 'practice possessive adjectives' in which they practiced filling the gaps in sentences with the possessive adjectives located on the Bee-bot mat. The teacher transferred a typical grammar exercise "complete the gaps" to the Bee-bot mat so that children apart from grammar practice they would also practice programming. The Bee-bot was integrated in the lesson plans; T1 integrated the Bee-bot in a language production exercise while, T2 in a grammar drilling activity; both applications were appropriate and suitable to lesson objectives and facilitated learning. The lesson plan of T1 was evaluated with 18 points out of 21 and the areas that need improvement is originality and materials design, while the lesson plan of T2 was evaluated with 16 out of 21, and the areas that needed improvement was originality, materials design, lesson plan structure and objectives. Despite the suggestions for improvement in certain areas, the lesson plans as implemented were satisfactory as they enhanced students' language learning.

5 Discussion and Conclusions

The teachers positively perceived the integration of the Bee-bot robotic toys in their teaching of English as a foreign language, after receiving the training and applying Bee-bot in their teaching in classes of 8 to 10 children, demonstrated positive opinions and displayed with their lesson plans that robotic toys activities can be integrated in foreign language teaching. The contribution of our research particularly lies on the fact that the teachers' perceptions of the Bee-bot remained positive after having the chance to apply it in their teaching. The results of this research come to confirm the research of [11] who made use of the Blue-bot toy in the third grade of primary school to teach Spanish as a foreign language; [11] pointed out that ER resources and robotic toys promote foreign language learning and suggested practicing areas of the foreign language curriculum by creating games and mats. In this research paper, the teachers highly evaluate the usefulness of robotic toys in foreign language teaching before and after using it in teaching and underline that the learners were very enthusiastic with this resource. The data in our research are not in line with [6] that state that the Bee-bot activities were interesting for children for very short time as in our research, the teachers pointed out that students' interest sustained throughout sessions. In addition, our research paper results are not in accordance with [4] who affirm that Bee-bot robotic toy is not flexible as it cannot be extended; in our research it has been proven that through appropriate materials and lesson plan design, the use of the Bee-bot can reinforce multidisciplinary learning. As also proposed in [21], the teachers in our research underline that the integration of robotic toys in the formal curriculum would assume holding teacher training sessions and developing ready-to-use material fitting the standard school programs in math, science and other disciplines. We have drawn the following conclusions:

- The training enabled foreign language teachers to feel self-confident and eager to use robotic toys in their teaching and encouraged them to consider that there are multiple applications of robotic toys both in foreign language learning and development of skills as problem-solving, teamwork and mathematical and critical thinking.
- Teaching practice with robotic toys enabled teachers to observe that the robotic toys have various applications in foreign language teaching (in grammar and vocabulary) and can also benefit students with attention deficit and dyslexia.
- Teaching practice with robotic toys led teachers to view robotic toys as an interdisciplinary resource suitable for children of various ages. Even though the implementation of Bee-bot activities involves challenges (time-management, mat design and classroom management), teachers are eager to continue using the Bee-Bot and are willing to learn more about ER technologies.
- Teachers were enthusiastic about using robotic-toy activities in class and able to carry out the activities assigned, even though in their first contact with this technology they faced difficulties with programming the robot to turn, laterality, sequencing and decomposing instructions.
- Teachers view this technology as interdisciplinary and propose its integration into the formal curriculum across disciplines, although such an integration would assume purchasing equipment, hiring teaching, designing ready-to-use materials and holding teacher training sessions.
- Teachers were able to integrate the Bee-bot resource in their daily teaching practice to address the objectives of their classes of English as a foreign language.
- Teachers' positive perceptions of the Bee-bot sustained from the training until almost a year later of teaching practice, in the follow-up session.

Future research would include studying further teachers' perceptions of robotic toys and ER technologies regarding their multidisciplinary integration across different areas of the curriculum.

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References

1. Fernaeus, Y., Håkansson, M., Jacobsson, M., Ljungblad, S.: How do you play with a robotic toy animal? A long-term study of Pleo. In: Proceedings of the 9th International Conference on Interaction Design and Children, pp. 39–48. Barcelona (2010)
2. Virnes, M.: Four seasons of educational robotics: substantive theory on the encounters between educational robotics and children in the dimensions of access and ownership, dissertations in forestry and natural sciences. University of Eastern Finland (2014)
3. Bee-bot Homepage: https://www.bee-bot.us. Accessed 30 Jan 2020
4. García-Peñalvo, F.J., Rees, A.M., Hughes, J., Jormanainen, I., Toivonen, T., Vermeersch, J.: A survey of resources for introducing coding into schools. In: Proceedings of the 4th International Conference on Technological Eco-systems for Enhancing Multiculturality, Salamanca, pp. 19–26 (2016)
5. Mantzanidou G.: Educational robotics in kindergarten, a case study. In: Merdan M., Lepuschitz W., Koppensteiner G., Balogh R., Obdržálek D. (eds.) Robotics in Education. RiE 2019, Advances in Intelligent Systems and Computing, pp. 52–58. Springer, Cham (2020)
6. Roussou, E., Rangoussi, M.: On the use of robotics for the development of computational thinking in kindergarten: educational intervention and evaluation, In: Merdan M., Lepuschitz W., Koppensteiner G., Balogh R., Obdržálek D. (eds.) Robotics in Education. RiE 2019 Advances in Intelligent Systems and Computing, pp. 31–44. Springer, Cham (2020)
7. Stoeckelmayr, K., Tesar, M., Hofmann, A.: Kindergarten children programming robots: a first attempt. In: Proceedings of Robotic in Education, pp. 185–192 (2011)
8. Komis, V., Misirli, A.: Étude Des Processus De Construction D' Algorithmes Et De Programmes Par Les Petits Enfants À L' Aide De Jouets Programmables. s. Dans Sciences et technologies de l'information et de la communication (STIC) en milieu éducatif. Clermont-Ferrand, France (2013)
9. Cacco, L., Moro, M.: When a bee meets a sunflower. In: Proceedings of 4th International Workshop Teaching Robotics Teaching with Robotics and 5th International Conference on Robotics in Education, Padova, pp. 68–75 (2014)
10. Highfield, K.: Robotic toys as a catalyst for mathematical problem solving. Aust. Prim. Math. Classroom **15**(2), 22–27 (2010)
11. Collado, E.: Robots as language learning tools. Learn. Lang. **22**(2), 28–31 (2017)
12. Sullivan, A., Kazakoff, E.R., Bers, M.U.: The Wheels on the bot go round and round: robotics curriculum in pre-kindergarten. J. Inf. Tech. Educ. Innov. Pract. **12**, 203–219 (2013)
13. Highfield, K., Mulligan, J., Hedberg, J.: Early mathematics learning through exploration with programable toys. In: Proceedings of Joint Conference Psychology and Mathematics, pp. 17–21 (2008)
14. Alimisis, D., Moro, M., Arlegui, J., Pina, A., Frangu, S., Papanikolaou, K.: Robotics & constructivism in education: the TERECoP project. In: Kalas, I. (ed.) Proceedings of the 11th EuroLogo Conference, p. 11 (2007)
15. Kim, C., Kim, D., Yuan, J., Hill, R.B., Doshi, P., Thai, C.N.: Robotics to promote elementary education pre-service teachers' STEM engagement, learning, and teaching. Comput. Educ. **91**, 4–31 (2015)

16. Caballero González, Y.A., García-Valcárcel Muñoz-Repiso, A.: Development of computational thinking and collaborative learning in kindergarten using programmable educational robots: a teacher training experience. In: Dodero, J.M., Ibarra Sáiz, M.S., Ruiz Rube, I. (eds.) 5th International Conference on Technological Ecosystems for Enhancing Multiculturality (2017)
17. Chevalier, M., Riedo, F., Mondada, F.: Pedagogical uses of thymio II: how do teachers perceive educational robots in formal education? IEEE Robot. Autom. Mag. **23**(2), 16–23 (2016)
18. Castro, E., Cecchi, F., Salvini, P., Valente, M., Buselli, E., Menichetti, L., Calvani, A., Dario, P.: Design and impact of a teacher training course, and attitude change concerning educational robotics. Int. J. Soc. Robot. **10**, 669–685 (2018)
19. Negrini, L.: Teacher training in educational robotics. In: Lepuschitz, W., Merdan, M., Koppensteiner, G., Balogh, R., Obdržálek, D. (eds.) Robotics in Education. RiE 2018. Advances in Intelligent Systems and Computing, vol 829. Springer, Cham (2019)
20. Moro, M., Agatolio, F., Menegatti, E.: The RoboESL project: development, evaluation and outcomes regarding the proposed robotic enhanced curricula. Int. J. Smart Educ. Urban Soc. (IJSEUS) **9**(1), 48–60 (2018)
21. Kradolfer S., Dubois S., Riedo F., Mondada F., Fassa F.: A sociological contribution to understanding the use of robots in schools: the thymio robot. In: Beetz M., Johnston B., Williams MA. (eds.) Social Robotics. ICSR 2014. Springer, Cham (2014)
22. Pittí, K., Curto, B., Moreno, V., Rodríguez, M. J.: Resources and features of robotics learning environments (RLEs) in Spain and Latin America. In: Proceedings of the First International Conference on Technological Ecosystem for Enhancing Multiculturality, pp. 315–322 (2013)
23. Fessakis, G., Gouli, E., Mavroudi, E.: Problem solving by 5–6 years old kindergarten children in a computer programming environment: a case study. Comput. Educ. **63**, 87–97 (2013)
24. Yin, R.: Case Study Research: Design and Methods, 5th edn. Sage Publications, London (2014)
25. Braun, V., Clarke, V.: Using thematic analysis in psychology. Qual. Res. Psychol. **3**, 77–101 (2006)

Mathematics Through Educational Robotics in a First Primary Class: A Comprehensive Study

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Abstract. This paper presents the results of an investigation about the impact of Educational Robotics in the mathematical teaching/learning process in the first class of a primary school. The research involved two first primary classes of the same school for a period of four months, and the robot used was a new floor turtle produced in Italy called MIND Designer. As a secondary research goal we also made an evaluation of the acquired social skills. We used both questionnaires involving three aspects related to maths and evaluation rubrics. The tests were submitted independently by a group of university experts in learning disorder for a meaningful comparison. The paper provides also some methodological and pedagogical remarks, linking Educational robotics to constructivist/constructionist views, design by competences, cooperative learning, computational thinking, and cultural artifacts.

Keywords: Educational robotics · Primary school · Mathematical skills · Constructionism · MIND designer

1 Introduction

Instructional design by competences is currently a teaching model capable of responding to the new needs of the school system and of the socio-cultural context it represents. Nonetheless, its implementation in class finds constant resistance due to the fact that reasoning in terms of competences implies to eradicate the consolidated idea of a School that should provide cultural elements and notions with specific objectives through the traditional lesson given by a supposed omniscient teacher. Unfortunately, the design by competences is often reduced to a change of labels to existing practices with the same objectives renamed as competences [1]. The actual broadening of knowledge in a wide spectrum of subjects and the possibility for pupils to have direct and indirect access to any kind of information promote interests and stimuli towards fields of knowledge that were unimaginable until some years ago. Thus, in the design by competences the basic

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curriculum is integrated with contextual needs and it is taken into account the specific characteristics of the pupils in a continuous learning process respectful of the different learning times and styles, not forcing a strict consequentiality between what is learned before and what happens to be learned after.

This paper describes an investigation which lasted one entire school year, aimed at evaluating whether and how Educational Robotics (ER) affects the development of basic competences, namely in the mathematical field; the experimentation involved two first grade classes of a Primary School during the 2018/19 school year. Design by competences requires suitable tools in favor of better teaching practices in order to promote changes and improvements. ER seems to respond to this need because its introduction induces teachers to change models and methods and to convey knowledge in innovative and experiential ways [2].

After a section dedicated to some pedagogical foundations about ER as a learning tool, Sect. 3 explains the motivation for adopting the robot we chose. Section 4 is the core section describing the research design: we present the school context, some implementation details, adopted evaluation tools. The following section shows evaluation data, with comparisons between the two involved classes and with data coming from an external similar research. The final section contains summarizing remarks.

2 Pedagogical Foundations: Primary Education Through Robotics

Globalization have profoundly changed the society in which we live: ICT makes it possible for a greater and faster planetary development on scientific, technical and economic levels. The school is responsible to prepare future generations of protagonist citizens in the new challenging scenarios, where flexibility in the learning process is a must. Concurrently, it is expected to critically choose how and how much to integrate the new with already acquired to support a common sense of growth, not forgetting the challenge to educate children for future jobs and technologies and to face problems whose characteristics are still difficult to imagine. In this perspective, ER finds space in the school system, from kindergarten to University, as a tool capable of combining the traditional school dimension with the new demands of increasingly complex contexts that require each student to elaborate his or her own cognitive strategy to successfully face such a complexity [3].

Contrasting the sort of Piagetian obligation to interpret reality in order to learn, Vygotskij highlighted the human need to respond to socio-cultural stimuli: culture is part of the nature of the individual and therefore he learns within its interactive contexts. We recognize learning as the integration of the theories of these two scholars in a single process of construction and reconstruction of knowledge, a continuous flow of interactions between the individual intelligences in a cultural and social context [4].

What Papert added with his Constructionist approach is a greater attention to the construction and manipulation of artifacts as part of the learning process because they trigger a parallel development of mental models [5]. Simple drawing robots, the LOGO language and Turtle geometry are the essence of this pedagogical approach. Papert also intuited that new computers and robots could have been used as powerful tools for a competitive skill: being able to learn [6].

Part of the Papert's intuition is now re-interpreted around the keyword *computational thinking* (CT) [7], i.e. a problem posing and problem solving attitude using the typical logic and constructions of programs executable by an agent that processes information [8, 9]. CT had already been included in the Italian National Indication Goals for the kindergarten and the first cycle curricula but it is now considered at a Ministerial level for one of the main "cultural tools for citizenship" meaning a "mental process that allows you to solve problems of various kinds by following specific methods and tools by planning a strategy".

This is clearly strictly linked to ER with the relevant add-on of seeing the code in real action. Literature shows that coding and ER are the most suitable tools for developing computational thinking in pupils [10]. Nevertheless, ER has not yet been included in our school curricula and the Italian literature available on the subject is limited, in spite of an apparent increasing interest in the subject, proven by robotic competitions, teacher training courses and funded projects.

Design by competences is proposed as a response to the new contextual needs imposed by socio-cultural changes that have developed since the last century and to the theoretical learning models referred so far. Competences aim to be a point of contact between scholastic, theoretical knowledge and real knowledge, the first favoring abstract languages and systematic and structured learning paths, the second favoring concrete languages based on practical, intuitive and personalized learning paths.

When ER is applied, formal school knowledge is integrated with experience-guided learning with 'authentic' problems conveying competences in a broad sense. ER promotes effectiveness for teaching actions in terms of competences in two forms, one laboratorial and the other, metacognitive. That means: learning is an active process occurring by discovery through the simulation of real situations; learning takes place through guided reflective processes on one's own work that lead to develop self-regulations [11]. These assumptions confirm that ER-based experiences can be designed to promote both disciplinary and social skills and the ability to learn how to autonomously organize one's work. At the same time, we understand how to collaborate within the group for new and better solutions through negotiated paths. As a secondary effect of the metacognitive process, through ER the shared construction of knowledge gradually leads to develop a metacognitive awareness of the learning development, and the control of it, as Brown [12] defines "learning to learn".

We would also relate ER with *cooperative learning* (CL), i.e. the interaction among pupils which naturally arises guided by the teacher in favor of his/her general goals. CL requires the identification of common and well-defined objectives, the choice of a working method that allows the progression towards the objectives and, finally, the definition of the roles and responsibility of each component. Therefore, CL allows you to work simultaneously on multiple aspects, and it is an active methodology generating meaningful learning and training creative people to face the still unknown challenges of the future [13]. Aspects like creative processes, social skills, problem solving, decision making, reducing overwhelming conflicts, ability to exercise the role of leader, and take advantage from this approach. ER fits significantly in all these aspects with its active teaching approach where elements from science, society and technology interact with each other in the construction, programming and manipulation of artifacts.

Teaching/learning mathematics requires tools that introduce and make 'alive' fundamental, not simple concepts. The ability to learn the world in numerical terms is an innate characteristic of the human being although conditioned by individual characteristics related to education and learning and, therefore, to the context within which it occurs [14]. In kindergarten and in the first cycle of primary school, children need to touch, see and experiment. Pupils can perceive the high level of abstraction in maths difficulty and tediousness, with the consequence of a gradual loss of interest. Traditional methods seem to increase the number of students who do not like this subject [15]. The perception that a task is tedious comes from a non-sufficient intrinsic motivation (the one which starts directly from the subject without taking into account the external advantages or rewards when a task is carried out). For this reason, it is important to work transversely on metacognition mechanisms and to apply new tools and new techniques to teach mathematics; moreover maths should be expressed through real problems that arise from real experiences in order to relate methods and knowledge learned outside the school with those learned inside the school.

Constructivist/constructionist methods suggest the use of 'mediators' which, according to Vygotsky, link practical activity to mind processes which express interaction between multiple zones of proximal development. Together with an address to CL, they allow to develop an ever-increasing autonomy in troubleshooting [15] with such mediators becoming cultural artifacts. In ER robots can play the role of cultural artifacts [13] and therefore we expect to have a significant impact in the specific area of teaching/learning maths by using them.

3 Suitable Robots for First Years in Primary School

Many papers and reports suggest starting with unplugged activities like asking pupils to act as robots (body sintonicity) and using paper tools. This prologue favors a better awareness of a robot's motions and the distinction between the robot's point of view of the environment and the one of an external observer. The following step is to use physical floor turtles: they are essentially modern version of the original Papert's turtle robots; most of them do not require the use of a computer at all, as they are equipped with buttons for programming the robot.

Currently the market provides several type of suitable robots with the aforementioned characteristics, both as accessible and inexpensive toys. Their significance as toys means that ER can introduce a form of 'gamification' in education that promotes a greater involvement in the learning processes by increasing intrinsic and extrinsic motivations. Among others products, we would mention the ones produced by the English company TTS-Group, particularly Bee-Bot and Blue-Bot (see Fig. 1A), the second equipped with a rechargeable battery, a BT connection and a transparent shell to implement the white-box paradigm. They are widely adopted in primary school and often cited in literature. The Italian toy manufacturer © Clementoni has more recently introduced a series of robots with essentially the same type (floor turtles), some of them programmable with physical buttons on the robot, other ones also or only through BT using a dedicated free app. Among these robots our attention was attracted by MIND Designer (see Fig. 1B): it provides three operating modes (FREE for exploration, EDU with coding challenges proposed by the robot itself, and APP for remote control), it has a slot for a marker to draw geometrical figures, it vocally invites pupils to interact and it also allows vocal commands, especially helpful when a visual impairment is concerned. Comparing with Bee/Blue-Bot, through its tablet app, MIND allows more flexible movements, arbitrary linear lengths and arbitrary angles for rotations. For all the abovementioned reasons, we chose MIND as the robotic platform for this research.

A B

Fig. 1. A – Bee-Bot and Blue-Bot. B – Mind Designer

4 Didactical Project Design

The research was developed in two not very different first grade primary classes in the same school during the 2018–19 school year, where the main official teacher was dedicated mostly to maths, IT and science. We, however, experienced ER with the pupils also during hours with teachers responsible for other subjects. Class A had 9 males and 9 females, class B had 10 males and 11 females. Due to the position of the school in the city, the presence of foreign pupils, relevant in other areas, was here very limited, so the activity was not significantly influenced by other priority needs such as language barrier reduction. The resources available were classrooms, each with an Interactive White Board, the school gym, and the school garden. No certified disable pupil was signaled out, despite this some pupils received special attention for specific personal needs.

Following the European recommendations regarding the key competences for life-long learning and the most recent national indications for the curricula of the first primary cycle, we decided to focus on mathematics, designing a one-year path to validate the impact of ER in this context. Within the national indicators, the goals for the development of mathematical skills at the end of primary school are described as: “the pupil moves confidently in the written and mental calculation with natural numbers”. Among the objectives of the third graders there is a know how to “read and write natural numbers in decimal notation, having awareness of positional notation; compare and order them, also representing them on the straight line “and” mentally perform simple operations with natural numbers and verbalize the calculation procedures”. These objectives were used as reference of assessment during the research together with social skills which are expected to grow positively influenced by ER.

We planned to use evaluation rubrics as measuring tools for certifying skills within such a rich and complex context. The evaluation categories require the observers to look at the pupils in a global perspective, which takes into account both the cognitive and the social aspects. In spite of our initial willing, it was not possible to involve a control group in the same school or in a similar one: for this reason we chose to compare our experimental data with the ones provided by AC-MT 6–11 Evaluation test of calculation skills from the MT Group on a sample of 91 pupils of first grade classes in the same period of the year in which the Post-Test was carried out by us (MT Group is a group of researchers who deals with the diagnosis and treatment of learning disorders at the University of Padua [16]; AC-MT means 'Abilities (for) calculus – Memory Transfer). In this choice we also positively considered that this sample included different schools and therefore different methodological approaches. AC-MT validated test focuses on the evaluation of two main skills: numerical knowledge, i.e. all the skills necessary to understand the concepts of quantity and their transformations, and calculation skills, i.e. the set of processes that allow the resolution of arithmetic operations [17]. It is widely used in Italy for researches on calculating and problem-solving abilities and on specific disabilities [18–20]. The structure of the AC-MT calculation test for the first classes plans two tests: an intermediate test verifying the level of the class after the end of the first four months, and the final test that measures the learning developed during the entire school year. Each test consists of two parts: the paper-and-pencil tests and the individual tests.

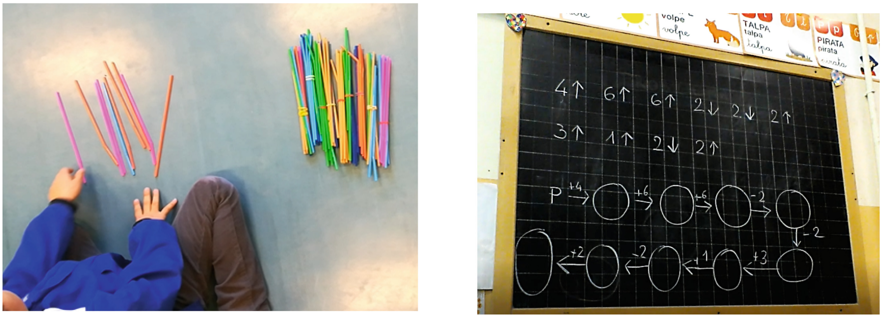
The paper-and-pencil tests are written tests to be proposed simultaneously with the entire class: they test the ability to apply the calculation procedures through written operations (two additions and two subtractions of natural numbers) and a more general numerical knowledge such as numerosity (6 pairs of numbers are presented and for each pair the pupil must identify largest number), composition of quantities from weighted digits, increasing and decreasing ordering. During one individual test the pupil and the examiner are placed in a quiet place and the child is orally asked to perform three additions and three subtractions within a reasonable amount of time. In addition, the child is asked to write some dictated numbers and then to enumerate in the order from one to twenty as quickly as possible: these two operations evaluate the syntactic and lexical mechanisms of number production.

Despite the unavoidable differences between the two classes, the essential aspects of the design of intervention was unique in order to have comparable final results. During the sessions we took into account we had to apply, as usual, a set of strategies that allow us to provide students with multiple means of representation, action, expression and involvement [21]. Here a list of fundamental choices that guided the design and implementation in general terms: a) Learning environments that favor equal communication between all, pupils and teachers; b) A tight didactic contract between pupils and teachers with clear shared rules; c) An overall design aimed at developing the competence of learning to learn; d) An integration between context-oriented teaching, according to the constructivist paradigm, and process-oriented according to the activist paradigm; e) A certain degree of flexibility to meet specific needs of the context; f) Laboratorial education based on exploration, observation, formulation of hypotheses and their verification, learning by doing; g) Cooperative learning model for negotiated and shared learning; h)

A ‘discourse community’ [22] within which pupils share themes and ways of speaking following the specific conventions of the different disciplines; i) An inclusive look at the choice of tools and practices in accordance with the Universal Design of Learning approach [21].

Now we describe the steps of intervention. In February we administered both the intermediate and final questionnaires (a Pre-test) to establish a starting point for the classes and for the comparisons at the end of the research. The experimental work was distributed between February and May, with two dedicated hours every week.

The propaedeutic first activity was focused on the counting ability with the use of plastic straws grouped in tens (see Fig. 2A).



A B

Fig. 2. A - Counting with plastic straws. B – First coding

Then we started to prepare the robotic scenario. Previously the pupils had already worked with a numerical line of one digit numbers on paper: we extended this knowledge asking them to prepare a line with numbers with more than one digit and dimensionally suitable for the robot, that is with slots 15 cm long, as they personally verified through taking measurement of the robot step. The MIND robot was introduced for the first time to familiarize and to experiment with some basic assumptions, for example the number reached starting from a number n and with m forward commands. In a successive session, we used a die to establish random repetitions of forward-backward commands; pupils were invited to choose a written code for the sequence of repetitions. Eventually they thought to use a number and an arrow (↑ forward ↓ backward) and the log was reported on a blackboard (see Fig. 2B).

A reinforcement session was dedicated to a deeper understanding of the greater and lesser relationships between numbers on the numerical line and, using again a die as random generator, we asked the pupils to guess the result of the sums and subtractions, then searching confirmation by the position of the robot. Incidentally, subtractions with sufficiently great numbers put the robot out of the natural numerical line, taking notice on some intuitions on negative numbers. What was experienced with practical activities was immediately documented on a copybook.

The next step was a simplified introduction of the concept of angle, using means like drawing two intersecting lines, folding a paper sheet, with the final goal to smoothly introduce perpendicularity. But, folding a paper sheet was also a way to perceive what parallel lines are and, at that point, the pupils were ready to prepare a complete grid for the robot.

A B C

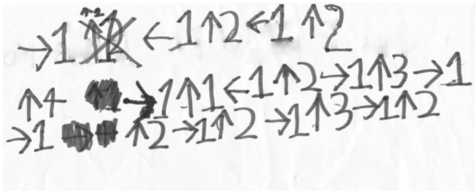
Fig. 3. A – The map. B – Working in the garden. C – The code

At this stage we introduced a multidisciplinary contextualization and, with the collaboration of the teacher in humanistic subjects, we presented and discussed a variation of the ‘Little Thumb’ story (Charles Perrault): a relevant element is a trick used by the protagonist to record a path in the wood. This was exploited to illustrate some observations with the robot such as defining a start and end point, to better understand orientation in space and to record a path in case you want to redo it backward.

At this point the pupils were ready to prepare the specific grid for MIND (see Fig. 3A). It included objects such as the house, trees, the position where Little Thumb and his little brothers were to be left by their father. In a preliminary simulation in the garden the grid was reproduced on the ground, scaled to measure one human step. The house and trees were represented by plastic cones (see Fig. 3B). One pupil acted as the father and, holding the map, conducted another pupil representing the little children not aware of the followed path. Once they reached the final point the ‘father’ run out and all the other pupils were asked to try to reconstruct the path backward to the house. They realized the need of using the map to do the task, interpreting backward the single movements and thus acting, in some sense, as the pebbles that Little Thumb had scattered along the way. The simulation was propaedeutic to code the chosen path on a blackboard, enriching the previous syntax with the new two commands (→ turn right ← turn left) (see Fig. 3C).

The last step was obviously to reproduce the whole story on the grid using the robot which impersonated Little Thumb with the task to go back home. All the decorations on the grid were made by the pupils themselves (see Fig. 4A). The pupils were divided into groups of 3–4 components, with a copy of the map for each group, then they were asked to ‘code’ the backward path using the agreed syntax (see Fig. 4B). They had the possibility to ‘debug’ the code by programming the MIND robot in turn having direct feedbacks without the explicit intervention of the teacher.

A



B

Fig. 4. A – The final scenario. B – Coding attempts

5 Evaluation

Though we carried out the same intervention in both the two first parallel classes, we preferred to maintain separate data for the comparison between Pre-Test and Post-Test and for the compilation of the evaluation rubrics, also taking into account that the development dynamics of the two classes were not perfectly identical. We also had to exclude a very few individual tests for very specific reasons.

Table 1 summarizes the evaluation of the **intermediate test** administered to the two classes and the data from the MT group, in evidence the average (AV) and the standard deviation (SD), for the three identified indicators: written calculation, numerical knowledge and mental calculation (MT suggested to account correct answers for the first two and errors for the third, being related to the time it took for the pupil to answer). This gives an approximate picture of the starting situation where Class A seems more competent and more homogeneous in mathematical aspects with respect to class B, the slightly bigger one, with an even higher performance result with respect to the MT group reference. From our first direct interactions with the classes, we also observed a more collaborative behavior of class A.

As previously specified, the **final tests** were proposed both in the period preceding the work in the classes (Pre-test) and at the end (Post-test), analyzing the same indicators (see Table 2). The last rows present data of the MT group for the Post-tests.

Table 1. Intermediate test

Class		Written calculation _/4	Numerical Knowledge _/14	Mental calculation errors _/6
A	AV	3.17	13.06	2.1
	SD	1.12	1.90	1.85
B	AV	2.42	10.79	2.42
	SD	1.43	4.65	1.46
MT group	AV	2.74	12.53	1.9
	SD	1.23	2.93	1.46

Table 2. Final tests

Class		Pre WC	Post WC	Pre NK	Post NK	Pre MC Err	Post MC Err
A	AV	2.11/4	2.89/4	16.33/22	20.78/22	1.89/6	0.50/6
	SD	1.56	1.10	2.19	1.40	1.52	0.69
B	AV	2.00/4	3.75/4	15.05/22	20.55/22	2.79/6	0.84/6
	SD	1.14	0.54	6.29	1.47	1.47	0.93
MT	AV	--	2.98/4	--	16.95/22	--	1.63/6
	SD	--	1.33	--	6.67	--	1.62

This table highlights the improvements for both classes, though for class B the s.d. for the numerical knowledge indicator remains relevant. Remembering that the test for NK included a series of different tests, their scores confirm the higher heterogeneity of class B with pupils who completed all the exercises correctly and pupils who completed them all incorrectly.

The evaluation rubric for mathematical skills we compiled is based on the following indicators: the written ability for decimal numbers, enumeration until 20, ordering in both directions, number comparison, simple written operations and simple mental operations. They confirm what already emerged in the statistical evaluation: most of the students are placed in the two highest of 4 levels; at the basic level there are few pupils and only for some specific indicators.

Now let's make some considerations regarding the impact of ER in the registered outcomes. Class A performed better at the beginning, probably due to a higher predisposition to traditional frontal teaching and methods. Their intermediate post final tests are generally very similar to those of the MT Group. Apparently, the ER activity seems to have been particularly beneficial for a small group of pupils while it acted as a significant motivational support for most of the class. With its relevant heterogeneity in the competence levels of individual pupils and a disadvantaged starting situation compared with the other class, class B found greater benefits from ER which promoted a greater collaborating atmosphere, provided that variety of languages through which to express and represent the acquired knowledge, and finally helped this class to reach a performance comparable with the other class and enhance its homogeneity, a desirable condition for good skill development.

As a completion of the research, we also prepared an evaluation rubric for social skills based on the Didactic Contract agreed in class between pupils and teachers. Social skills are the key through which the students can learn to participate effectively and constructively in their daily life in the development of self-awareness, particularly in relation with other subjects or other cultures (see Table 3).

Social skills assessment, both at individual and class level, can be very complex for two main reasons: it is a gradual process that develops in different ways for each pupil and it is hard to find reliable tools to check them, especially in the first classes where the construction of positive dynamics between pupils and with teachers has just begun; the second reason is that the assessment is based on the observations of the behavior

Table 3. The social skills evaluation rubric

Indicators		Levels			
		Advanced	Intermediate	Base	Initial
The pupil moderates of voice volume depending on the context	A	16/18	2/18	0/18	0/18
	B	21/21	0/21	0/21	0/21
The pupil regulates his/her spatial position depending on the activity	A	13/18	5/18	0/18	0/18
	B	18/21	3/21	0/21	0/21
The pupil accepts and negotiates diverse ideas	A	16/18	2/18	0/18	0/18
	B	18/21	3/21	0/21	0/21
The pupil listen to the other classmates	A	14/18	4/18	0/18	0/18
	B	14/21	7/21	0/21	0/21
The pupil waits his/her turn	A	13/18	5/18	0/18	0/18
	B	15/21	6/21	0/21	0/21

and attitudes that are manifested simultaneously with the teaching requests and with the moments of development of personal knowledge. We decided to use direct observations during the work in class utilizing video and audio recordings, and an exchange of information with the teachers. As already observed for mathematical skills, Table 3 shows that, also in the development of social skills, pupils had a very heterogeneous starting situation, but they finally reached levels of competence similar to each other, even in the cases of some problematic pupils. ER demonstrated its supporting value because it naturally invites teachers to an interdisciplinary collaboration and, along with laboratory and cooperative methods, it helps pupils to develop self-regulation mechanisms, to relate to each other, to search alternative paths and to negotiate personal ideas, recognizing the value of other ideas.

6 Concluding Remarks

Ultimately, in all tests the values achieved are above the average of MT Group and with considerably smaller s.d., in particular in the case of the numerical knowledge test, together with a good level of homogeneity. The intermediate tests were presented to the pupils of the two compared groups during the same period of the school year and their starting situation was very similar. This condition gives a significant value to the higher results obtained in the final tests by the group exposed to ER. Furthermore, if we added all the scores obtained by each pupil in the mathematical tests in the pre-test phase and then in the post-test phase, we would observe a generalized improvement, with some very relevant positive differences. Generally speaking, the learning success comes from the adopted method but this is not the only important element in the learning process. While moving a simple wooden figure following given instructions may lead to automatisms without reasoning, robot programming activates deep cognitive processes and executive functions such as attention, planning, memory, self-regulation, meta-cognitive strategies, feedback reactions. Moreover, in our proposal the introduction of ER was strictly related to a pluriannual project dedicated to CT and coding in the perspective of their abovementioned guiding role.

These results prove that ER played an important role in the development of mathematical and social skills, with some clear indications that pupils would not have reached equally high levels of performance with only traditional teaching methods. Another positive side effect emerged was increased motivation and attention towards a fun and rewarding tool, facilitating the role of the teacher. MIND proved adequate and all the activities were performed in normal accessible areas (not a shared, sophisticated lab). Propaedeutic activities, contextualization, experimental and trial-and-error approach, multidisciplinarity, were all motivated aspects of our intervention to make the student at the center of his/her learning process, capable of reflecting on his/her own discoveries, investigating reasons in a continuous consolidation and expansion of knowledge, simply in a few words able to promote the 'learning to learn' competence.

References

1. Castoldi, M.: Progettare per competenze. Franco Angeli (2011). (in Italian)
2. Denicolai, L., Grimaldi, R., Palmieri, S.: Video and educational robotics: an innovative integration of audio-visual language and coding. In: Proceedings of INTED 2016, Valencia (2016)
3. Morin, E.: Complex thinking for a complex world–about reductionism, disjunction and systemism. Systema Connect. Matter Life Cult. Technol. **2**(1), 14–22 (2014)
4. Pardjono, P.: Active learning: The Dewey, Piaget, Vygotsky, and constructivist theory perspectives. Jurnal Ilmu Pendidikan **9**(3), 163–178 (2016)
5. Papert, S.: Mindstorms: Children, Computers and Powerful Ideas. Basic Books, New York (1980)
6. Slotnick, S.: In memory: Seymour Papert. https://www.media.mit.edu/posts/in-memory-seymour-papert/. Accessed 30 Jan 2019
7. Wing, J.M.: Computational thinking. Commun. ACM **49**(3), 33–35 (2006)
8. Wing, J.: Research notebook: computational thinking—what and why. Link Mag. **6** (2011). http://www.cs.cmu.edu/~CompThink/resources/TheLinkWing.pdf. Accessed 30 Jan 2019
9. Perković, L., Settle, A., Hwang, S., Jones, J.: A framework for computational thinking across the curriculum. In: Proceedings of the Fifteenth Annual Conference on Innovation and Technology in Computer Science Education, pp. 123–127 (2010).
10. Roussou, E., Rangoussi, M.: On the use of robotics for the development of computational thinking in kindergarten: educational intervention and evaluation. In: International Conference on Robotics and Education RiE 2017, pp. 31–44. Springer, Cham (2019)
11. Messina, L., De Rossi, M.: Tecnologie, formazione e didattica, Carocci (2015). (in Italian)
12. Brown, A.L.: Metacognitive development and reading. Theoretical issues in reading comprehension: perspectives from cognitive psychology, linguistics, artificial intelligence, and education, pp. 453–481 (1980)
13. Vicente, F.R., Zapatera, A., Montes, N., Rosillo, N.: STEAM robotic puzzles to teach in primary school. a sustainable city project case. In: International Conference on Robotics and Education RiE 2017, pp. 65–76. Springer, Cham (2019).
14. Rugani, R., Regolin, L., Vallortigara, G.: Discrimination of small numerosities in young chicks. J. Exp. Psychol. Animal Behav. Process. **34**(3), 388 (2008)

15. Leoste, J., Heidmets, M.: Bringing an educational robot into a basic education math lesson. In: International Conference on Robotics and Education, RiE 2017, pp. 237–247. Springer, Cham (2019).
16. Cornoldi, C., Lucangeli, D.: Arithmetic education and learning disabilities in Italy. J. Learn. Disabil. **37**(1), 42–49 (2004)
17. Cornoldi, C., Lucangeli, D., Bellina, M.: AC-MT 6–11. Test di valutazione delle abilità di calcolo e soluzione dei problemi. Gruppo MT. Erickson, Italy (2012). (in Italian)
18. Fanari, R., Meloni, C., Massidda, D.: Visual and spatial working memory abilities predict early math skills: a longitudinal study. Front. Psychol. **10**, 2460 (2019)
19. Sella, F., Re, A.M., Lucangeli, D., Cornoldi, C., Lemaire, P.: Strategy selection in ADHD characteristics children: a study in arithmetic. J. Attention Disord. **23**(1), 87–98 (2019)
20. Cester, I., Mioni, G., Cornoldi, C.: Time processing in children with mathematical difficulties. Learn. Individ. Differ. **58**, 22–30 (2017)
21. Rose, D.H., Gravel, J.W.: Universal design for learning. In: Baker, E., Peterson, P., McGaw, B. (eds.) International Encyclopedia of Education, 3rd edn. Elsevier, Oxford (2010)
22. Borg, E.: Discourse community. ELT J. **57**(4), 398–400 (2003)

Spike Up Prime Interest in Physics

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Abstract. The popularity of using robotics sets in schools is likely to continue the rising trend even two decades after the outbreak started by the introduction of LEGO MINDSTORMS sets. Yet, their use outside the usual scenario of constructionist robotics hands-on activities is still very limited and rare. We are concerned with using the sets in interdisciplinary scenarios, in particular to learn about and teach physics in elementary and secondary schools. We have designed a set of ten publicly available physics experiments that can be performed with the newly released LEGO Education Spike Prime to demonstrate physics principles and phenomena in playful sessions. We describe the experiments and their preliminary testing.

Keywords: Teaching materials · Physics · Spike prime

1 Introduction

For more than 20 years, versatile construction robotics sets from LEGO Education have attracted strong attention of progressive schools and individual teachers who aim to offer the best learning experience to their pupils. Typical use-cases include hands-on activities with the goal to learn about robotics, sensors, automated control, and programming. These activities implicitly contribute to enhancing the learners' potential to catch on in the subjects of mathematics, physics and others. By creating their own representations of the observed phenomena, learners develop a substrate for making associations to real-world from the theoretical material learned in those subjects. There have also been a few explicit instances of using robotics sets in interdisciplinary scenarios *to teach physics, mathematics, or other subjects* [11–13]. Yet, this potential has not been uncovered to a satisfactory extent and its merit has not been fully recognized and understood. The presence of the robotics sets in schools is popular. Their capabilities in demonstrating scientific principles and phenomena in a creative and constructionist way remain to be discovered, constituting a relevant field of study. The motivational factor of LEGO improves the learning rate. Pupils experience immersion and flow. Carefully designed experiments allow students to gain more insight into doing science [10]. Among the reasons for slow adoption of the robotics sets in interdisciplinary scenarios are inflexible curricula and schedules in schools, insufficient hours for the respective subjects, lack of teaching materials and ideas, lack of teachers' interest, in some cases the high cost of specialized hardware, and insufficient attention of the research community to this topic.

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Treating the topic properly is a challenge. It requires a strong and active experience with the robotics sets, deep insight into subjects like physics or mathematics, the pedagogical experience, and extensive creativity. This potential is understood by LEGO Education. For instance, in their latest contribution to the robotics sets family released earlier this year, the LEGO Spike Prime, they have included a force sensor measuring forces in Newton units. In this article, we present a compact series of publicly available physics experiments that are possible and built around the Spike Prime. Each experiment contains the task description, detailed building instructions, and software to perform the experiment, but they are open-ended with the aim of further experimentation. We provide pictures and videos from our realization of the experiments as well. Teachers and students are welcome to modify them and explore further. Our ideas originate from previous studies [1, 14], where we were involved, several tasks that we have designed for the Robot League competition [15], the long-term cooperation with the Department of Didactics in Mathematics, Physics and Informatics at our faculty, the textbooks on Physics for primary and secondary schools in Slovakia [2, 3], and our own ideas. In this article, we also show some examples of these inspirations. In the following sections, we will make a short overview of recognized hardware/software kits for making scientific physics experiments in schools, mention the related work on using robotics sets for teaching physics, introduce our set of experiments, provide feedback from our tests with pupils, and conclude with remarks for future developments.

2 Hardware Solutions for Teaching Physics

Preparing a comprehensive set of hardware tools for physics experiments usually leads to a long run project. It takes great efforts to find and develop reliable and durable good quality parts and equipment and to prepare a mature software environment with the ground educational principles of low floor and high ceiling. Several of such systems are used in schools. Only small set of schools can afford them and thus there are some interesting alternatives for those that can't [5]. The increased availability of smartphones opens to further promising applications [6]. These systems typically contain set of sensors, an external unified interface unit that connects to a computer and a software for collecting, visualizing and reporting the results, often including some advanced experiment automation and control including scripting. Some of them have also designed interfaces for connecting with LEGO Education sets. An obvious obstacle is that the commercial systems (including LEGO Education) tend to be more or less closed systems, prohibiting easier integration and interoperability of the equipment. The lack of being open is still an issue, while the developers seem to at least have overcome the platform compatibility and portability partially (Windows, Mac, Android).

2.1 IP-Coach (CMA)

Originally developed at the University of Amsterdam in the 80s, CMA Coach is still in development, reaching version 7, claiming to be "the most versatile and complete software for STEM Education" providing interfaces suitable from primary to college level. Available in various scale – including some that are recommended for student work at home. The system is student-centered and designed with the true scientific spirit. Among the features are storing sensor calibration, using video camera in experimentation, modelling and comparing the model prediction with the measured data, interactive animations.

2.2 LogIT

DCP Microdevelopments, a UK based company provides science education sensor equipment: tens of different sensors, several types of data loggers, and software for data logging branded under the LogIT name. For our case, it is important that there is a logIT LEGO Mindstorms adapter bringing the two worlds together. Furthermore, LogIT website comes with tens of experiments in Physics that can be realized with the equipment (or otherwise) at primary and secondary levels [7, 8]. This is a useful resource for everyone operating in our field.

2.3 Pasco

Probably the major overseas competitor for the CMA Coach is Pasco. Schools in Slovakia usually do not have the options to purchase Pasco equipment, except of some individual projects. Some talented teachers show examples of inspiring projects [9]. Pasco set and products include teacher guides.

2.4 Vernier

Another strong player with a full selection of sensors, interfaces, loggers, software, scientific lab equipment offering educator trainings is Vernier. In our context worth mentioning is the LEGO Mindstorms interface that makes the tens of various sensor accessible in the projects using the popular robotics sets.

3 Related Work

Barbara Bratzel is known for her series of books on teaching physics using LEGO Mindstorms [11, 13]. Several experiments are described also in a short paper [12]. LEGO Education has been running its LEGO Education Academy training programs for teachers. The specialized LEGO sets with the focus on Physics, namely Simple & Powered Machines (9686), Pneumatics Set (9641), Renewable Energy (9688), Simple Machines (9689), Early Simple Machines (9656) are all accompanied with building instructions for several exploratory projects. These sets are very specialized and significantly smaller number of schools or households are the proud owners of those as compared to the general robotics sets, which gain larger popularity. We still see an advantage in harnessing their potential. Even though they are a wonderful example how LEGO can be used to demonstrate physics principles using hands-on activities, they contain only limited options for experiment automation, control, and scripting.

4 LEGO Education Spike Prime

As contrasted to the renowned EV3 sets, the new universal construction set is designed to be easy to use and simple yet strong and powerful. It contains a programmable module (LEGO® Technic™ Large Hub for SPIKE™ Prime) with 6 input/output ports using LEGO Power Functions 2.0 type connectors, same as those used in WEDO 2.0, BOOST, and LEGO Trains. It has a built-in Bluetooth, Gyro, and simple square matrix LED display, three push buttons and micro-USB connector for program download and charging – again an improvement over EV3. A surprising limitation is the inability to collect measured data and transfer them to a computer for further processing and visualization. The only exception being lists, but in the current version of the software, it is not possible to export the lists. As we will show, we have overcome this constraint. Yet, their maximum length is somewhat limited.

5 Physics Experiments with Spike Prime

We will introduce all 10 experiments in selected topics of physics we have designed. For each, we describe its inspiration or motivation, the concept, the activity in the experiment, and ideas for further experimentation and modifications. Some are shown in full detail, however, the details of all of them including Studio models, rendered images, pictures, videos, complete building instructions to download or to view, programs to download or to view, all is available at the project website [4], which serves as the resource for teachers and students.

5.1 Measuring Speed

The task is to build a device for detecting crossing a speed limit through measuring with ultrasonic sensor. An object (for instance a car) is moving towards the device and the device uses its ultrasonic sensor to measure the time needed by the vehicle to cross a certain distance. Several measurements are averaged and can be compared to the speed limit value. The measuring device indicates the result to the driver. A similar task occurred in the Robot League [15] two years ago, see Fig. 1 for an example solution.

In this exercise, the pupils first build the vehicle and sensor module according to the instructions, then experiment – the times, calculated speeds, and an average of the velocities – which is an estimate of the average speed, not so proper one, as they learn in the second exercise (Figs. 2, 3, 4 and 5). Speed is shown on the screen, see Fig. 6. The suggested modifications and exploration include measuring the actual maximum speed instead of averaging several measurements, exploring different positions of mounting the sensor wrt. measurable distances and modifying the vehicle by attaching motors to make it move on its own.

Students work in pairs or small groups. Measuring speed is not that simple as it looks like, as it depends on many different conditions – the way the vehicle is started, in which direction, shape of the robot, or the wall, and the results will not always show the expected values. The students perform the experiments and discuss in their groups, record videos or take pictures. Finally, they make a short presentation to others.

Fig. 1. Measuring speed with ultrasonic sensor, from Robot League 8/2018, team Šachisti.

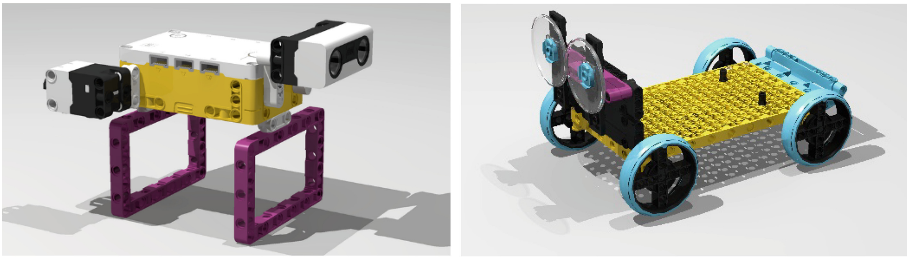

Fig. 2. 3D models prepared in Stud.io 2.0 of both parts.

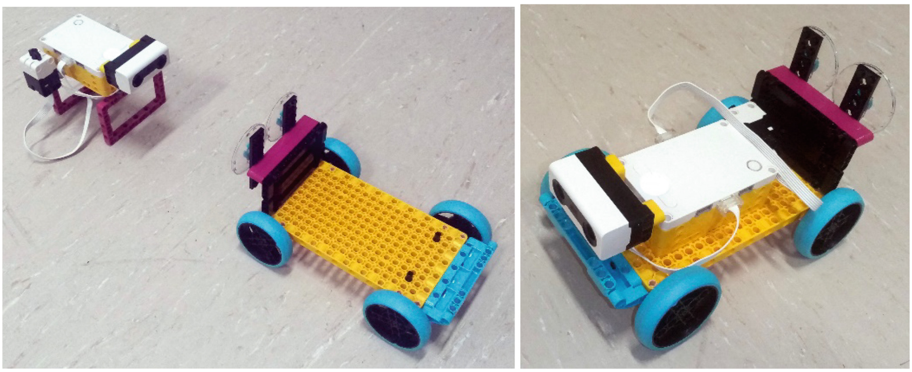

Fig. 3. Models built of Spike Prime, vehicle moving towards sensor module (left), vehicle with sensor module on-board moving towards a wall (right).

5.2 Average Speed

As the pupils learn in this exercise, the average velocity is not the average of the velocities – even when the travelled distances are the same. The task is inspired by an experiment suggested by a teacher from the elementary school of our robot club who has originally prepared it with NXT robots [1] (Fig. 7).

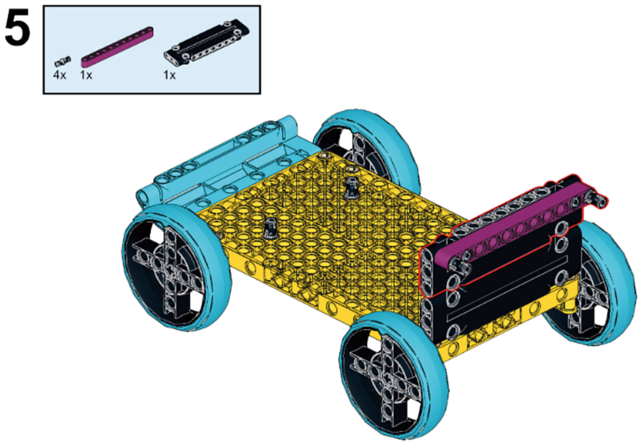

Fig. 4. One example step from building instructions.

In our experiment, a motor-powered vehicle is moving forward with a constant velocity 30% between cities A and B and continues with a constant velocity 70% from B to C, where it stops. Then it calculates velocities for both segments based on the known distances (100 cm each) and the measured times. Finally, it displays the average of the two velocities as well as the proper average velocity of the complete trip. Pupils can modify the program to use different velocities or change it so that it will calculate the velocity even when the segments have a different length, measuring it with rotation sensor (Fig. 8).

5.3 Rotational Inertia

This is an exercise, where pupils will discover that the time a free rotation of an object lasts does not depend only on its weight. The model is capable of setting an object into rotation with a low friction, and it uses a color sensor for measuring the time until the rotation stops. By using objects of the same weight, but with a different rotational inertia momentum, the students notice and observe the influence of the mass distribution in the rotating object on the kinetic energy it can absorb.

5.4 Center of Gravity

In this more practical hands-on exercise, there is no need for programming, but pupils will learn about the concept of center of gravity that is required for successfully completing modifications in the next exercise. Pupils are encouraged to try attaching also different objects so that the center of gravity will change. Try to estimate its position by guessing first, then verify the guess by a measurement. The center position is estimated as an intersection of two vertical lines passing through different points, Fig. 9.

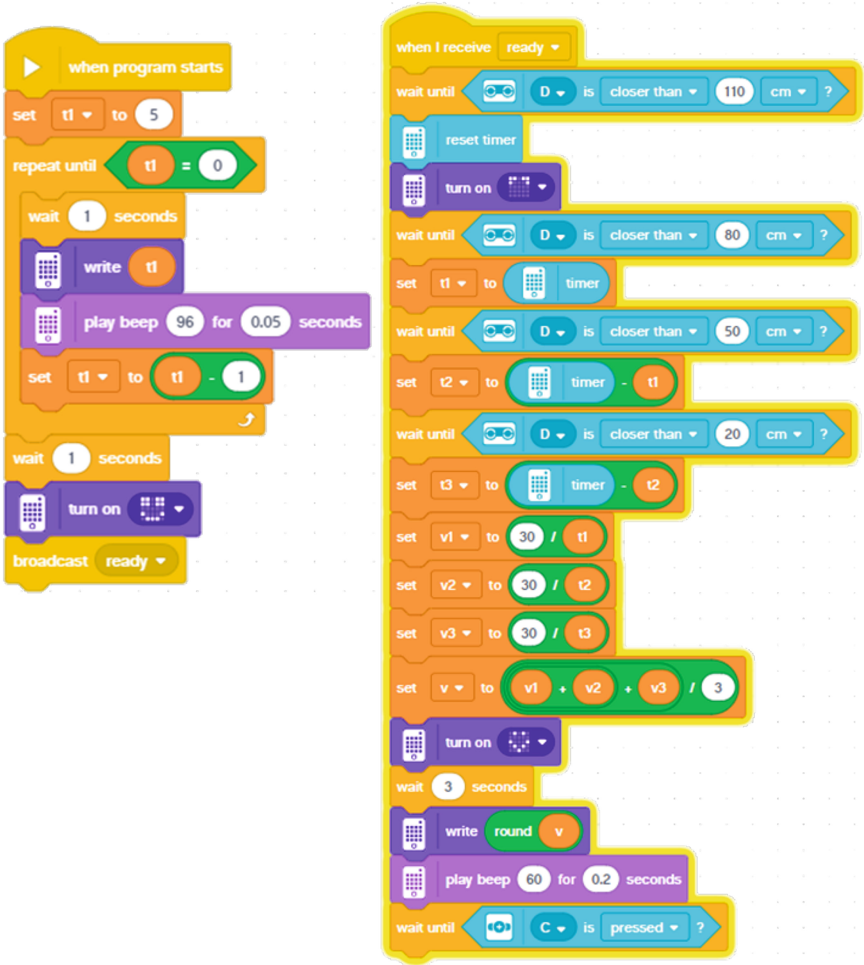

Fig. 5. Program for performing measurements that the students download to the hub.

5.5 Scales

This exercise is inspired by a task in Robot League, which itself was inspired by a beautiful model of scales in FLL 2014 (Fig. 10).

In this exercise, pupils build a model of scales for measuring the weight. The object will be hung at the end of the scale's arm, and the gravity will compete with the gravity of the hub and the arm. Both competing parts try to pull the arm their way, but since the centers of gravity and the fixed point of center of rotation are not on the same line, for each given weight, there is a unique equilibrium location, when the forces are in balance. By reading the hub's gyro sensor the hub can backwards-calculate the mass of the object at the tip of the arm. After estimating the center of gravity using the method from the previous exercise, we were able to tune a precision of about 2 g (comparable to those of a typical electronic kitchen scales).

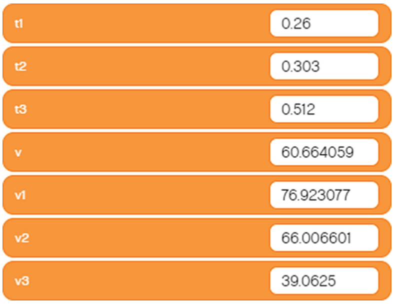

Fig. 6. Example of measured result.

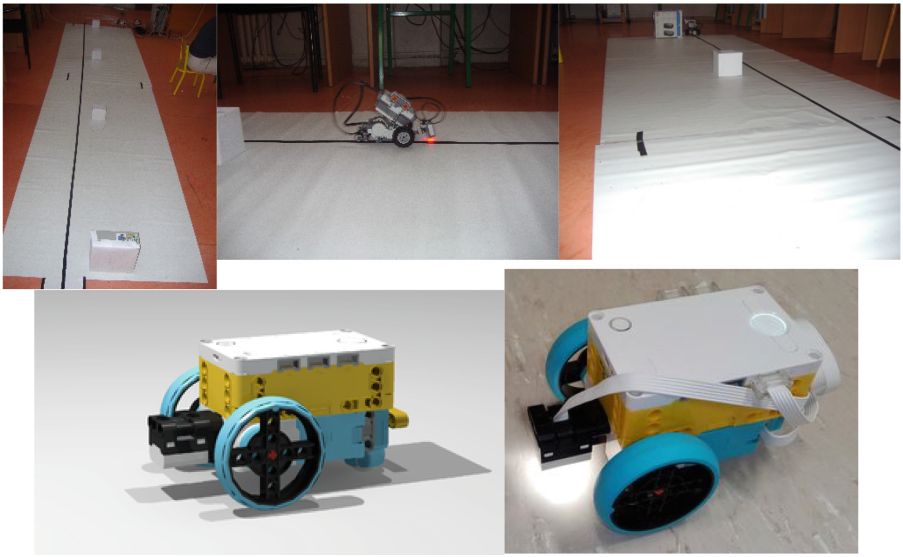

Fig. 7. Measuring average speed on trajectory with several segments with varying speed, top: original idea [7], bottom: our Spike Prime version – easy to build and measure.

5.6 Mechanical Lever

Pupils will discover how the simplest mechanism for amplifying or diminishing force works and how the force can be amplified or diminished. The model contains a force sensor, that will measure the force applied to it. In the experiment, pupils attach objects of different weight at the end of the free long arm of the mechanical lever, and observe the force reported by the sensor. Pupils are encouraged to notice what makes the lever strong and stable so that it can hold even some heavy objects and how the force is transmitted from the lever to the sensor (Figs. 11 and 12).

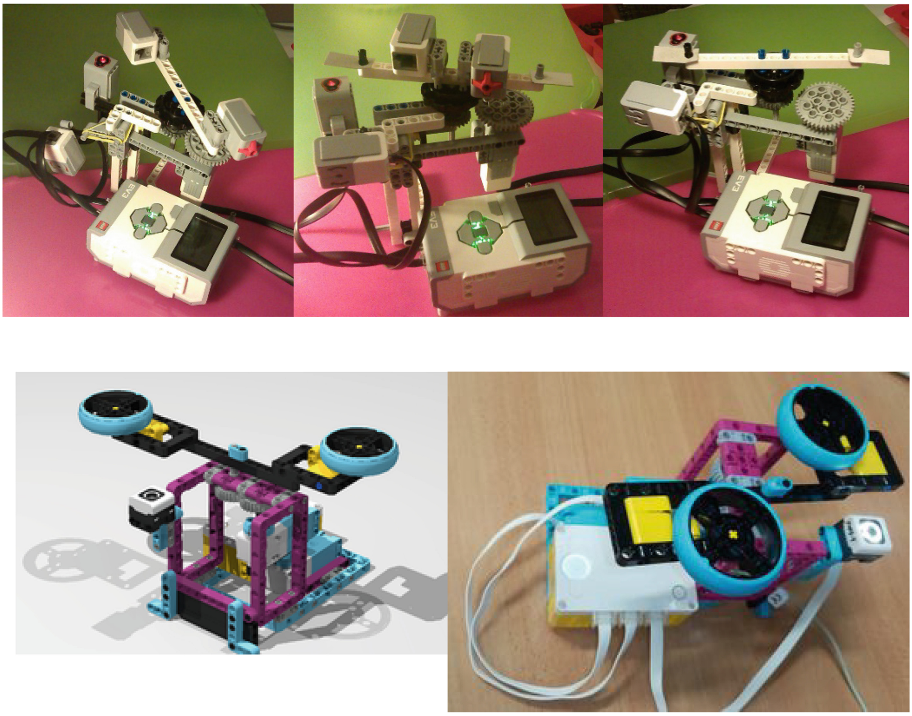

Fig. 8. Measuring momentum of inertia for three different weight distributions, top: our original version from [9], our Spike Prime version, which is improved.

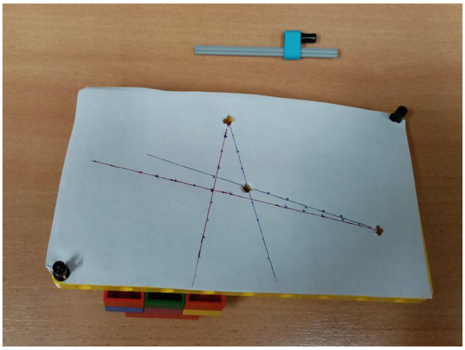

Fig. 9. Finding the center of gravity of an object with modifiable mass distribution.

5.7 Pulleys for Lifting Weights

In this project, the students discover a very useful pulleys mechanisms that allows lifting objects that are too heavy. Here, we use the possibility to control not only the motor speed but also its raw power. In this way with the help of the rotation sensor, we slowly

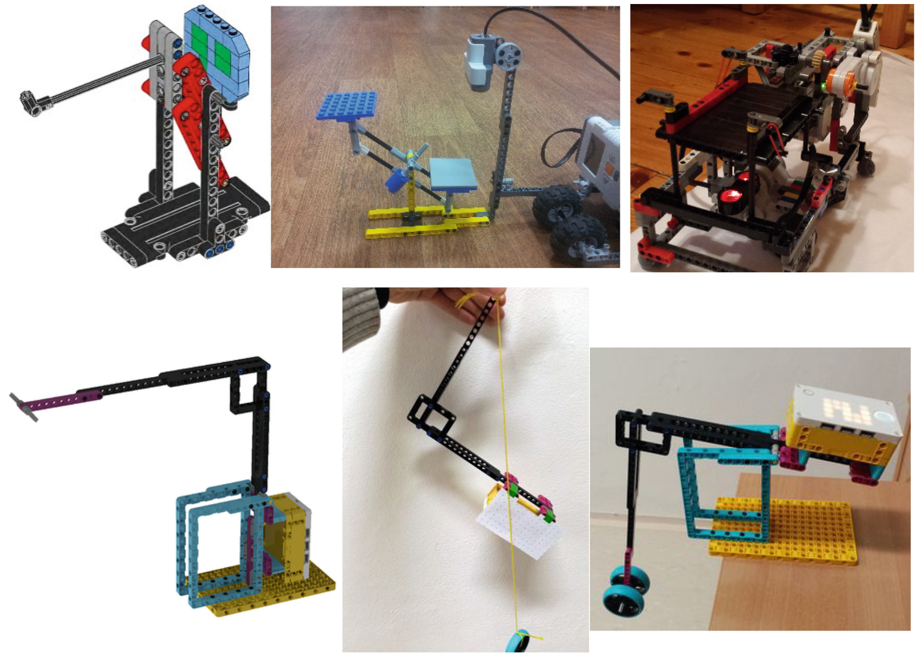

Fig. 10. Mechanical scales from FLL 2014, and two solutions of scales from Robot League 3/2015 (top), and our scales design for Spike Prime.

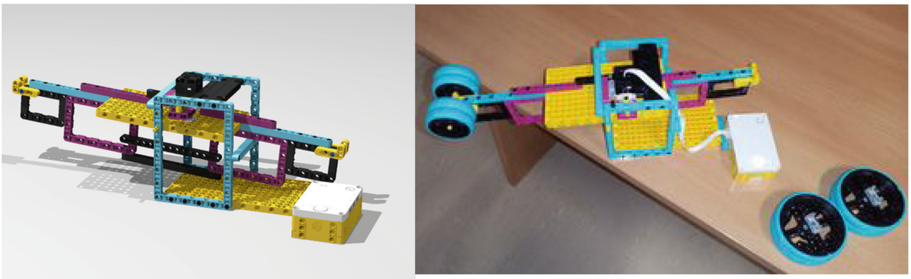

Fig. 11. Mechanical lever model, virtual and real. The reinforcements help to avoid bending of the lever even for more heavy objects.

accelerate the motor until the power is sufficient to lift the object of varying weight. This power is reported on the hub display.

5.8 Mathematical Pendulum

In this exercise, the pupils discover by experimentation the relation between the various parameters of the pendulum and the resulting behavior (Fig. 13).

Namely, they modify the weight, the length, and the starting position of the pendulum and observe the amplitude and the period of the oscillations. We have designed a tool

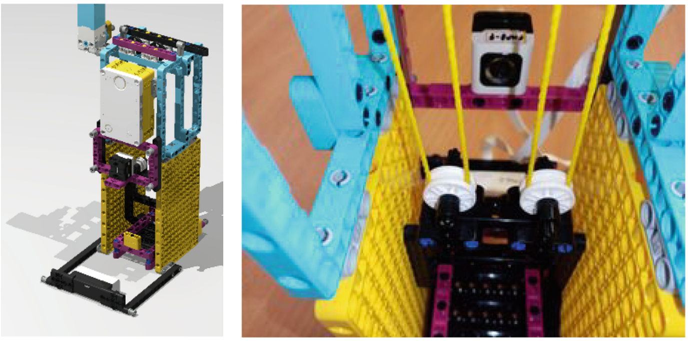

Fig. 12. A pulley mechanism with three alternate pulley configurations.

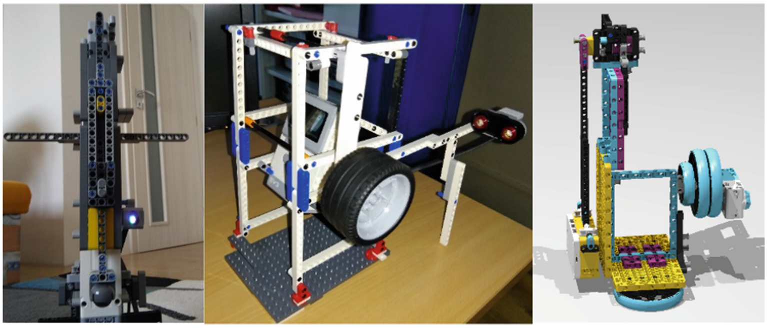

Fig. 13. Mathematical pendulum as constructed by teams BoscoBoti (left) and Jakubovskí Roboti (center), Robot League 3/2019 and our Spike Prime pendulum (right).

that allows exporting the data from the Spike Prime project (the measured gyro angle) and importing them into Excel for visualizing the data in the chart. In our realization of the experiment, the chart shows the expected behavior beautifully – the resulting period depends only on the arm length, see Fig. 14.

5.9 Static Wave Generator

When using a rope (string) that is tight to a flexible end, it is possible to tune the base frequency or higher harmonic frequencies, measure the speed of the wave travel in the rope and tune the frequencies for different number of nodes in a static wave. The pulses to the rope are generated by an oscillating mechanism (Figs. 15 and 16).

5.10 Centrifugal Force

A moving body would continue in a straight motion unless we apply a force. If it is bound by a string, or some other way it will move along a circular trajectory, but it will pull the string with a centrifugal force. How large is this force? Pupils measure the force using the force sensor in this exercise and visualize the results in chart again (Fig. 17).

Fig. 14. Visualization of the oscillations: period depends only on the pendulum length (top) and remains constant while the pendulum moves; max amplitude decreases over time (bottom).

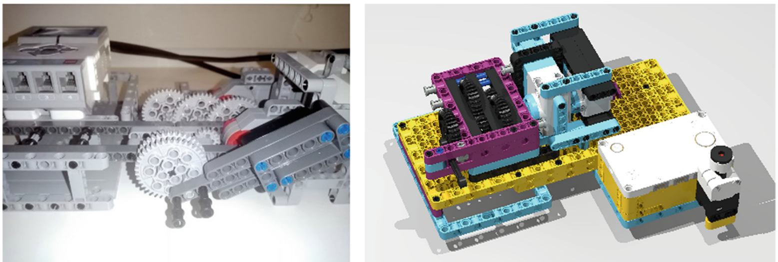

Fig. 15. Static wave generator, team Šachisti, RL 1/2020 (left), Spike Prime model (right).

6 Preliminary Testing

We have tested some of the experiments in the elementary school robot club. We have found that the children felt very comfortable using the building instructions, and had fun building the models. They were also confidently downloading and running the programs for the experiments. In the case of the scales experiment, we have discovered a small discrepancy in the scales model resulting in different measured values, but we have corrected the model based on this experience. We have shared the materials with the teachers who follow the LEGO Education resources in our country and we are currently

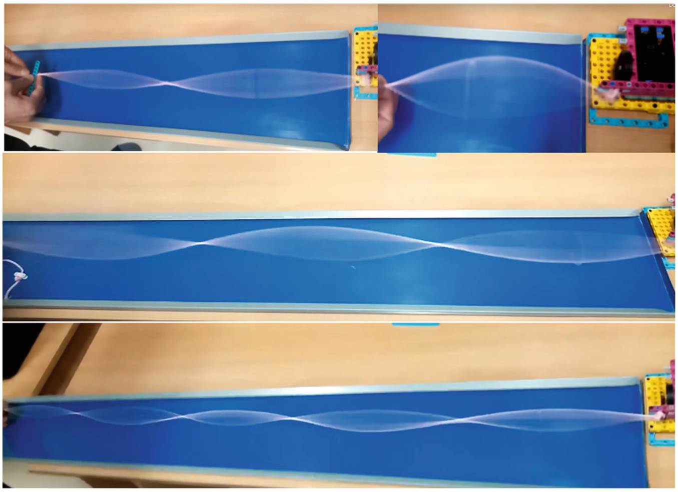

Fig. 16. Static wave generator, examples of produced static undulation.

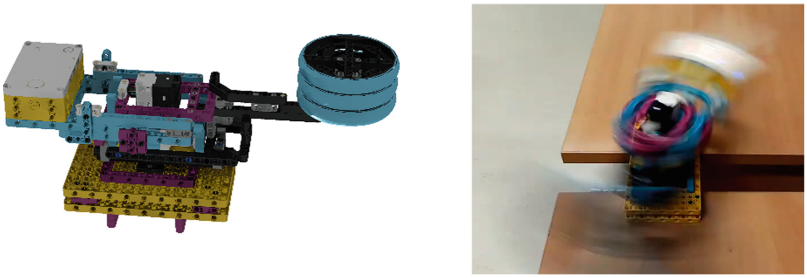

Fig. 17. Centrifugal force model and its operation.

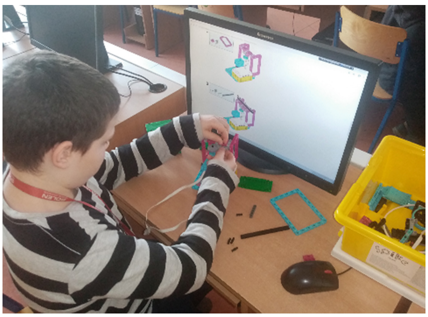

Fig. 18. Evaluation in the robot club.

performing further testing and evaluation including the Spike Prime on-line community (Fig. 18).

7 Conclusions and Future Work

In this paper, we present an approach to teaching and learning Physics that is based on the constructionist principles, aiming to result in faster learning curve due to robotics sets working as a catalyst for children motivation and by giving them real-world experiences that they can connect with the theoretical knowledge covered in their school Physics subject. We propose to achieve this by providing a set of 10 open-ended experiments with complete building instructions for the models, programs for performing the experiments, as well as media supplementary material – such as pictures and videos of our realizations. All projects contain ideas for further experimentation, modifications, measurements. Instead of providing the answers, they are rising questions. Pupils work in groups and present their results to the group to discuss the challenges and obstacles they resolved. We believe this to be an example of constructionist learning. The primary target and purpose of the LEGO robotics sets as educational tools. Our plans are to further validate our approach with more experiments in the classroom and if successful, extend the set of activities further by a degree of magnitude. To make the Spike Prime set compatible with our goals, we have designed special scripts that allow extracting the measured data from the project for the purpose of further processing and visualization. These scripts can be useful for the community. All media and files are available online as public domain at [4].

References

1. Lehocká, D.: Didaktické materiály k téme robotické stavebnice a Imagine Logo. Final report of DVÚI. Štátny pedagogický ústav Bratislava (2010)
2. Demkanin, P., et al.: Fyzika pre 2. ročník gymnázia a 6. ročník gymnázia s osemročným štúdiom. Združenie Educo (2010)
3. Demkanin, P., Horváthová, M.: Fyzika pre 3. ročník gymnázia a 7. ročník gymnázia s osemročným štúdiom. Združenie Educo (2012)
4. Petrovic, P.: Spike up Prime Interest in Physics – portal with instructions for students and teachers. robotika.sk/spike/
5. Kodejška, Č., De Nunzio, G., Kubínek, R., Říha, J.: Low cost alternatives to commercial lab kits for physics experiments. Phys. Educ. 50(5), 597 (2015)
6. González, M.A., et al.: Doing physics experiments and learning with smartphones. In: Proceedings of the 3rd International Conference on Technological Ecosystems for Enhancing Multiculturality, Porto (2015)
7. LogIT World: Secondary Teaching Resources. www.logitworld.com/index.php/secondary-higher/teaching-resources
8. LogIT World: Primary Teaching Resources. www.logitworld.com/index.php/primary-junior/primary-teaching-resources
9. Krejčová, J.: Dovnútra automobilu. Tvorivý učiteľ fyziky VIII, Smolenice (2015)
10. Round, J., Lom, B.: In situ teaching: fusing labs & lectures in undergraduate science courses to enhance immersion in scientific research. J Undergrad Neurosci Educ. Summer 13(3), A206–A214 (2015)
11. Bratzel, B., Rogers, C.: STEM by Design: Teaching with LEGO Mindstorms EV3. College House Enterprises, LLC (2016)

12. Church, W., Ford, T., Perova, N., Rogers, C.: Physics with robotics using LEGO® MINDSTORMS® in high school education. In: AAAI Spring Symposium: Educational Robotics and Beyond (2010)
13. Bratzel, B.: Physics by Design with NXT Mindstorms. College House Enterprises (2009)
14. Petrovic, P.: Robotický manuál. Deliverable of stage KA01 in EU-funded project "Od studenta k vědci" (CZ.1.07/1.1.16/02.0111) Jihomoravské centrum pro mezinárodní mobilitu. Brno (2015)
15. Balogh, R., Petrovič, P.: Robot League – A Unique On-Line Robotics Competition. In: Merdan, M., Lepuschitz, W., Koppensteiner, G., Balogh, R., Obdržálek, D. (eds.) RiE 2019. AISC, vol. 1023, pp. 344–355. Springer, Cham (2020). https://doi.org/10.1007/978-3-030-26945-6_31

Robotics Competitions

Learning 21st Century Skills Through Educational Robotics Competitions

Selected Results of an Evaluation Study of the World Robot Olympiad in Germany in 2019

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Abstract. Educational robotics competitions such as the World Robot Olympiad (WRO) are popular out-of-school learning settings for Science, Technology, Engineering and Mathematics (STEM) education, especially Computer Science (CS) education. The aim of this competition (alike many other initiatives) is to prepare students for a life in the digital age by fostering their 21st century skills and motivate them to choose a profession the field of STEM. Regardless, many initiatives fail to monitor their impact. In 2019, the organizers of the WRO conducted an impact evaluation study in collaboration with the CS education group of the University of Würzburg to address this issue. In this article we present the results of this evaluation study regarding the students' learning of 21st century skills.

Keywords: Educational robotics · Competitions · 21st century skills · Evaluation · Impact

1 The World Robot Olympiad

The WRO[1] is an international educational robotics competition, which wants to get students (aged six – 19 years) enthusiastic about STEM, especially CS. Within the competition, students work in teams of two or three together with a team coach on annually changing educational robotics tasks, which are based on the annual theme (e.g. in 2019 the theme was *SMART Cities*). Depending on the category which teams participate in, they build and program a robot using the LEGO MINDSTORMS system or other microcontroller systems such as RaspberryPi or Arduino. Teams can particpate in the following categories:

[1] Online here: https://www.worldrobotolympiad.de/ or https://wro-association.org/home/ (last accessed 10th March 2020)

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- Regular category: Teams build and program a LEGO MINDSTORMS robot to solve tasks on a 3 m^2 parcour (see Fig. 1).
- Football category: Teams compete against each other in a two vs. two robot football match.
- Open category: Teams build and program a robot model using microcontrollers and other materials in a research project tackling real-life problems [11].

Within the three categories exist different age groups. For the Regular and Open category there are three age groups: *Elementary* (six – 12 years), *Junior* (13–15 years) and *Senior* (16–19 years). There are different tasks for the age groups in the Regular category. In the Football category exists one age group (six – 19 years). Additionally, the *Starter* age group was added to the Regular category (six – 12 years) and to the Football category (six – 15 years) in 2018. The reason for the introduction of this age group was to make the access to the competition easier for younger students by simplifying the tasks. In the Regular category students are given a simplified version of the tasks of the Elementary age group and the in the Football category teams only compete in a football match with one robot instead of two per team [11].

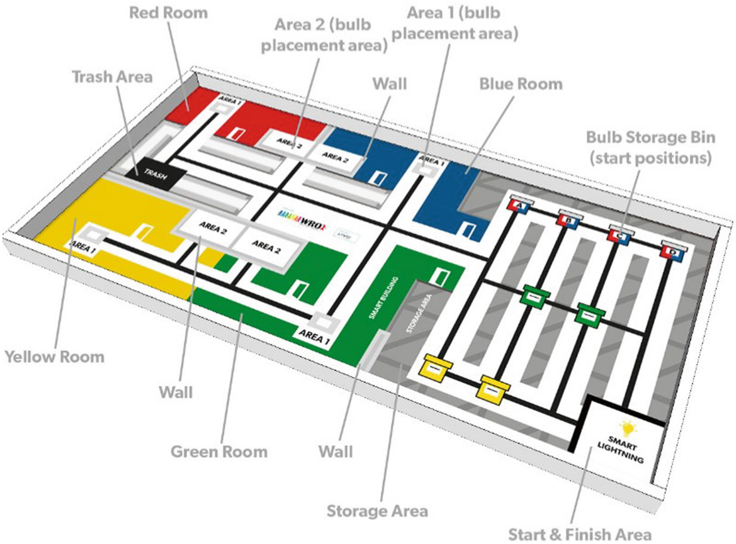


Fig. 1. Example task *Smart lightning* of the Junior age group of the Regular category of the 2019 season of the WRO. The mission of this task was to replace old light bulbs with smart light bulbs. The teams' robots would take new smart light bulbs from the storage area and bring them to the different rooms (red, blue, yellow, and green areas) in the building. Additionally, the robot would find old light bulbs and bring them to the trash area. Thus, the robot modernizes the light system in the building to save energy. [10]

The tasks for each year are released in the middle of January and teams spend their time developing a working robot prototype to compete with in the regional competition until the end of April. Teams, who come out on top in the regional competition, get promoted to the national or possibly even to the world final, whose location changes every year (e.g. the world final in 2019 took place in Győr, Hungary) [11].

Throughout the last years, the number of participants in the WRO has steadily increased from around 5000 teams in 2004 to more than 26,000 teams in 2018. In Germany, the number increased from 32 teams in 2012 to 683 in 2019 [10, 11].

As educational program, the major goal of the WRO is to "[h]elp young people acquire 21st century skills like creative thinking, cooperation and communication" and "[w]iden the view of young people and encourage them to be our future scientists, engineers, makers and inventors" [10]. They are trying to do this by "[bringing] together young people all over the world to develop their creativity, design and problem solving skills through challenging and educational robot competitions and activities" [10].

2 21st Century Skills

Preparing students for their working life is one essential goal of education in general. Like many other programs, the WRO tries to tackle the lack of specialists in technological industries. In the years to come, there will be an increasing number of jobs in the field of CS, especially with fields such as data science, robotics and artificial intelligence gaining more importance across many industries [4]. Regardless, there is also a great demand for non-professional computer scientists to incorporate CS concepts and practices into their skill set due to a ubiquitous penetration of technology in arguably all industries [4].

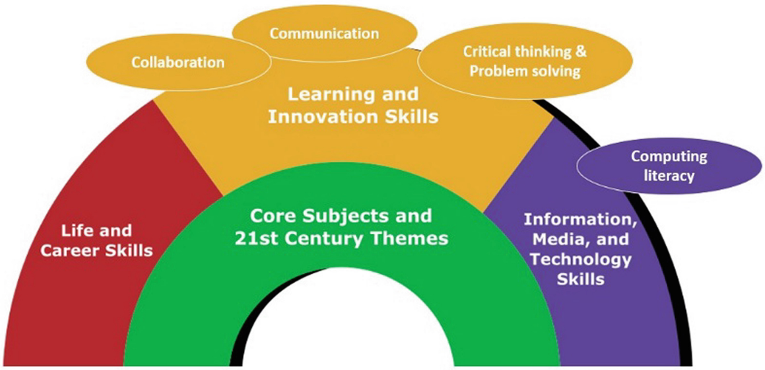


Fig. 2. Framework of 21st century learning skills by [8] with examples of sub-skills, which were in the focus of this study.

This shift in the use of technology at the workplace requires a new set of skills which is mainly referred to as *21st century skills*. Trilling and Fadel [8] provide a framework of these skills dividing them into the domains *core subjects and 21st century themes*, *life and career skills*, *learning and innovation skills* and *information, media, and technology skills (or digital literacy skills)* (see Fig. 2).

While Trilling and Fadel give one popular description of 21st century skills, other authors or organizations developed other frameworks, which might have added or removed specific skills, restructured skill domains, etc. A comparative analysis of frameworks for 21st century skills by [9] concludes that in many or most frameworks the following skills are included: collaboration, communication, digital literacy, citizenship, creativity, critical thinking, problem solving and productivity. [5] argue that these skills are called 21st century skills since they are more related to the current economic and social developments of our knowledge-based society (with a vast inclusion of information and communication technologies) compared to those of the past century, which is characterized as an industrial age.

3 Evaluation Study of the WRO in Germany

3.1 Motivation

In the recent years, criticism emerged in the educational robotics community that there is a lack of systematic quantitative research on the impacts of educational robotics on e.g. students' learning [1, 7]. In contrast, most of the research studies investigating the impact of educational robotics in the literature are descriptive and focus on individual, small scale initiatives [2]. Instead of just reporting a plethora of teachers' experience reports with educational robotics, the educational robotics community is required to conduct more impact evaluation studies using more sophisticated methodological approaches.

Additionally, the organization and implementation of the WRO is a very time-consuming and costly endeavor. As the annual reports of the association TECHNIK BEGEISTERT e.V., the organizers of the WRO in Germany, show, the association highly depends on sponsorship money and donations [11]. However, many sponsors demand evidence of the program's success [7].

3.2 Research Design, Questions, and Methodology

In their reference guide for designing evaluations of K-12 educational robotics programs, [7] describe two possible forms of evaluation:

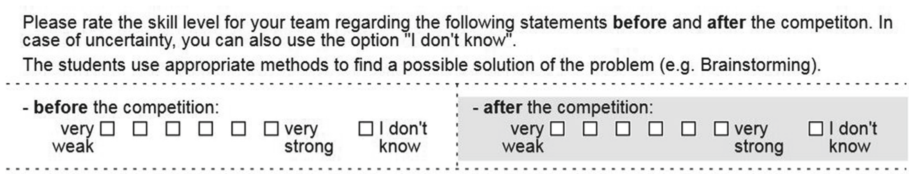
- Formative evaluation: *Formative* evaluations are conducted when the program is being developed and follows a spiral process. Before each new iteration of the program, robot platforms, curricula, teaching materials, etc. are being reviewed if they need to be modified. This kind of evaluation is suitable for program improvement of young programs.
- Summative evaluation: *Summative* evaluations are conducted to measure the impact (or effectiveness) of the program on e.g. students' learning, attitudes, interests, etc. This kind of evaluation follows the steps of 1) identifying a target audience, 2) determining the impacts you wish to have on this audience, 3) identifying the kind of evidence you need to prove this impact and 4a) selecting appropriate evaluation and 4b) measurement methods.

In accordance with the motivation of this study mentioned in Sect. 3.1, the aim of this study is to provide a scientific proof of the program's effectiveness and deliver a large-scale systematic quantitative impact study. Thus, it falls into the category of summative evaluation. In detail, it was the aim to investigate a) the learning of students (target group) regarding their 21st century skills and b) the influence of the WRO on their career choices (impact categories). However, this paper will only present results on a) with the following research questions[2]:

- RQ1: Can students improve their 21st century skills in terms of …?
  - Collaboration and teamwork (learning and innovation skills)
  - Communication (learning and innovation skills)
  - Problem solving (learning and innovations skills)
  - Building and programming a robot (digital literacy skills)
- RQ2: Can we identify differences regarding the skill development in different sub-groups as, e.g. categories (Regular, Open and Football) or age groups (Starter, Elementary, Junior, Senior)?

To get the anticipated results, we used a pre-post-test-research design (using *then-test* data, i.e. pre- and post-test data with retro perspective pre-test) (evaluation method). Team coaches were asked to fill out a questionnaire (measurement method) and assess their teams' learning before *and* after the competition on a five-point Likert scale. They were given the questionnaire at their regional competitions.

The 21st century skills were measured using self-constructed scales (with three to six items per scale) based on the definitions from literature. An example item (including answering options) of the scale for problem solving is displayed in Fig. 3:


Please rate the skill level for your team regarding the following statements **before** and **after** the competiton. In case of uncertainty, you can also use the option "I don't know".

The students use appropriate methods to find a possible solution of the problem (e.g. Brainstorming).

- **before** the competition:	- **after** the competition:
very weak ☐ ☐ ☐ ☐ ☐ ☐ very strong ☐ I don't know	very weak ☐ ☐ ☐ ☐ ☐ ☐ very strong ☐ I don't know

Fig. 3. Example item of the scale for problem solving of your questionnaire to assess students' learning of 21st century skills.

The scales of the questionnaire for measuring skill development in the areas of building and programming a robot, collaboration and teamwork, communication and problem solving were tested for (construct) validity (using exploratory factor analysis) and reliability (using internal consistency using Cronbach's alpha) and demonstrated to be useful for our purposes [3].

2 Selected results of the study on the influence of the WRO on their career choices can be found in [6].

In data analysis we used standard tests from inferential statistics to compare mean values (non-parametric Wilcoxon test) from pre- and post-test and tests to differentiate between different subgroups (non-parametric Kruskal-Wallis-test with post-hoc-tests) [3].

Results[3]

From the 683 teams, which participated in the WRO in 2019, team coaches from 413 teams (equals a total of 1053 students, who participated in this study) filled out our questionnaire (response rate = 60%).

Out of the 413 teams, 350 teams (85%) participated in the Regular category, 46 (11%) in the Open category and 17 (4%) in the Football category. In the Regular and Open category, 44 teams (11%) participated in the Starter age group (only Regular category), 99 (25%) in the Elementary age group, 163 (41%) in the Junior age group and 89 (25%) in the Senior age group. In the Football category, five teams (29%) participated in the Starter category and twelve (71%) in the Traditional category.

Most of the teams (313 out of 411, 76%) are regular school teams (in comparison to private teams or teams, who collaborate with other institutions such as universities, etc.) and most of the students of the teams visit a German gymnasium (grammar school). 874 students (83%) of the participating students in this study are boys.

RQ1: Can students improve their 21st century skills?

Our overall results show a significant increase in all the different areas of 21st century skills. Table 1 presents the pre- and post-values for the skill level for the different areas of collaboration and teamwork, communication, problem solving and building and programming a robot.

Table 1. Overall results of the skill development for the areas collaboration and teamwork, communication, problem solving and building and programming a robot.

Skill	Median pre	Median post	z-value	p-value	N	Effect size (Cohen's d)
Collaboration and teamwork	3,33	4	−13,504	<.001	377	1,936
Communication	2,33	3	−11,846	<.001	296	1,899
Problem solving	2,5	3,25	−15,065	<.001	361	2,602
Building a robot	2,85	4	−15,151	<.001	376	2,504
Programming a robot	2,67	4	−13,611	<.001	327	2,287

[3] As this is just a short excerpt from the results of this evaluation study, interested readers can continue reading about the results in the corresponding technical report and on the website here: http://tb-ev.de/wirkung (in German) and in the executive summary (in English) here: https://www.worldrobotolympiad.de/website/docs/tb/Evaluation-Study-WRO-Germany.pdf (last accessed 3rd August 2020).

Overall, we observe strong effects (in terms of effect size) for all the areas. These results are also visible in Fig. 4.

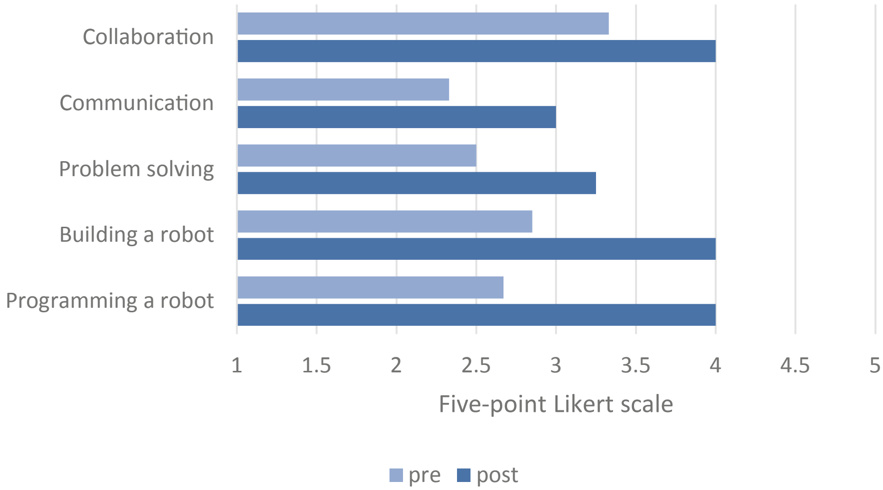


Fig. 4. Overall results of the skill development for the collaboration and teamwork, communication, problem solving and building and programming a robot.

RQ2: Can we identify differences regarding the skill development in different subgroups as, e.g. categories (Regular, Open and Football) or age groups (Starter, Elementary, Junior, Senior)?

Additionally, we investigated differences (using the normalized values[4]) between different subgroups of the participating teams.

Regarding the category of the WRO (Regular, Open and Football) results show that the Regular category is significantly (with small to medium effect sizes) more useful for the learning of building and programming a robot (digital literacy skills) than the other categories (see Fig. 5). Additionally, the Open category improves the communication skills significantly (with a small effect size) more than the other categories. Possible explanations for these differences could be the different emphases of the categories. Whereas the Regular category focuses especially on building and programming a robot, the Open category also requires students to present their robot model they developed in their research project to the judges on the competition day.

[4] The skill development (in %) was calculated as normalized gain (Hake's g):

$$Hake'sg = \frac{postscore - prescore}{\max score - prescore}$$

This formula views the achieved gain in relation to the highest possible gain (relative gain).The comparison of subgroups was conducted using this relative gain.

The collaboration and teamwork and problem solving skills can be developed equally in all three categories.

Regarding the different age groups of the WRO, we observe no significant differences in skill development between the age groups (see Fig. 6). Nonetheless, there are significant differences (with medium effect sizes) concerning the pre-values (i.e. the prior skill level of the teams as assessed by their team coaches) for all areas (see Fig. 7). Even though it is hardly surprising that older teams show a higher prior skill level, it is surprising not to observe any differences in the skill development of different age groups, as one might expect that younger teams learn more than older ones. Instead, just the prior skill level differs, especially between the age groups Elementary and Junior (see Fig. 7). Yet, it is a positive result to conclude that students can improve their skills independent of their prior skill level.

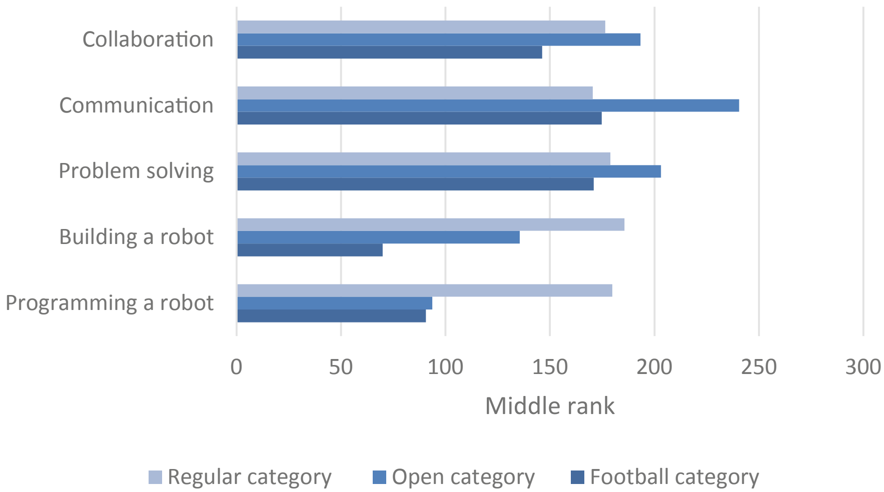


Fig. 5. Results of the skill development for collaboration and teamwork, communication, problem solving and building and programming a robot in comparison of the three categories (Regular, Open and Football) of the WRO. (The middle rank, which is used to describe to scores of the teams in Fig. 5, 6 and 7, is a basic measure for many non-parametric statistical tests (e.g. Wilcoxon or Kruskal-Wallis-test). In general, ranking is a process of data transformation of e.g. ordinal values, in which they are replaced by their rank when the data is sorted. To calculate the middle rank, the sum of ranks is divided by the number of elements in the subgroup.)

Moreover, similar results have been found when comparing teams based on e.g. the gender of the teams (boys, girls, and mixed teams) or their experience with the WRO (in number of prior participations). Again, there are no significant differences in skill development, but teams, who consist of girls at any rate, show significantly (with small to medium effect sizes) lower prior skill levels in the areas of building and programming a robot and problem solving than teams, who only consist of boys. No differences have been found for collaboration and teamwork and communication in their prior skill levels. Regarding the experience with the WRO, we note significantly (with small to medium effect sizes) lower prior skill levels for less experienced teams than more experienced ones.

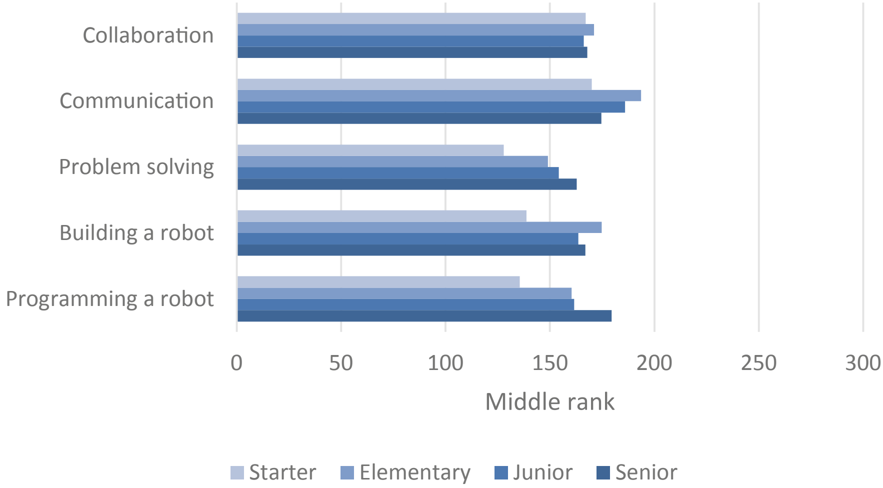


Fig. 6. Results of the skill development for the areas collaboration and teamwork, communication, problem solving and building and programming a robot in comparison of the age groups of the Regular and Open category of the WRO. Due to the different age limits of the age groups in the Football Category, they have been excluded from this analysis.

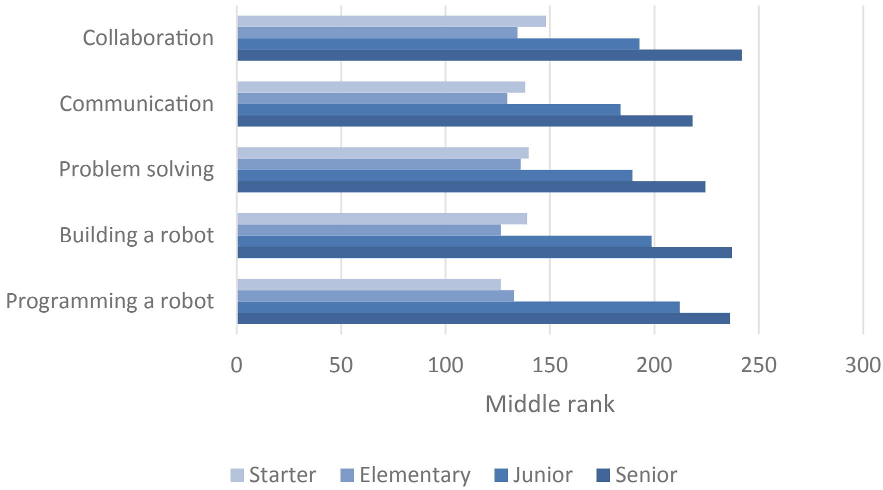


Fig. 7. Results of the prior skill level for the areas collaboration and teamwork, communication, problem solving and building and programming a robot ein comparison of the age groups of the Regular and Open category of the WRO. Due to the different age limits of the age groups in the Football Category, they have been excluded from this analysis.

4 Conclusion and Outlook

This paper presented selected results of the evaluation study of the WRO in 2019. It shows that this competition is successful in providing a learning setting for students to improve their 21st century skills (i.e. collaboration and teamwork skills, collaboration skills, problem solving and building and programming a robot skills) using educational robotics. We found differences of the three categories of the WRO and their potential to foster specific skills. Yet, no differences were found regarding students' learning in different age groups, teams with a different number of boys and girls, and their experience with this competition, but only in their prior knowledge. Thus, it is a positive result to conclude that every student participating in this competition can profit from it and the competition is equally effective.

Regardless, the WRO is not the only initiative promoting students' learning through educational robotics competitions. In order to be able to judge the impact of our study in comparison to similar programs, future work will consist of comparing our study with evaluation studies from other educational robotics competitions. This comparison could focus on a) methodology, e.g. formative vs. summative evaluation, target audience, impact category or evaluation and measurement methods and, if applicable, b) results. Examples for other popular competitions are the *FIRST LEGO League*[5] *(FLL)* or the *RoboCup*[6]. In Germany, results on evaluation studies are available on the competitions' organizers webpage[7]. On an international level, the organization FIRST (*F*or *I*nspiration and *R*ecognition of *S*cience and *T*echnology) accompanies its programs with different evaluation studies to measure its impact[8]. Thus, other organizations provide resources for a meta-review of evaluation studies of these programs, which would give a broad view of the impact evaluation of the programs on students' learning among other impact categories and could help to foster the understanding of the role of educational robotics competitions as out-of-school learning settings for STEM education.

References

1. Alimisis, D.: Educational robotics: open questions and new challenges. Themes Sci. Technol. Educ. **6**(1), 63–71 (2013). https://files.eric.ed.gov/fulltext/EJ1130924.pdf
2. Benitti, F.: Exploring the educational potential of robotics in schools: a systemtatic review. Comput. Educ. **58**(3), 978–988 (2012). https://doi.org/10.1016/j.compedu.2011.10.006
3. Cohen, L., Manion, L., Morrision, K.: Research Methods in Education. Routledge, London (2017)
4. Fincher, S., Robins, A.: The Cambridge Handbook of Computer Science Education Research. Cambridge University Press, Cambridge (2019)

[5] Online here: https://www.first-lego-league.org/de/ or http://www.firstlegoleague.org/ (last accessed 10th March 2020).

[6] Online here: https://www.hands-on-technology.org/de/projekte/robocup-junior.html.

[7] The evaluation results of the FLL and RoboCup Junior in Germany can be found here: https://www.hands-on-technology.org/de/vision/wirkung.html (last accessed 10th March 2020)

[8] The results of multiple evaluation studies on the programs can be found in FIRST's resource library here: https://www.firstinspires.org/resource-library/first-impact (last accessed 10th March 2020).

5. van Laar, E., et al.: The relation between 21st century skills and digital skills: a systematic literature review. Comput. Hum. Behav. **72**, 577–588 (2017). https://doi.org/10.1016/j.chb.2017.03.010
6. Pöhner, N., Hennecke, M.: Educating future scientists, engineers, makers and inventors - The influence of students' participation in educational robotics competitions on their career choices in Science, Technology, Engineering and Mathematics (STEM). In: Ihantola, P., Falkner, N. (eds.) Proceedings of the 19th Koli Calling International Conference on Computing Education Research. ACM, New York (2019). https://doi.org/10.1145/3364510.3366151
7. Stubbs, K., Casper, J., Yanco, H.: Designing evaluations for K-12 robotics education programs. In: Barker, B., et al.: Robotics in K-12 Education: A New Technology for Learning, pp. 31–53. IGI Global, Hershey (2012)
8. Trilling, B., Fadel, C.: 21st Century Skills: Learning for Life in our Times. Jossey-Bass, San Francisco (2009)
9. Voogt, J., Roblin, N.: A comparative analysis of international frameworks for 21st century competence. J. Curriculum Stud. **44**(3), 299–321 (2012). https://doi.org/10.1080/00220272.2012.668938
10. World Robot Olympiad (International). https://wro-association.org/home. Accessed 22 Nov 2019
11. World Robot Olympiad (German). https://www.worldrobotolympiad.de/. Accessed 22 Nov 2019

The European Robotics Hackathon (EnRicH)

Fostering Robotic Solutions for the Radiological and Nuclear Application Domain

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Abstract. Natural disasters, industrial catastrophes and terror acts pose potential risks to everyone's live and prosperity. Properly assessing such situations, especially in combination with radiological and nuclear (RN) threats, is a significant challenge. Several incidents in the past decades have underlined the urgent need for robotic platforms in scenarios involving radiation. However, the technical challenges when dealing with RN scenarios are immense. Unfortunately, engineers and developers often have no realistic testing possibilities, especially with regard to radiation sources, and cannot properly develop their robots for the demands of a real RN disaster site. Additionally, there is also a limited interest of the scientific community in getting their systems to work in the presence of radiation. One possible means to draw the attention of the robotics community towards such special tasks is through trials and competitions. Additionally, competitions also provide real world scenarios for testing which otherwise are often missing, allow a comparison and evaluation of the performance of different robot systems, and foster the use of important technical standards. This work describes advantages of this competition-based approach in general, and describes in detail one event with RN tasks and scenarios, which addresses all the mentioned aspects: the newly established European Robotics Hackathon (EnRicH).

Keywords: Robotics competitions · Search and rescue (SAR) · Radiological and nuclear (RN) · Disaster response · Standardization

1 Introduction

All over the world natural disasters and crisis situations, such as earthquakes, tsunamis, hurricanes or nuclear catastrophes, pose an unpredictable yet significant risk to the lives and prosperity of the population. The ability of first response search and rescue teams to safely and efficiently provide aid in the harsh environments of disasters means a substantial challenge. Several disasters in the last years (Fukushima nuclear power plant, Katrina hurricane, Tohoku tsunami and earthquake) have underlined the need for robotic platforms able to assist Search and Rescue (SAR) operations.

There is immense potential for the use of unmanned systems in such scenarios, especially when involving radiological and nuclear (RN) threats. One of the main advantages of robots in these scenarios is the protection of the personnel involved. Unmanned

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systems can operate in environments that under normal conditions are inaccessible to humans. Since the operating time of a robot is generally only limited by the battery charge condition, in principle it also facilitates 24/7 operations.

Since the early 2000's robotic solutions have been utilised in many response efforts in disaster incidents, demonstrating their potential to reduce the risk of loss of life, accelerate response times and gather essential data [1]. Robots can be deployed for many dangerous tasks, like search and rescue, radiation measurement, disrupted area mapping, structural damage assessment, and manipulation tasks. In principle, they can operate in areas with high radiation or danger of explosions, collapsing structures, or extreme heat. Some systems have been also designed for use in scenarios involving radiation, e.g. [2, 3]. In contrast to general purpose approaches, robots specially developed for the RN domain often concentrate solely on finding, mapping and classifying radiation sources [4, 5]. However, most of these systems are research projects or technical demonstrators. Only on rare occasions robots have been used in real RN disaster environments, and this usually caused huge adaption and hardening efforts, while at the same time producing only limited results [6, 7]. In theory robot technologies have proven to be useful to assess a situation, but they are often too immature or fragile for the use in a real disaster, clean-up or deconstruction scenario.

In summary, although robotics research has produced impressive results in general, there is still significant room for improvement with respect to the use of robotics in RN-related applications. Apart from technical problems, this is often due to a lack of testing possibilities, difficulties in evaluating and comparing robot systems in the field, and sometimes also a lack of interest in such an 'exotic' and potentially dangerous application. Robotic competitions were suggested as a possible solution to these problems. This paper aims at justifying this approach. Section 2 provides necessary background information and looks in detail at two important topics where competitions have advantages, i.e. benchmarking of robot systems and standardization aspects. Additionally, the special field of RN-related competitions is pictured. Section 3 describes the currently established European Robotics Hackathon (EnRicH), which pays regard to these general considerations and which explicitly tackles RN scenarios. Section 4 concludes this paper with some summarizing remarks and a short outlook on future developments.

2 Background

Apart from the pure benchmarking idea, to find a winner for some special application, competitions provide a variety of further advantages. In [8], for example, the opportunity to exchange ideas and possible code re-use are mentioned. In [9], the authors especially consider standardization aspects, which can be promoted through trials and competitions. At competitions, generally, there is a great pressure of time: a schedule must be adhered to, and the robots must be able to perform their tasks exactly at the given time slot. While development may run for many months prior to the competition, development time during the competition itself is limited. Since the real world is involved, there will be many situations that cannot be fully anticipated in advance and that must be adapted to on-site. Changes in the trial environment might range from the different colour of paint for an object of interest, over changing lighting conditions, up to major terrain modifications. Overall, the competition approach greatly helps balancing the theoretical performance of a system with its practical usability in deployment to the real world.

The following subsections address in detail the idea of benchmarking through competitions, explain how standardization efforts can be supported, and describe first attempts to bring competitions to the important yet difficult field of radiological and nuclear tasks and applications.

2.1 Benchmarking in Robotics Competitions

Comparing different approaches and methods in the field of applied robotics is a difficult task [10]. In many cases, results are reported only for a specific robotic system. Tasks are carried out in a static and often specially defined environment, making it hard to compare the outcome with results from other research groups, other approaches and other robots. The common means of 'proof by video' or 'proof by (one) example' are insufficient for obvious reasons, even if widely used in the robotic community.

As one possible solution, robot competitions have been proposed for benchmarking robot systems [11]. Of course, competitions do not automatically solve all problems in comparing scientific approaches. The difficulties of controlled experimentation and repeatability remain. In outdoor trials, for instance, weather and lighting conditions can dramatically change even for consecutive runs. Starting positions differ and obstacles are not always accurately placed, as described in [12]. The authors also notice that new kinds of problems arise. Participants often tend to exploit rules or create special-purpose solutions related only to a specific trial instead of developing adaptive and flexible approaches. However, compared to standardized benchmarks, competitions are more desirable in many ways. They provide a context in which all participants can evaluate their techniques under similar conditions and make solid comparisons. If the trials are of periodic nature they allow the competition to evolve with the state of the art. This also allows foiling techniques tailored to specifics of a particular benchmark.

In the field of outdoor robotics, several well-known competitions have been established over the last two decades. The first DARPA Challenge, for example, took place already in 2004. The task was to follow a 241 km long path, defined by several thousand UTM waypoints. Due to the difficult terrain and some teething problems, no participant was able to solve this task. In 2005, the task remained basically unchanged, and four participants successfully completed the race. In 2007, the DARPA Grand Challenge modified its goals from driving autonomously on difficult terrain to interacting with other vehicles in an urban scenario. In the recent years, the topics of the DARPA challenges moved away from autonomous driving towards other robotic tasks. Currently, for example, the DARPA Subterranean Challenge [13] addresses the important yet difficult field of underground operation. The European Land Robot Trial (ELROB) [14] is somehow comparable to the DARPA Grand Challenge in its attempt to gauge the functionality of outdoor robots. However, the ELROB presents a wider choice of user defined tasks instead of only one single over-defined scenario. Different users often express completely different requirements and specifications for robot systems depending on the possible fields of application. Instead of combining demands into one large scenario, like in the DARPA Grand Challenge, it might be more meaningful to have different tasks, which correspond to the various application scenarios.

Apart from these large unmanned ground vehicle (UGV) competitions, there exists a growing number of contests for all kinds of indoor and outdoor robots. One event, for instance, with hundreds of competitors and dozens of different categories is the annual RoboGames competition [15]. In the recent years a variety of new contests has been established, among which several are explicitly regarding outdoor and/or disaster response robotics. Examples include the Mohamed Bin Zayed International Robotics Challenge (MBZIRC) with its urban firefighting challenge [16], the World Robot Challenge with the Disaster Robotics Category or the European Robotics League (ERL) Emergency [17]. A relatively new approach, developed from the benchmarking idea, is to use competitions as decision support for research contracts or in procurement processes. Originally used by DARPA, this approach was also tried by the British and Australian Ministries of Defence, and also – with limited success – by the International Atomic Energy Agency (IAEA) in their Robotics Challenge in 2017 [18].

2.2 Standardization in Robotics Competitions

Standardization can be seen not only as the process of developing and implementing technical standards but simply as a necessity towards the goal of smarter robots. The acceptance of unmanned systems will increase with the adoption of standards that enable interoperability with existing systems and structures. The step of standardization within competitions will generate a state in which all parties can realize mutual gains, by making guided mutually consistent decisions. The sum of these effects will lead not only to more comparable results for the competition itself but also to a significant speed-up in research. Introducing open standards will also boost the co-operation between industry and academia substantially as well as interaction between teams.

Standards may be introduced in nearly all fields of robotics-related hardware and software, e.g. technical interfaces; cables and connectors; protocols, encodings and data formats; or even complex systems like payload specifications, software architectures or a complete robot middleware.

Two competitions that have been active in the field of standardization are the already mentioned European Land Robot Trial (ELROB) and the euRathlon [19]. The euRathlon was funded by the EU and lasted from 2013 until 2015. Together with the European Robotics League, a Horizon 2020 project, euRathlon finally led to the still ongoing European Robotics League (ERL) Emergency contest. Some of the ELROB and euRathlon standardization efforts will be described in the following sub-sections.

Protocol and Software Standards. In all ELROB events since 2010, for example, necessary electronic data transfer had to be done via the WebDAV protocol. Participating teams had access to the mission data through a dedicated ELROB server using WebDAV (HTTP V1.1 based). When a mission was finished, the results had to be put on the same server again. The organizers specified the required data formats beforehand, and all of them were open and licence-free to ensure the open sciences spirit. Result data not in these required standard formats was accepted only for archiving purposes but not used for a participant's evaluation.

Additionally, for all ELROB and euRathlon events the use of the popular middleware Robot Operating System (ROS) [20] is strongly encouraged. ROS is well developed and accepted in land, air and (under-)water robotics and provides advantages, like open and free usage, good logging and debugging abilities, good support for hardware and software, a large user and support group, etc. To foster the use of ROS, available datasets from former events are logged in ROS format, and software elements and examples provided by the organizers are also ROS-based. In euRathlon 2013 and ELROB 2016, for example, teams could borrow radiation sensors for the RN scenario, and received the necessary ROS driver for an easy software integration for free. As a result, on several occasions in both, ELROB and euRathlon, teams successfully exchanged software pieces as well as replacements for broken hardware.

Platforms and Payload-Carrier. A further standardization effort is the use of a common robot platform and exchangeable payload-carriers for the competition. Such a platform and payload-carrier would obviously save costs for many teams and ease the exchange of software and knowledge. Teams that are not interested in hardware aspects could simply use the platform provided by the organizer and mount their devices on the payload-carrier. In the case of a trial, they simply plug the payload-carrier onto the platform and are ready to go. Since everyone is using the same hardware basis, the re-usability of software is easy to achieve. Teams concentrating, for example, on vision issues, can simply use the navigation software created by others.

As mentioned above, one of the first attempts took place during euRathlon 2013. Special sensors including the ROS interface were offered on a loan basis, thus relieving the teams from buying expensive special purpose hardware and writing driver code on their own. The two sensors, an AUTOMESS 6150AD radiation sensor and a DRÄGER X-AM 7000 gas detector, could be used in several scenarios to identify and map threats for the emergency forces. The hardware interface used was a simple RS232 connection. However, due to the lack of a standardized payload-carrier, yet the sensors simply had to be taped to the robots.

For euRathlon 2014 and 2015, the teams could borrow a standardized AUV robotics kit. The selected vehicles were the SPARUS II AUV provided by the University of Girona and two Teledyne Doppler Velocity Logs (DVL). These systems were reliable, easily customizable, and offered an integration of additional sensors and actuators. The teams receiving the platforms were selected by the euRathlon project consortium after evaluation of their team applications. Priority was given to the quality and novelty of the proposed algorithms. As a result, especially during the "Grand Challenge" in euRathlon 2015 many sophisticated software solutions could be seen even from teams relatively new to the maritime robotics domain [19].

Common Shared Data Sets (CSDS). Standardized datasets are sometimes used for comparison of methods and even whole systems, and, in fact, they are a good basis to accelerate the progress of research. This is often used in combination with simulation. Many fields in science and engineering have employed datasets to evaluate similar approaches and techniques and to allow their comparison. A classical way to do so is to provide standardized Common Shared Data Sets (CSDS). One example is the project RAWSEEDS [21].

Regarding robotics competitions, teams that are new or teams with limited access to proper hardware and training areas face the problem that they cannot test their system against typical settings appearing at the competition. In addition, the comparison of methods or configurations requires an exactly reproducible data stream from all (sensor) inputs.

To give the participants an impression of the different scenarios, the ELROB and euRathlon organizers decided to provide several example datasets beforehand. The CSDS are collected in realistic environments and under different conditions. Every year, the datasets are expanded using new data collected during the competition, either by the organizers themselves or by the participating teams. The datasets are recorded as so-called ROS bags and are easy to use with the ROS software framework. The datasets include all relevant sensor and navigation information, like for example laser sensors looking at different angles, a Microsoft Kinect providing video and RGBD data, and additional inertial measurement (IMU) data, as well as timestamps for all data.

Although it is not compulsory for the participants to provide their data for the CSDS pool, the organizers strongly urge them to share their data with the community. For example, the euRathlon organizers decided that the CSDS pool was only made available to those participants who agreed to provide datasets from their own runs as well.

2.3 RN-Related Robotics Competitions

Lessons learned from the Chernobyl and Fukushima disasters and also from decommissioning, for example, of old nuclear power plants show that robots have important advantages in the RN domain. They can operate in extreme environments with high radiation or danger of explosions, extreme heat or collapsing structures. They can manipulate the environment and take samples. Robots can also be used for long-time surveillance of contaminated areas and for monitoring the movements of a threat, using real-time data from mobile sensors. Possible scenarios can be roughly divided into two groups. First, there are prevention scenarios where unmanned systems can be used to prevent incidents involving radioactive material. Second, there are response scenarios where unmanned systems gather information after RN incidents have occurred. In both cases, three main tasks for robotic systems can be identified: spatial mapping of RN sensor data, active search for RN sources, and taking samples – often by using a mobile manipulator (e.g. sweep or material sampling).

First, the use of robotic systems was considered for the more general field of Search & Rescue (SAR) and disaster response [22]. Consequently, newer robotic competitions also address SAR and disaster response scenarios, e.g. the RoboCup Rescue or the already mentioned project euRathlon. Whereas the RoboCup Rescue events take place in a standardized but rather artificial indoor setting [23], the euRathlon was inspired by the Fukushima disaster and, thus, had very realistic – and challenging – tasks and scenarios [19]. Injured workers had to be found and special valves had to be identified and closed – even underwater. But still the RN aspects of the Fukushima catastrophe were left out, on the one hand due to practical problems, but on the other hand also due to very little knowledge about radiological and nuclear topics in the robotics community.

Only in the very recent years, competitions have started to address explicitly RN-typical tasks and to involve real radiation scenarios. Examples are the latest European Land Robot Trials ELROB 2016 and 2018, the IAEA Robotics Challenge or the European Robotics Hackathon (EnRicH) [24]. However, since the upcoming ELROB 2020 has dropped the RN scenario [14] and the IAEA Robotics Challenge – although meant for procurement in the field of radiological inspections – left out real radiation completely [25], only the EnRicH continues to work with radiation and its specific problems. Consequently, the remainder of this work will describe this event in more detail.

Fig. 1. The NPP in Zwentendorf, Austria, where the EnRicH took place. The picture shows the participants of EnRicH 2019. *(Image courtesy of Clemens Schwarz/ARWT)*

3 EnRicH – The European Robotics Hackathon

In 2017 the European Reference Network for Critical Infrastructure Protection (ERN-CIP) task group on Radiological and Nuclear Threats planned to conduct a workshop on the use of unmanned systems in the RN domain. Additionally, the task group wanted to run a parallel robotic trial similar to the ELROB 2016 radiological and nuclear reconnoitring scenario [14]. In the end only the robotics trial was realized. The so-called European Robotics Hackathon (EnRicH) started in 2017 as a biennial event, taking place in the inoperative nuclear power plant (NPP) in Zwentendorf, Austria (see Fig. 1). The boiling water reactor of the Zwentendorf NPP is one of the very few in the world which was completely built but never put into operation. Instead, the plant was transferred into a training centre in which repairing and dismantling measures but also critical incidents can be trained under realistic conditions. Although – as it is common for software hackathons – EnRicH contained some contest elements, the main goal was to foster the development of robotic solutions for the RN domain, bringing together roboticists and RN specialists. The results of the first EnRicH in 2017 were carefully analyzed [24], and the organizers – to which the authors belong – decided to modify the scenario, add another task, and further increase their standardization efforts.

3.1 The EnRicH 2019 Event

Naturally, a nuclear power plant contains areas which cannot be safely entered by personnel, not only due to inherent radiation in the reactor building, but also because of

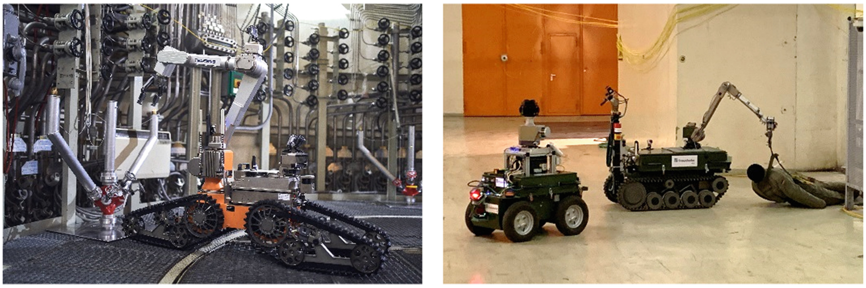

Fig. 2. Two of the possible tasks of EnRicH 2019: In several artificial pipe systems a radiation source had to be found and the corresponding valve closed (*left*). Artificial human bodies, “missing workers”, had to be found and brought to a safe place (*right*).

unpredictable radioactive contamination after an accident. EnRicH facilitates the scenario of the second type. Originally, it was a simulated accident with a radioactive fuel rod, and the robotic systems had to explore the scene. However, in retrospect the organizers found it too dangerous to let the robots interact with the radioactive material directly. Thus, in 2019 the radiation sources were hidden in an artificial pipe system, like in the left part of Fig. 2.

Tasks. During the hackathon the participating teams could choose among several tasks, all close to the three typical RN tasks listed in Sect. 2.3: map the scene, locate the radiation sources inside the pipes, and use a mobile manipulator to close the corresponding valves. The mapping task had two sub-tasks: first, build a 3D map of the area and, second, create a radiation map of the scene in 2D or 3D. Additionally, the systems could search for simulated human bodies like in the right part of Fig. 2, and transport them out of the dangerous area. The teams could work on any combination of these tasks. Due to the active radiation sources inside the scenario, no one was allowed to accompany the robot. Instead, the building was equipped with cameras, enabling the necessary supervision from outside.

Standardization Efforts. As described, one of the major goals of the organizers is to foster standardization in the field of robotics. Thus, also for the EnRicH they implemented several of the approaches described in Sect. 2.2. First and most important, they encouraged the use of the ROS framework for the robot systems involved. Of course, in principle the participants can use any software to steer their robots. Nevertheless, the example sensor datasets from the environment, for instance, are provided only in the ROS bag format. Additionally, participants can borrow the necessary RN detector, a SSM-1 by Seibersdorf Research (see Fig. 3), as well as the appropriate ROS driver and interface software. The organizers defined and published a ROS message format for the detector, enabling the teams to seamlessly develop and integrate it into their system even before they received the sensor hardware – assumed that they use the ROS framework. As another protocol standardization, participants are encouraged to use the list-mode data format IEC 63047, which was recently defined by the European Commission’s Joint Research Centre (JRC) in Geel, Belgium, and which is especially meant for higher-level transfer of radiation measurements [26].

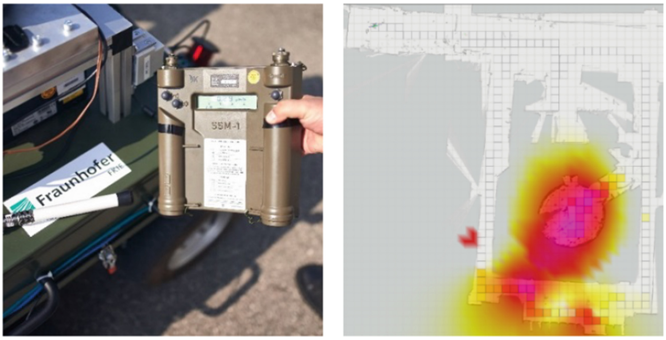

Fig. 3. The radiation detector available on a loan basis for EnRicH participants new to the RN domain (*left*). An example radiation map of the scenario: the most radiation was located in the circular reactor room; two additional sources can be seen below (*right*).

After each event, the teams were requested to hand over the sensor data recorded during their runs. If provided in the standardized ROS bag format then it is included into the EnRicH Common Shared Data Set, and in return the team is granted access to the ROS bags delivered by other teams, allowing them to train their algorithms against real sensor data coming from the former years' actual scenarios. After only two events, more than 50 ROS bags with nearly 100GB of data have been collected.

Results. The EnRicH organizers expected major difficulties for any kind of communication means due to the massive concrete walls and metal interiors inside the NPP. Therefore, a WiFi communication infrastructure was provided for the robotic systems. As a result, the teams could fully concentrate on the proposed tasks and were free from the otherwise typical communication issues. Ten teams attended the event, of which one had no RN equipment and only worked on the 3D mapping task. The other nine teams tried to build a radiation map of the scene, but most of these maps simply marked the area in which the sources where placed as a 'hot zone', giving no further information about the radiation intensity in the remaining scenario. Only the two best teams in this task delivered maps that nearly covered the whole area (see the right part of Fig. 3 for an example). Regarding the 3D maps of the environment, the results were much better, probably because this is a much more common task in the robotics domain. Figure 4 gives two pretty examples, one even with true colour textures mapped onto the 3D model.

Eight teams had systems equipped with a mobile manipulator arm, enabling them to identify the radiation sources in the pipes and close the corresponding valves (like the robot in Fig. 2). Surprisingly, although all eight teams had suitable radiation sensors for this task, only three of them successfully closed correct valves. The winning team, which found and closed all five valves, was part of a professional EOD company. The other participants were either lacking experience in working with RN sensors or had technical problems with their manipulator hardware and were not able to turn the valves reliably. The same difficulty appeared when grabbing and moving the simulated "missing worker", although the dummy body weighed only slightly more than 10kg. Only three teams were able to carry it out of the scenario back into the starting area.

Of course, these problems were partially due to the tight time schedule. A run lasted 45 min, and mapping the whole 1000 m^2 of the scenario, identifying and closing the five radioactive valves, as well as finding and "rescuing" the artificial body was very challenging. With more time, probably some of the systems could have delivered better results. However, as each team had at least two time slots during the trial days, participants could have worked on different tasks an each day, instead of trying to solve everything in one run. One team even used two robots in parallel to share the work.

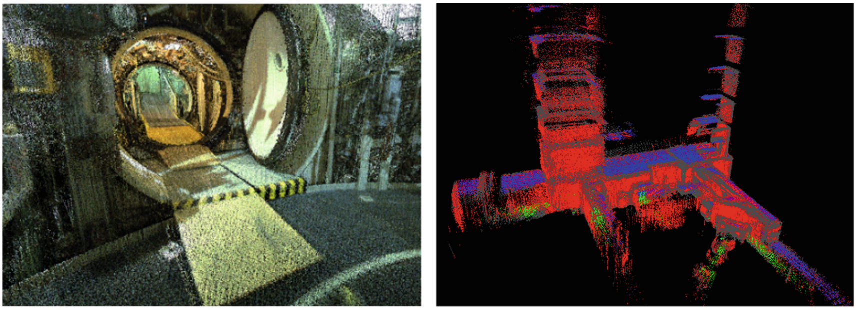

Fig. 4. Example 3D maps generated during EnRicH 2019: an interior true color RGBD view from inside the reactor room (*left*) and a nearly complete map of the scenario level (*right*).

4 Conclusion and Outlook

The problems of robots in the field of hazardous operations and emergency response, especially when involving radiological and nuclear components, are diverse. Trials and competitions can be a constructive way to push forward unmanned systems towards coping with the challenges of realistic SAR and disaster response operations, also when they include radiological and nuclear threats. Additionally, such events are a good means to bring together users, the R&D community and industry, and – last but not least – to foster standardization.

However, events like the EnRicH have shown that there are still many technical challenges, not only in general, e.g. regarding communication, sensors, situational awareness, mobility/locomotion and robustness; but also especially when using RN-related equipment. Among the various reasons for these problems, insufficient testing and, regarding the RN part, a significant lack of background knowledge and experience play an important role. There is also a huge gap between what research is able to deliver, the existing industry state of the art and the user requirements. This includes, for example, the complete absence or non-compliance to standards, best practices and norms. Maybe the upcoming EnRicH in 2021 will show considerable improvements in this important yet often disregarded robotics sub-domain.

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References

1. Snyder, R.: Robots assist in search and rescue efforts at WTC. IEEE Robot. Autom. Mag. **8**, 26–28 (2001)
2. Giesbrecht, J., Fairbrother, B., Collier, J., Beckman, B.: Integration of a high degree of freedom robotic manipulator on a large unmanned ground vehicle. In: Gerhart, G.R., et al. (eds.) Unmanned Systems Technology XII – Proceedings of SPIE, vol. 7692 (2010).
3. Schneider, F.E., Welle, J., Wildermuth, D., Ducke, M.: Unmanned multi-robot CBRNE reconnaissance with mobile manipulation. In: Proceedings of the 13th IEEE International Carpathian Control Conference (ICCC), pp. 637–642 (2012)
4. Christie, G., Shoemaker, A., Kochersberger, K., Tokekar, P., McLean, L., Leonessa, A.: Radiation search operations using scene understanding with autonomous UAV and UGV. J. Field Rob. **34**, 1450–1468 (2017)
5. Lazna, T., Gabrlik, P., Jilek, T., Zalud, L.: Cooperation between an unmanned aerial vehicle and an unmanned ground vehicle in highly accurate localization of gamma radiation hotspots. Int. J. Adv. Rob. Syst. **1–2**(2018), 1–6 (2018)
6. Nagatani, K., Kiribayashi, S., Okada, Y., Otake, K., Yoshida, K., Tadokoro, S., Nishimura, T., Yoshida, T., Koyanagi, E., Fukushima, M., Kawatsuma, S.: Emergency response to the nuclear accident at the Fukushima Daiichi Nuclear power plants using mobile rescue robots. J. Field Rob. **30**(1), 44–63 (2013)
7. Yoshida, T., Nagatani, K., Tadokoro, S., Nishimura, T., Koyanagi, E.: Improvements to the rescue robot quince toward future indoor surveillance missions in the Fukushima Daiichi nuclear power plant. In: Yoshida, K., Tadokoro, S. (eds.) Field and Service Robotics, Springer Tracts in Advanced Robotics 92, pp. 19–32. Springer, Heidelberg (2014)
8. Helmer, S., Meger, D., Viswanathan, P., McCann, S., Dockrey, M., Fazli, P., Southey, T., Muja, M., Joya, M., Little, J.J., Lowe, D., Mackworth, A.: Semantic robot vision challenge: current state and future directions. In: Proceedings of the IJCAI-09 Workshop on Competitions in Artificial Intelligence and Robotics, Pasadena (2009)
9. Schneider, F.E., Wildermuth, D.: From laboratory into real life: the EURATHLON and ELROB disaster response robotics competitions. In: Proceedings of the 16th International Carpathian Control Conference (ICCC), Szilvásvárad, pp. 452–457 (2015)
10. Del Pobil, A.P.: Why do we need benchmarks in robotics research? In: Proceedings of the IROS-2006 Workshop on Benchmarks in Robotics Research, Beijing (2006)
11. Behnke, S.: Robot competitions – ideal benchmarks for robotics research. In: Proceedings of the IROS-2006 Workshop on Benchmarks in Robotics Research, Beijing (2006)
12. Anderson, J., Baltes, J., Tu, K.-Y.: Improving robotics competitions for real-world evaluation of A.I. In: Proceedings of the AAAI Spring Symposium on Experiment Design for Real-World Systems, Palo Alto (2009)
13. The official DARPA Subterranean Challenge website. https://www.subtchallenge.com/, Accessed 29 July 2020
14. The official ELROB website, https://www.elrob.org, Accessed 23 Dec 2019
15. The official RoboGames website, https://robogames.net, Accessed 20 Dec 2019
16. Mohamed Bin Zayed International Robotics Challenge (MBZIRC) (2020). https://www.mbzirc.com/challenge/2020, Accessed 29 July 2020

17. The official ERL Emergency competition website. https://sites.google.com/view/erlemergency2020/competition, Accessed 23 Dec 2019
18. Schneider, F.E., Wildermuth, D.: Robotics challenges for radiological and nuclear reconnaissance applications. In: Proceedings of the IAEA Symposium on International Safeguards: Building Future Safeguards Capabilities, Vienna (2018)
19. Winfield, A.F.T., Franco, M.P., Brüggemann, B., Castro, A., Cordero Limon, M., Ferri, G., Ferreira, F., Liu, X., Petillot, Y, Röning, J., Schneider, F.E., Stengler, E., Sosa, D., Viguria, A.: euRathlon 2015: a multi-domain multi-robot grand challenge for search and rescue robots. In: Alboul, L., Damian, D., Aitken, J. (eds.) Towards Autonomous Robotic Systems. Lecture Notes in Computer Science, vol. 9716. Springer (2016)
20. The Robot Operating System (ROS). https://www.ros.org, Accessed 20 Dec 2019
21. Official RAWSEEDS website. https://www.rawseeds.org, Accessed 20 Dec 2019
22. Schneider, F.E., Wildermuth, D.: Assessing the search and rescue domain as an applied and realistic benchmark for robotic systems. In: Proceedings of the 17th International Carpathian Control Conference (ICCC), Tatranská Lomnica, pp. 657–662 (2016)
23. The RoboCup© Federation. https://www.robocup.org, Accessed 20 Dec 2019
24. Schneider, F.E., Wildermuth, D.: Real-world robotic competitions for radiological and nuclear inspection tasks. In: Proceedings of the 20th International Carpathian Control Conference (ICCC), Wieliczka (2019)
25. IAEA Robotics Challenge - Anonymized Report. SG-RP-14918, International Atomic Energy Agency (IAEA), Department of Safeguards (2018)
26. Paepen, J., Lutter, G., Schneider, F.E., Garcia Rosas, F., and Röning, J.: Performance of the IEC 63047 demonstration device. EUR 29787, Publications Office of the European Union, Luxembourg (2019). https://doi.org/10.2760/041774

Educational Contribution from Summer Robotic League

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Abstract. The Slovak competition the Summer Robotic League is for pupils aged between 9 and 16 who want to better prepare their teams for the international competition FIRST LEGO League or for pupils who just love robotics. The Summer Robotic League exists since 2013 and has not yet been explored in terms of educational aspects. The archive offers a variety of students' solutions that are suitable for qualitative analysis. In this article we therefore focus on the analysis of the tasks in selected year of The Summer Robotic League. In our research we used qualitative methods of data collection and data analysis. We analysed the submitted solutions of participants and tried to find dependencies between tasks and solutions and we identified misconceptions related to used programming concepts in participants' solutions. These results should serve to better design tasks in the next Summer Robotic League.

Keywords: Robotics · Competition · LEGO · Educational aspects · Misconceptions

1 Introduction

We have been working in the field of educational robotics since 2012 [1]. Our findings suggest that using educational robotics in leisure time activities or competitions is easier and more effective as using educational robotics in compulsory education. An appropriate incorporation of educational robotics into compulsory education is relatively complicated process. In every country this process can involve many obstacles i.e. evaluation of students' work, finance for the purchase of robotic kits, incorporation of robotics into suitable school subject, unskilled teachers or teachers, who do not want to teach educational robotics. However there are many studies that are dealing with robotics in competitions [2, 3], robotics in after school activities [4, 5], robotics with children with special needs [6–8], robotics in summer camps [9, 10], robotics used for skills development [2, 11, 12], or robotics with gender differences and dependencies [3, 13, 14]. But there are not so many studies about teaching programming with robotics in compulsory education [15–17]. Yet pupils are learning programming also during robotic competitions [18]. However at competitions there are gifted pupils, which are also strongly motivated. During the preparation for competitions there are probably no discussions about didactically correct introduction of new concepts. Gifted pupils are dealing with

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challenges and they somehow manage. In competitions there are also involved enthusiastic average pupils without any special talents in robotics. Therefore we focused our interest on how to formulate assignments and tasks to support knowledge of average pupils in the robotic competition Summer Robotic League. We studied how to create tasks that are interesting for all participants and that can adhere certain educational principles. We also examined misconceptions and mistakes during programming part of selected robotic competition.

2 The Summer Robotic League

The Summer Robotic League (SRL) is robotic competition which was created in 2013 by some colleagues in Slovakia and it takes place in the first half of the year, i.e. during the summer semester. In this competition there are teams of pupils that are solving interesting tasks with robotic kit LEGO Mindstorms NXT or LEGO Mindstorms EV3. Pupils in the team do not have to be from the same school, nor do they have to be the same age. Teams must be multi-member and pupils should be between 9 and 16 years old.

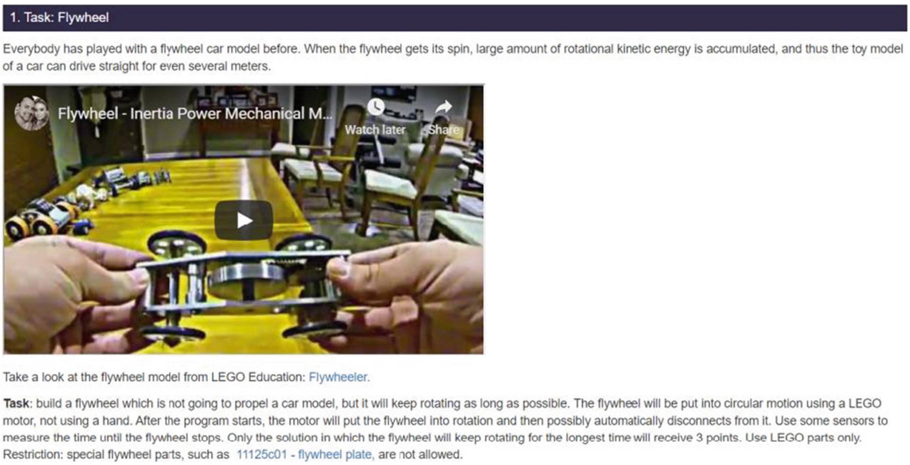

Fig. 1. Example of assignment from the competition SRL. Task 1 of 6 rounds.

Many teachers are grateful for the opportunity for their pupils to participate in SRL, because via SRL pupils can work on refreshing tasks, they can construct their own robotic models, they can solve complex problems and they can be also part of the team. SRL has huge potential to work with gifted or enthusiastic pupils. At first competition consisted of ten rounds and each round contained one task. Now competition contains eight rounds and each round contains two tasks: one task is easier (Fig. 1) and another task is more difficult. Each task is consisted of written description of some challenge and a picture or a video for motivation or for better understanding of the challenge. Teams of participants can find tasks in web site [19] and there usually appear next round with new two tasks every two weeks. Also teams have to upload their solutions on website every two weeks. Each solution should contain files with programs to control robotic model, photos of created robotic model and photos of the team, video with solution and also written description of solution. Solutions are graded by three judges to ensure better objectivity. One judge can give three points at maximum for solution of one task. This maximum will be awarded to the competition team if it has completed the assignment. The assignment is fulfilled if the robot exhibits the behaviour defined in the task. This can be seen in the uploaded video and the attached programs. Each team receives average value of points for one task from three judges. Each team also receives written evaluations (feedback) of their solution from each judge.

3 Methodology

A lot of teams consisted of gifted pupils are participating in SRL every year. Therefore SRL has a potential to systematically work with these pupils. So we decided to better understand pupils' solution. We tried to examine, which tasks pupils like, which tasks are too difficult for pupils and so on. For that reason we analysed all the tasks in SRL in year 2019. As we mentioned before, competition contains eight rounds, each round contains two tasks. There were 21 teams of participants and there were various numbers of participants in each team (usually up 2 to 5). Four judges (one man and three women) evaluated solutions.

In our research we used qualitative methods of data analysis [20]. We coded various types of data. In the beginning of our research was necessary to better understand the nature and composition of the tasks, so we used open coding on written descriptions of the tasks. For this we use online software: atlas.ti. Tasks are available on the web site of the competition [19]. We also coded solutions of the participants and we mainly focused on programs to control robotic model. There were submitted a total of 150 different programs. So, we considered the commands used, their order, repetitivity, necessity/uselessness, etc. Based on these codes, we created categories and subcategories, and looked for relationships between them as they relate to each other. We also worked with information about teams of participants. For example: how many teams were solving certain task and how many points team received for certain task. Based on this information and a qualitative analysis of the properties of tasks and student solutions, we were able to answer our research questions:

1. Q1: Which tasks are (un)interesting for participants? How can we characterize these tasks?
2. Q2: How can we characterize, that task is difficult or easy (task which was unsuccessfully or successfully solved)?
3. Q3: What misconceptions are most often committed by participants when programming their solutions?

We described the process in more detail in the next chapter Results.

4 Results

Based on the research questions and results of a qualitative data analysis we divided our results into three parts: interesting tasks, successful tasks and misconceptions in programming.

4.1 Interesting Tasks

At the beginning of the article, we wrote that in each round, one task is easy and the other more difficult. However, the creators of the competition specially create such tasks as to encourage creativity. The assignments themselves do not define the exact procedure of the solution, on the contrary, they leave it to the pupils which strategy they choose to solve. Therefore, it happens that some creative students (perhaps with less knowledge) solve a difficult task at first glance, in a relatively trivial way. Therefore, in our research we understood the term *interesting tasks* as such tasks that students most often solved. In this section we examine tasks and their influence on solutions based on number of participants. Based on qualitative data analysis of tasks and their solutions we created a scale and we placed tasks into this scale. The scale consists of three levels, which were created according to number of participants who were solving each task (Table 1).

Table 1. 3 levels of the scale

Level of the scale	1.	2.	3.
Percentage of all participants of SRL in year 2019	More than 70%	70%-40%	Less than 40%

The first level of the scale contains tasks interesting for participants. That means that tasks were solved, at least 70%, of all the participants of selected year of the competition SRL. The main characteristic of mentioned tasks was their difficulty, i.e. when solving these tasks, participants were constructing robots without sensors and these robots should represent an instrument used in ordinary life.

In **the second level** of scale, there are not so interesting tasks for participants, i.e. tasks were solved from 40% to 70% of all the participants. The main characteristic of these tasks was the need of using basic properties of sensors when solving tasks. For example the use of the light sensor to follow a line or the use of ultrasonic sensor to detect some object. An interesting characteristic feature of these tasks was the orientation on sport or human-like movements.

The third level of scale contains tasks, which were solving by low number of participants - less than 40% of all participants. Therefore, we consider at least interesting. The main characteristic of these tasks was also their difficulty, i.e. when solving these tasks, participants needed to use more complex programming concepts such as sending messages via bluetooth or participants needed to track object via ultrasonic sensor. Into third stage of scale we also placed tasks which contain specific restrictions (use a maximum of two sensors, do not use specific sensor, etc.). The last characteristic of discussed tasks was abstraction of the tasks, i.e. when solving these tasks, participants were constructing robots which should detect a number of vertices of drawing triangle, or detect number of symmetry of drawing object, etc.

After assigning individual tasks to the appropriate levels of the scale and looking for the basic characteristics of that scale, we came to the following conclusions:

- Tasks, where participants were constructing instruments from the real world, increase the interest of participants to solve task. Tasks, where participants needed to use abstraction are less preferred by them.
- In particular, participants prefer sport tasks and tasks, where they should construct robotic model that performs activities that are similar to human movements.
- The use of sensors also affects interest of participants to solve task. If the sensors are used trivially in the task, it is solved by more teams.
- An important factor that influences interest of the participants to solve the task is the creation of a map for the robot's navigation (for example, drawing a road using a black line). Tasks that require the creation of such a map for the robot reduce the interest of participants to solve such tasks.
- The use of more complex programming techniques, such as Bluetooth communication, greatly reduces interest of participants to solve such task.

4.2 Successful tasks

In this section, we discuss the results of the second research question about (un)successfully solved tasks. A large number of other factors influenced the overall success of the tasks. We know from the judges that they gave points mainly motivationally, which means that we cannot determine exactly that tasks with many points scored can be classified as easy - successful. In addition, each judge could create their own scale to give teams points. However, as we knew that judges usually deduct decimal points and only in the case of serious deficiencies they give less than 2 points, we decided that a successful task is one that was solved by at least 70% of the participating teams, who scored 2.5 points out of 3 points. Based on the analysis of the solutions, there appeared several new hypotheses/questions for further research:

- The tasks, which were solved by a small number of teams, were usually given a full score. However, these were mostly very skilled teams with talented participants.
- More successful tasks have become those that using the principle of a tool used in ordinary life.
- The assignment of the task also has an impact on the success of the particular task. Assignments of the tasks that were more precise for programming or robot design have become more successful.
- Tasks that require creation of the map for the robot (for line tracking) increase the task's success.

4.3 Misconceptions in programming solutions

In this section, we describe the six most common mistakes that pupils made when creating programs.

1. Participants used **infinite cycles** in their solutions, in which all commands/procedures were embedded. However, in order to end such a program, participants had to shut down control unit manually (see Fig. 2). If they did not use the infinite cycle, the program would run smoothly and would end when the execution of commands was terminated.
2. In some cases, the participants were using **cycles with challenging method**. There was an infinite cycle in which participants calculated the current cycle transition using variables. Once they had reached the required number of repetitions, they forced an infinite cycle to stop. However, the programming environment in which they worked allows the use of cycles for a given number of repetitions, and thus there is no need to use an infinite cycle.
3. Another mistake we have found when analyzing programs is that participants had a problem working with **variables**. Variables can be overwritten in the programs. However, some participants unnecessarily created new variables to remember some results. However, the difficulty of such a program is higher. Alternatively, participants created a variable, then they assigned a value to the variable, but they did not work with it in the program.
4. On the other hand, **conditional commands** were relatively well handled, but they were not always effective. Participants used conditional commands at a good level (we believe they understood how conditional commands should be used). But instead of one complex condition, they created a series of simpler conditions. In some cases, this could result in the forgotten testing of one of the necessary conditions, or multiple testing of one condition.
5. We also examined **effectiveness** of programs. According to the submitted programs, we have seen that the effectiveness of programs is not important for participants. Participants were satisfied with the program, regardless of its time demands or memory demands. The programs contained unnecessary commands, unnecessary repetition of commands, and participants were satisfied with such a program without the need for improvement. We realize that at a given age, participants do not think about effectiveness, yet they could be encouraged to follow at least the fundamentals of decent programming.
6. Finally, there is a deficiency that is partly related to the design. Participants used the **engine control commands** for running the engines for x seconds (see Fig. 2). However, such a use is not so good, because the robot gives power to the engines based on how much percent battery is charged. Therefore, running the engines for x seconds is very inaccurate. It is better to use the running the engines for x turns. Some solutions were not accurate or properly solved, because of the mentioned setting of the motors.

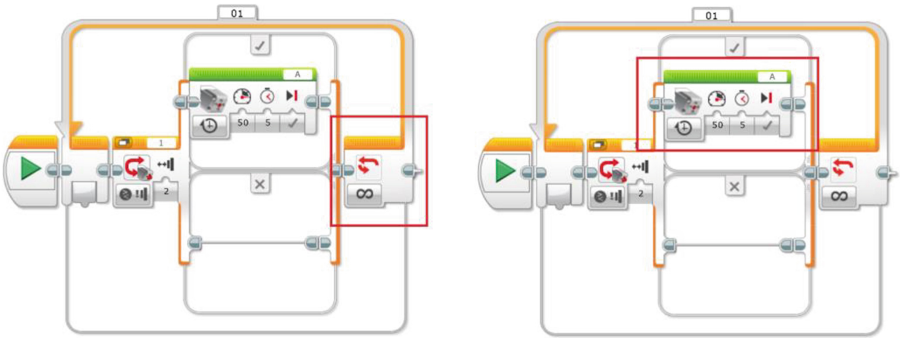

Fig. 2. Demonstration of the participants' solution where you can see two mistakes at once. On the left part you can see the improper use of the infinite cycle which is highlighted in the red frame. On the right part you can see the inaccurate use of engine control command, which is highlighted in the red frame.

5 Discussion

We realize that the results of this research are results of pilot study and they need to be verified on data from multiple years of the competition. In further research, we would like to compare our claims with the results of the analysis of the competitions from older years and thus increase the accuracy of our theory. Based on these results, we are going to propose a series of tasks, or at least a number of sequential tasks, that would lead the participants of Summer Robotic League to better understanding and knowledge and also with the use of new tasks there could be fewer "misconceptions" in participants' solutions.

We are already actively working on this goal and, if we succeed, we would have included several tasks in competition in 2020. This series of tasks would increase or at least keep the enthusiasm of as many participating teams as possible. We observed that the number of participating teams decreases over time (see Fig. 3). We are aware of the factors that cause reducing the number of the participating teams, but we cannot fully take them into account in our data analysis. These are factors such as the school year, which include various national testing, excursions, exams, Olympics, holidays, etc. Due to the fact that the teams are from different regions of Slovakia, they have holidays at different times. Participants in teams have also different ages and therefore they are from different classes and not all of them have the same exams/tests in the same period. Therefore, we cannot justify e.g. reduced number of uploaded solutions in some round of the competition.

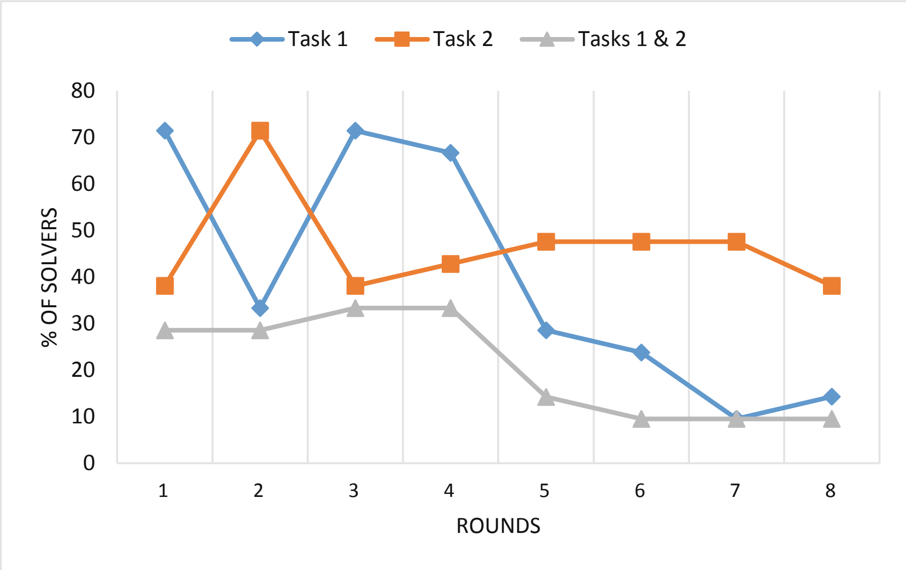

Fig. 3. Graph of solved tasks according to the competition rounds.

6 Conclusion

In this chapter we summarize the answers to our three research questions. In the first question we examined interesting tasks, i.e. tasks that many teams have solved. We observed that interesting tasks should include real-world problems (tasks) that the robot imitates, without using sensors or other specified constraints. These tasks are not very abstract and do not require the creation of a map or route that the robot should follow. There also appeared a question: when (in which round) to include such tasks in order to remain motivated and not boring for the more skilful teams?

We were also interested in what tasks were difficult for participants. However, we had a problem in defining difficult tasks. Points for solved tasks were given by judges rather motivationally. Therefore, difficulty could not be entirely based on the low number of points earned for solved task. So it was necessary to examine a low number of solved tasks. Such tasks, however, were mostly solved by skilled / talented teams that earned almost always full scores. These tasks mostly involved the use of complex concepts, or constraints in the form of instructions to use a specific sensor while building robotic model. So the question about difficult tasks could not be fully answered. Rather, there appeared another questions: Should there be one easy and one very difficult task from the beginning of the competition? Should we create a series of three or four tasks that gradually learn participants to work with a more complex sensor? Should we incorporate difficult tasks only as bonuses for teams that participated at least three times?

In an effort to better understand participants' solutions, we examined their misconceptions - errors that occurred in participants' uploaded programs. These errors included the incorrect use of the infinite cycle, unsuitable constructed conditions, forgotten commands, too many unnecessary variables, or the use of inappropriate engine control commands resulting in the inaccuracy.

We believe that these results will inspire the creators of the tasks of the Summer Robotic League and also help them formulate more interesting tasks, or at least combine tasks in terms of difficulty to keep the interest of the weaker teams. The authors of competition are also trying to involve foreign teams into competition, so we believe that our results will be a welcome help.

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References

1. Mayerová, K.: Pilot activities: LEGO WeDo at primary school. In: Proceedings of 3rd International Workshop Teaching Robotics, Teaching with Robotics: Integrating Robotics in School Curriculum, pp. 32–39. Springer, Italy (2012)
2. Eguchi, A.: RoboCupJunior for promoting STEM education, 21st century skills, and technological advancement through robotics competition. Rob. Auton. Syst. **75**, 692–699 (2016)
3. Sullivan, A., Bers, M.U.: VEX robotics competitions: gender differences in student attitudes and experiences. J. Inf. Technol. Educ. **18**, 97–112 (2019)
4. Ching, Y.H., Yang, D., Wang, S., Baek, Y., Swanson, S., Chittoori, B.: Elementary school student development of STEM attitudes and perceived learning in a STEM integrated robotics curriculum. TechTrends **63**(5), 590–601 (2019)
5. Daniela, L., Strods, R., France, I.: Activities with educational robotics: research model and tools for evaluation of progress. In: Smart Learning with Educational Robotics, pp. 251–266. Springer, Cham (2019)
6. Di Lieto, M.C., et al.: Improving executive functions at school in children with special needs by educational robotics. Front. Psychol. **10**, 2813 (2019)
7. Daniela, L., Lytras, M.D.: Educational robotics for inclusive education. Technol. Knowl. Learn. **24**, 219–225 (2019)
8. Bargagna, S., et al.: Educational robotics in down syndrome: a feasibility study. Technol. Knowl. Learn. **24**(2), 315–323 (2019)
9. Pöhner, N., Hennecke, M.: The teacher's role in educational robotics competitions. In: Proceedings of the 18th Koli Calling International Conference on Computing Education Research, pp. 1–2. ACM, Finland (2018)
10. Gonçalves, J., et al.: Educational robotics summer camp at IPB: a challenge based learning case study. In: Proceedings of the Seventh International Conference on Technological Ecosystems for Enhancing Multiculturality, pp. 36–43. ACM. (2019)
11. Kandlhofer, M., Steinbauer, G.: Evaluating the impact of educational robotics on pupils' technical-and social-skills and science related attitudes. Rob. Auton. Syst. **75**, 679–685 (2016)
12. Usart, M., Schina, D., Esteve-Gonzalez, V., Gisbert, M.: Are 21st century skills evaluated in robotics competitions? the case of first LEGO league competition. In: 11th International Conference on Computer Supported Education, pp. 445—452. Science and Technology Publications, Lda. (2019)

13. Atmatzidou, S., Demetriadis, S.: Advancing students' computational thinking skills through educational robotics: a study on age and gender relevant differences. Rob. Auton. Syst. **75**, 661–670 (2016)
14. Sullivan, A., Bers, M.U.: Girls, boys, and bots: Gender differences in young children's performance on robotics and programming tasks. J. Inf. Technol. Educ. Innov. Pract. **15**, 145–165 (2016)
15. Cesaretti, L., Storti, M., Mazzieri, E., Screpanti, L., Paesani, A., Principi, P., Scaradozzi, D.: An innovative approach to school-work turnover programme with educational robotics. Mondo Digitale **16**(72), 2017–5 (2017)
16. Tocháček, D., Lapeš, J., Fuglík, V.: Developing technological knowledge and programming skills of secondary schools students through the educational robotics projects. Procedia-Soc. Behav. Sci. **217**, 377–381 (2016)
17. Karsenti, T., Komis, V., Romero, M., Depover, C.: Robotics in Primary Education–Robotique en Éducation Primaire: Introduction. Review of Science, Mathematics and ICT Education (2019)
18. Angeli, C., Valanides, N.: Developing young children's computational thinking with educational robotics: an interaction effect between gender and scaffolding strategy. Comput. Hum. Behav. **105**, 105954 (2019)
19. Summer Robotic league. https://liga.robotika.sk/, Accessed 27 Jan 2020
20. Creswell, J.W.: Educational research: Planning, conducting, and evaluating quantitative. Upper Saddle River, New Jersey (2002)

Robotics Competitions as an Integral Part of STEM Education

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Abstract. The paper highlights the increasing role of robotics competitions in STEM education based on information pertinent to "Robotex Cyprus 2019", an annual robotics competition. Relevant data were collected through a questionnaire reflecting the views of participants ($n = 474$) regarding their engagement and satisfaction during the preparation stage of the competition.

Keywords: Educational robotics · Robotics competitions · STEM education

1 Introduction

Modern world and new challenges require skills that students develop in science, technology, engineering and mathematics. These disciplines are collectively referred to as STEM. National policies worldwide promote STEM education and educational robotics has become an integral part of this effort. Robots constitute a technological paradigm that embraces various aspects of STEM education: (i) Science (physics, mechanics, electricity, etc.); (ii) Technology (computers, ICT, electronics, etc.); (iii) Engineering (design, programming, optimization, etc.); (iv) Mathematics (calculations, geometry, algorithms, etc.). Robotics widely recognized pedagogical value led to the development of robotics courses across primary and secondary education, beyond university curricula [1]. As a topic, robotics is appealing to students and promotes "active learning" by engaging them in doing things practically. It increases the interest of students to pursue a degree or a career path in a STEM related field, for which exists a need in the job market. Moreover, educational robotics is widely seen as a means of fostering innovation and creativity, while robotics clubs are becoming popular within educational institutions. Beyond relevant courses, robotics competitions are often embraced as an added stimulus [2–6]. Key benefits of robotics competitions have been identified in [2] and include:

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inspire interest in STEM; understanding science & technology; develop analytical and computer programming skills; sharpen problem solving capability; develop design and integration skills; foster creativity and innovation; cultivate technical skills; help bridge the gap between theory and practice with hands-on experience; promote teamwork and social skills; improve presentation skills; promote ethical standards. Relevant to the last one is the wider issue of "Roboethics" [7, 8].

2 Robotics Competitions and the Paradigm of Robotex Cyprus

Robotex Cyprus is a robotics competition held in Cyprus, which is based on the well-established Robotex International Competition organized annually in Tallinn, Estonia. The event was successfully organized for the third consecutive year achieving considerable participation levels (teams: 335; robots: 522; participants: 1025; coaches: 95). Robotex Cyprus 2019 provided students with the opportunity to participate at a wide range of challenges, some of which have been established in similar events worldwide [2]. Competition challenges are often themed (e.g., sumo, recycling, rescue, firefighting, soccer), but others focus on a generic task (e.g., line-following, sorting, maze solving). This year's competition included the challenges depicted in Fig. 1.

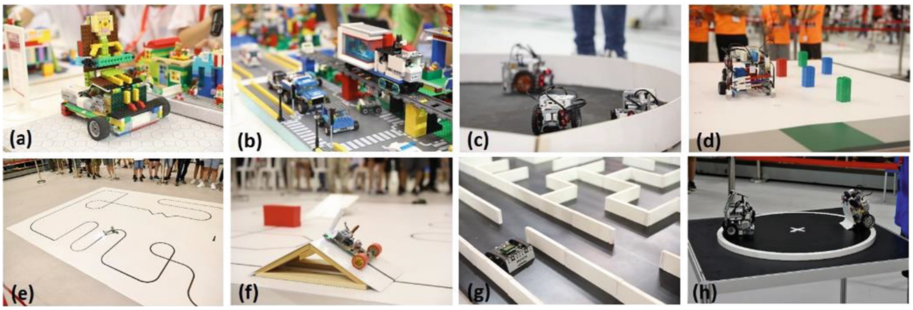

Fig. 1. Challenges included in Robotex Cyprus 2019 competition. (a) Educational Robotics Projects; (b) Robotics4All; (c) Folkrace; (d) Colour Picking; (e) Line Following; (f) Enhanced Line Following; (g) Maze Solving; (h) Sumo.

During Robotex Cyprus 2019, a dedicated survey in the form of a questionnaire was used to document the views and perceptions of the participants (sample: $n = 474$) in a systematic manner. The survey aimed to capture the participants' engagement and satisfaction while preparing for the competition. The objective was twofold. First, to evaluate the overall process and second, to exploit the received feedback towards improving future competitions for the benefit of the participants. Collected data identified wider issues regarding robotics competitions and STEM education in general, which have been accordingly categorized and discussed here, together with some reflections drawn from the experiences on behalf of the organizers. Topics include: gender and age participation in STEM fields; pedagogical value of team work and interactions between the team members; the role of the tutor; and the role of the organizers. Note that the presented information concerns the data gathered through the questionnaires – not the overall officially registered data. Rating questions were based on a one to five (1–5) rating scale, where 1 corresponds to "*strongly disagree*" and 5 to "*strongly agree*".

The participation of players and teams/robots per challenge, as shown in Table 1, is indicative of their popularity but is also coupled with their degree of difficulty. For this particular case, data concerned the overall participation – not just the survey sample. Also, note that many of the registered teams participated in more than one challenge. For each challenge, teams were divided into categories based on their educational level, also reflecting a corresponding skill level: primary school, gymnasium, lyceum/high school, university, and adults. The distribution of participants between categories is depicted in Fig. 2a. Some challenges were platform-specific (e.g., Lego, Engino), whereas others were open to custom-made systems, integrating off-the-shelf components (mechanical hardware, microprocessors, motors, sensors, etc.). The latter approach provides more flexibility and further opportunities for creativity to design [9]. At the same time, it requires more skills and as a result involved participants of the higher educational levels.

Table 1. Participation of players and teams per challenge (note that many of the registered teams participated in more than one challenge).

Challenge	Number of players	Number of teams/robots
Educational robotics projects	257	65
Robotics4All	24	12
Folkrace	78	27
Colour picking	30	10
Line following	556	180
Enhanced line following	78	25
Maze solving	132	19
Sumo	438	134

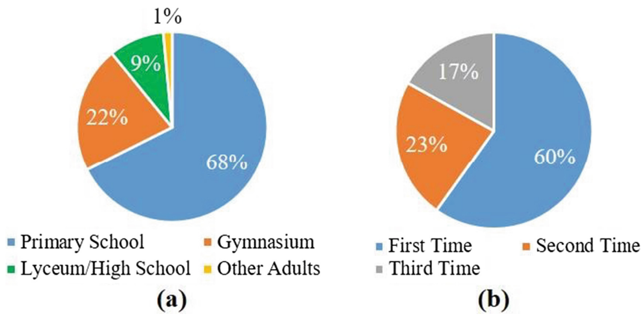

Fig. 2. (a) Team level; (b) Previous participation in Robotex Cyprus.

The attractiveness of educational robotics competitions is expressed by the fact that approximately 40% of Robotex 2019 participants also participated in the competition before, as depicted in Fig. 2b. Indicative of the appeal of the competition to students is the satisfaction, the effort and the time they invested during preparation, as shown by their responses to relevant questions, presented in Fig. 3a and 3b, respectively.

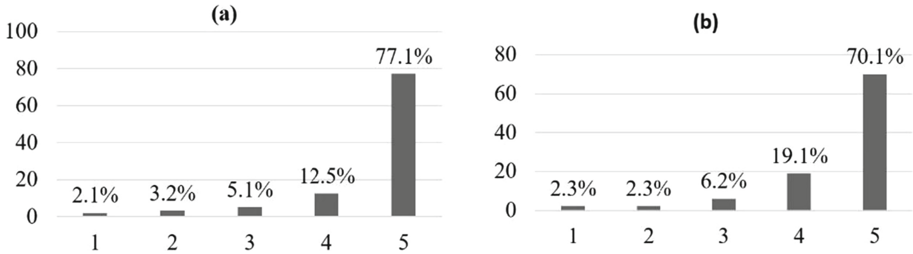

Fig. 3. (a) Responses to question: "I had fun during the preparation process for the robotics competition?"; (b) Responses to question: "I worked hard during the preparation period?"

3 Participation of Women in STEM Fields

The questionnaires also recorded demographics data, which reveal a broader issue regarding gender participation in STEM fields. The participation is characterized by a predominantly male distribution: 73% male and 27% female (see Fig. 4a). Regarding the composition of the teams, approximately half of the teams (47%) were male-only. On the opposite end, only 4.9% were female-only. Interestingly, the majority of the teams (48.1%) were of mixed composition, as shown in Fig. 4b. Regarding the team leaders, in 78.4% of the cases was male and 21.6% was female (Fig. 4c). Increasing female participation and encouraging leadership is a key identified aspect that will be systematically pursued in future competitions.

The gender disparity issue is shown to extend to the team coaches, of which 71.9% were male and only 28.1% were female (Fig. 4d). This reflects a wider disproportion that exists within the professionals in STEM fields, where women have been under-represented. It is widely recognized that bridging the gender gap in STEM disciplines will help reduce skills gap, have a positive impact on employment and productivity of women, and ultimately foster economic growth. The origins of this phenomenon is a multifaceted topic, which is beyond the scope of this paper. The existing imbalance has been widely acknowledged by scholars and policymakers, resulting to systematic actions towards increasing the participation of women in STEM education.

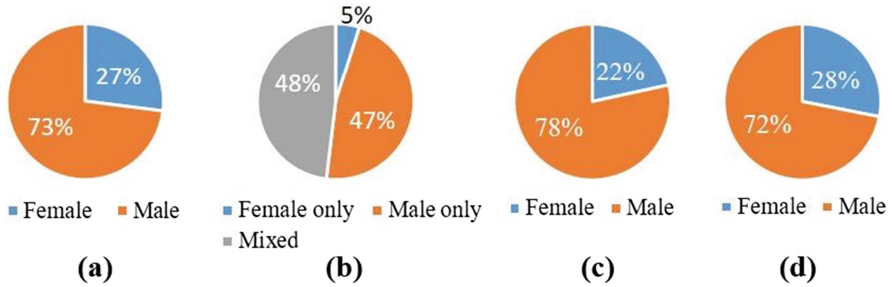

Fig. 4. (a) Participants' gender; (b) Gender composition of teams; (c) Team leaders' gender; (d) Coaches' gender.

4 Team Work - Interactions Between Team Members

Educational robotics competitions are principally team-oriented with members working collectively towards the common goal. Each member may undertake a specific role (robot builder, programmer, etc.). Team members exchange knowledge and experiences while complementing each other's skills. Effective communication and collaboration between team members is an essential element, while the size of the teams should be appropriate for that purpose. On one hand, the team size should be small enough for all its members to be kept actively engaged. On the other hand, it should encompass all required skills. Undoubtedly, diversity increases the potency of "team learning". In the case of Robotex Cyprus 2019, the maximum allowed size of the teams was 6 for the Robotics Themed Projects Challenge (Educational Robotics) and 5 for all other challenges. Interestingly, teams with four team members was the most common (30.4%), followed by three-member teams (26%), as depicted in Fig. 5. Each team had a leader, whose role also included representing the team during the competition. To maximize the benefit, it is important to cultivate the "team spirit", which is the feeling of belonging, exhibiting pride and showing interest towards common goals.

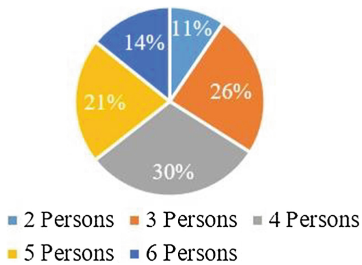

Fig. 5. Team sizes in Robotex Cyprus 2019.

While preparing for a robotics competition it is important for the team to follow a structured approach, as discussed in [2]. Adopting best practices is pertinent to the standard engineering design methodology and the effective use of algorithmic procedures towards solving a given problem. Documenting the work is also important and this responsibility should be formally assigned to a team member. A post-competition evaluation can help identify the strengths and weaknesses of the undertaken approach, so that lessons learned are applied in preparation for forthcoming competitions.

Direct interactions between the team members are particularly important for each individual in understanding the material and include: (i) Explaining the material to the team; (ii) Having the material explained by other team members; (iii) Discussing the material with the team. The importance of the above three practices is supported by the findings of the survey, as presented in Fig. 6(a, b and c, respectively). The group activities that students are engaged in during the preparation contribute towards: (i) Increasing the understanding of the material; (ii) Maintaining focus; (iii) Stimulating interest in the material. The aforementioned realizations are supported by the data in Fig. 6(d, e and f, respectively).

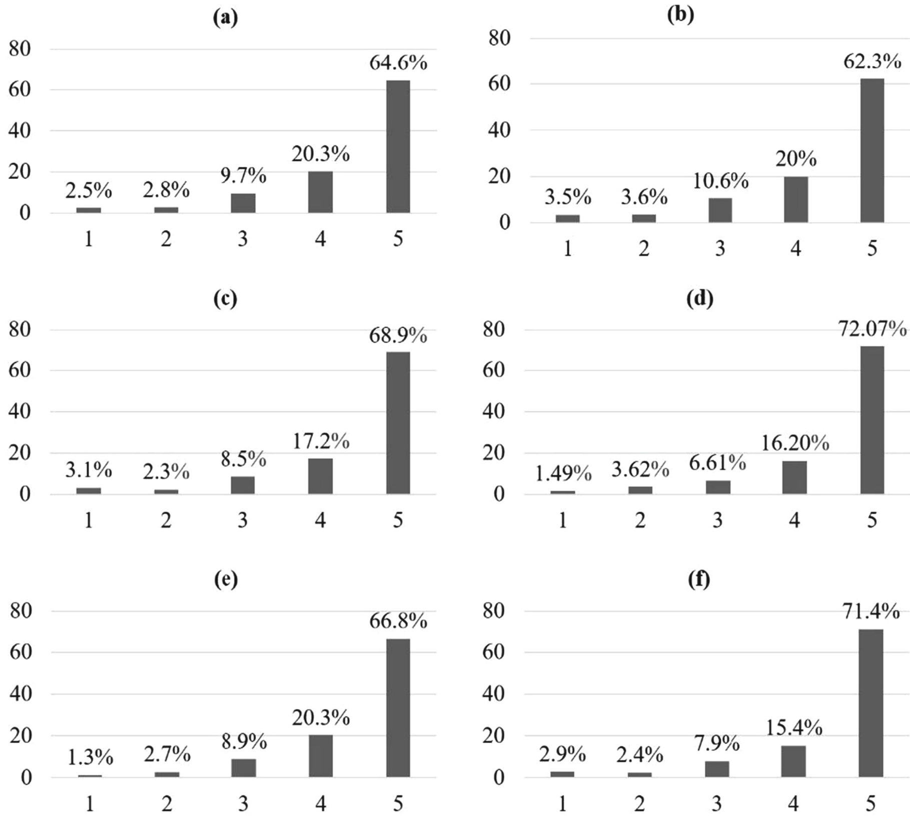

Fig. 6. (a) Responses to question: "Explaining the material to my team improved my understanding of it?"; (b) Responses to question: "Having the material explained to me by my team members improved my understanding of the material?"; (c) Responses to question: "Discussion with the team members contributed to my understanding of the material, the process and the objectives of the preparation?"; (d) Responses to question: "The team activities increased my understanding of the material?"; (e) Responses to question: "The group activities stimulated my interest in the material?"; (f) Responses to question: "I was focused during the preparation process and the group activities?"

5 The Role of the Tutor – Interactions with the Tutor

The guidance of a tutor plays a catalytic role during the preparation stage. In the case of Robotex 2019 tutoring was undertaken by both public and private high-school teachers, as well as teachers at private training institutes. Their background was mainly engineering, computer science and physics. Ideally, the tutor is an enthusiastic individual with knowledge and expertise in a content area or discipline related to robotics. A good tutor does not provide the team with ready-made solutions to the problems but rather acts as a facilitator helping them to find solutions and perform the work themselves by encouraging learning, critical thinking and application of basic principles. Moreover, the tutor plays a key role in promoting team-work and team-learning. The way students perceive the role of the tutor towards maintaining their interest and contributing to learning during the preparation process, is presented in Fig. 7a and 7b, respectively.

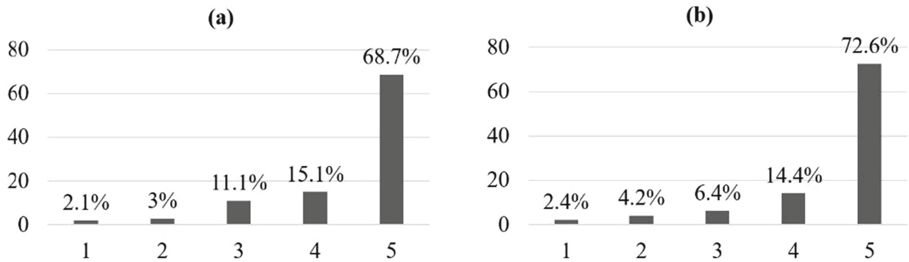

Fig. 7. (a) Responses to question: "The instructor's enthusiasm made me more interested in the preparation process?"; (b) Responses to question: "The instructor's effort contributed to my learning?"

6 The Role of the Competition Organizers

The organizers play a central role in every stage of the competition. Starting from the conception of the competition they are required to establish an inspiring, stimulating and unambiguous framework, define the challenges and their corresponding rules, secure funding and sponsorships, manage communications and logistics, prepare each challenge's setup, train the coaches, run the competition and finally evaluate the overall effort. The competition challenges need to be carefully selected so they are both appealing and stimulating to students. Towards this direction, providing training to coaches and referees through seminars and workshops was a key component for improving the level of the competition and achieving its educational goals. Among the obligations of the organizers is to ensure fairness and transparency; this aspect is perceived as particularly important among the participants. Finally, a successful competition requires that the organizers establish and maintain a close and sincere relationship with all stakeholders including students, coaches, school teachers, parents, sponsors, and national education bodies.

7 Conclusions

Robotex Cyprus is a robotics competition which has been established as an annual national event. Towards improving its organization and maximizing its benefits, feedback was collected via questionnaires focusing on the preparation stage of the competition. Collected information highlighted and reinforced the relevance between robotics and STEM education and the contribution of robotics competitions in the wider adoption of STEM related disciplines. Robotics is attractive to students and is rich in relevant content. Within the framework of a robotics competition the students have the opportunity for hands-on experience and "active learning". Moreover, as suggested by the analysis of the collected data, the effectiveness of "team learning" process is supported by the documented interactions between the students. In that context, the catalytic role of the tutor during the preparation of the team for the competition was further highlighted. On a different note, collected data verified the existing gender disparity and the need to act upon increasing female participation in STEM fields. A central role towards the success of such endeavors belongs to the competition's organizing committee, which is required to establish and implement an inspiring and effective framework for the event. This will eventually maximize the educational benefit for the students and nurture a STEM culture - the ultimate goals of robotics competitions.

References

1. Afari, E., Khine, M.S.: Robotics as an educational tool: impact of lego mindstorms. Int. J. Inf. Educ. Technol. **7**(6), 437–442 (2017). https://doi.org/10.18178/ijiet.2017.7.6.908
2. Christoforou, E.G., et al.: Educational robotics competitions and involved methodological aspects. Adv. Intell. Syst. Comput. **1023**, 305–312 (2020). https://doi.org/10.1007/978-3-030-26945-6_27
3. Murphy, R.R.: 'Competing' for a robotics education. IEEE Rob. Autom. Mag. **8**(2), 44–55 (2001). https://doi.org/10.1109/100.932757
4. Akagi, T., Fujimoto, S., Kuno, H., Araki, K., Yamada, S., Dohta, S.: Systematic educational program for robotics and mechatronics engineering in OUS using robot competition. In: IEEE International Symposium on Robotics and Intelligent Sensors, vol. 76, pp. 2–8 (2015)
5. Eguchi, A.: RoboCupJunior for promoting STEM education, 21st century skills, and technological advancement through robotics competition. Rob. Auton. Syst. **75**, 692–699 (2016). https://doi.org/10.1016/j.robot.2015.05.013
6. Chew, M.T., Demidenko, S., Messom, C., Sen Gupta, G.: Robotics competitions in engineering eduction. In: ICARA 2009 - Proceedings of the 4th International Conference on Autonomous Robots and Agents, pp. 624–627 (2009). https://doi.org/10.1109/ICARA.2000.4804032
7. Veruggio, G., Operto, F.: Roboethics: social and ethical implications of robotics. In: Springer Handbook of Robotics, pp. 1499–1524. Springer, Heidelberg (2008)
8. Christoforou, E.G., Müller, A.: R.U.R. revisited: perspectives and reflections on modern robotics. Int. J. Soc. Robot. **8**(2), 237–246 (2016)
9. Plaza, P., et al.: Arduino as an educational tool to introduce robotics. In: Proceedings of 2018 IEEE International Conference on Teaching, Assessment, and Learning for Engineering, TALE 2018, pp. 1–8 (2019). https://doi.org/10.1109/TALE.2018.8615143

Impact Evaluation

Perspectives of Educational Robotics in the Ongoing Technological Transformations

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Abstract. The paper discusses educational robotics' potential to contribute to the process of societal transformation caused by the Fourth Industrial Revolution (4IR). An overview of educational robotics' questions is presented based on the authors' experience teaching supplementary education programs to K-12 students in digital fabrication environment as well as on several external review papers. A case study is presented to reveal and confirm some of the problems common for such project-oriented creative STEM related activities in supplementary education environment. One of which being inclusion in practical technical studies of different groups of students - a common challenge for the given educational robotics context.

Keywords: Educational robotics · STEM · Technological literacy · Digital fabrication · Inclusive education · Blended learning · Assistive education · Engineering · Supplementary education

1 Introduction

We live in the times of the global technological and social transformation.

There has been a lot of effort applied by many authors to investigate the consequences of change and propose a systematic description of challenges which require actions to successfully transform and adapt all of the affected areas of human activity to the new reality.

Digital fabrication, the term used by Neil Gershenfeld in his article "How to Make Almost Anything" [1], appeared as part of the 4IR. "Digital" would not be possible without computers which appeared more than 60 years ago but according to another pioneering engineer, who was in the roots of this technical introduction, Alan Kay: "Except for science almost nobody in the world uses computers for what they are actually good for" [2].

Another summarizing thought comes from the PRIA's website [3]: "Just as 'Mass Production' was the paradigm of the industry of the 20th Century, 'Mass Customization' is that of the 21 Century".

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Fabrication today, just like computers years ago, becomes personal. So if we suppose the production-education interaction exists [4] - it is only the matter of time when education also becomes personal, repeating that path of production.

Personal also means more capable and effective and these abilities can't be achieved without technological literacies coming to the scene for everyone on a life-long basis.

Educational robotics while having deep roots in history along with computing and control, today has all the chances to contribute to this complex collective effort as it naturally incorporates all the benefits of technological advancement.

Time also dictates teachers to be more effective. This pushes common management mechanisms in educational systems to increase the number of students per teacher (in a group). This way teachers can not maintain the same level of knowledge and skills in the alumni without proper technological support. And since the given context described below is of creative nature the question on how to organize such renewed educational process is not idle, simple or solely of academical nature.

At this time the authors address the solution as most of researchers in the field - with programming and software, the easiest part to automate and improve.

Education being inclusive also raises questions of individual tracking of progress for students while accepting the more diverse audience. For example girls are not common for the presented educational robotics context and making the learning process more attractive for them means better understanding of their way of doing things which is obviously different from what is being done in class today (consider the numbers in Sect. 3.3).

It is also worth to mention that most teachers today mainly regard technologies as means to increase comfort, amplify the existing approaches [5].

2 Educational Robotics Overview, Questions and Critics

Today there are many review papers on educational robotics. Some of those concentrate more on critics [6], some try to provoke discussion in order to shift paradigms and bring new technologies into the classroom [7], some try to classify approaches and methods [8,9], some tend to bring attention to the youngest students' specifics (pre-K, K-5, [10]), some are recent (K-12, [11]).

Educational robotics is not a new research area. Some of the reviewers date its roots back to 1960-s when constructionism was founded by the work of Paper (by introducing the programming language to control a turtle robot) [8]. Others emphasize the work of Piaget on constructivism (1974) in connection to the Papert's constructionism (1980) [7]. Finally there are those who see significance in late additions to constructivism by Ginsburg (1988) and Bruner (1997) [11].

No matter which point in time to choose it is evident that educational robotics is being formed for years now but still is far from common understanding of its contents and methods.

In the newest history the topic gained its "second breath" at around 2010 when the Robotics in Education (RiE) conference started. And as long as there is enough research effort and interest the conference successfully continues today.

At the time when RiE began in 2010 a review by Bredenfeld et al. [6] identified only 6 conferences and workshops with "more or less strong focus on educational robotics". But at the same time reported that all of those were limited in terms of scale ("one institution/event related", "the results are presented on negligible number of students"). Research at that time didn't share common methodology and presented results were of trivial nature. The paper proposed better networking of existing workshops and competitions for better serious output and long-term evaluation.

Recent reviews show the usage of the common systematic review process [10,11], though there is still no common classification approach to all of the research happening.

Educational robotics is a complex discipline. Most of the criticism from the reviews originates from these grounds as it is easy for the researchers to overestimate one part of it, underestimating or even neglecting the other. When properly addressed educational robotics could give synergistic effects with existing curricular [8].

While different researchers put different meanings in "educational robotics" it is important to note the two completely different approaches which tend to be mixed by researchers and reviewers. The first proposes to build robots and the second - to use them as the means for other subjects. The first concentrates on the engineering perspective and the second - on the integration means.

Both approaches require technological literacy and this way they intersect at the beginner level. But later activities need to be distinguished by the aims of the educational process. It is of course not obligatory for everyone to know how to make one's own robot, but at least using it should not be a problem for a 21st century citizen.

That is the reason why programming is very important and most research concentrates on using robots (ex. using a pre-build robotic construction kit and/or common pre-selected parts) rather than building them from scratch.

3 Case Study, Statistics and State of the Art

The authors work on educational robotics' aspects with and for young scholars (K-12, university) for many years. The previous efforts and approaches were discussed in a number of articles: [12–21].

A case study is presented below to show the outcomes and trends of such work to form the basis for better understanding of the current situation in education (specifically in the supplementary education for children of the K-12 age group). The authors try to relate some of the aspects of these results of their own to those known worldwide.

3.1 Case Context

The case relates to the Russia's well-know educational complex "Vorobyovy Gory" (Moscow state budget vocational and educational institution, VG for short) in which one of the authors work with children in an educational robotics lab.

VG started as an after-school hobby center for children in 1936. It quickly gained popularity among the youth and in 1937 it welcomed around 3500 students. While technical education was a priority at the time the groups were not limited to engineering, they included sciences like history or geography, creative workshops and design classes on writing, painting, dancing, singing and so on. More on the history of this unique educational organization in [22].

Such emphasis on the diversity of ways to support child's development was only amplified with years and now VG is the largest institution of supplementary education in Russia [23] with more than 17000 supplementary students in the 2018/2019 educational year [24].

Supplementary education as discussed in [25], is the main, biggest and successful effort for VG, but there are 16 other educational institutions as well united under the common "roof" including childcare centers, schools and a technology college. Such diversity and scale makes it easier to progress on educational challenges and work out a unique way of solving problems which are difficult to address in other less diverse and interconnected educational organizations.

Here, opportunities have been created for educational research and creative development of children and youth in the fields of science and culture, technical, artistic and social creativity, ecology, ethnography, physical education and sports. Total number of students in all sectors exceeds 20700 in the 2018/2019 educational year [24].

VG's traditions and approaches to education reflect more than 80 years of teaching expertise shared among the staff.

Given the above description students coming to VG have a very broad range of possibilities within technical and other areas of interest. This fact characterizes the educational environment to be very competitive in terms of quality of the provided programs. It is also important that the supplementary education classes are not obligatory - the students are free to leave a program any time if they are not interested.

The process of selecting a program for future students and their parents starts late August each year and continues for 2–3 weeks. At this time the VG's facilities and workshops are open to everyone coming for a visit from the city and suburbs. Programs are presented to visitors by teachers in different forms to ignite interest.

The period resembles in its nature and spirit the educational robotics outreach program by "Automation and Control Institute" at TU Wien [26]. Similar to the description by Jäggle, Lammer, Hieber and Vincze within the technical field context in [27], the work of teachers during the "open-door" period is aimed at promoting the literacies of the 21st century and further practice of those (including also non-technically oriented in the vast VG educational ecosystem). Another example: Lepuschitz, Koppensteiner and Merdan in [28] share the concern of lacking interest in the STEM fields and their "multiple-entry" approach.

A typical program is meant to be taken for 1 school year. Unlike obligatory school studies, supplementary activities have their specifics in a long run as students can stop attending classes at all or miss the significant number of them, showing an unstable attendance pattern due to various reasons (illness, school load and stress, lack of interest to name a few). This factor leads to special care in developing and carrying out a successful supplementary education program.

The authors are interested in those trends children are showing repeatedly year after year and the reasons behind them (those that relate to the educational process). Some of the findings related to technical studies are presented below.

3.2 Educational Robotics Lab and Its Processes

The technical focus (3513 students) is one of the VG's supplementary education focuses along with science (2331), sports and fitness (4361), arts (5177), tourist and regional studies (195), social and pedagogical studies (2142). Educational programs are free for majority of the students (13949), which is also true for technical/engineering education (3282) [24].

The educational robotics lab is part of the Center for Technical Education. In its present state the lab is active since 2014. The lab develops progressive educational programs on engineering among K-12 students (children from 6 to 18 years old).

Original educational programs developed by the lab's teachers are divided in 3 difficulty levels. All of the programs are united by the idea of teaching how to build a mobile robot from scratch in digital fabrication environment. Upon finishing the design students participate in a friendly competition [29].

Such aim puts a firm deadline for the learning and teaching action. Tasks of the competition change each year, this results in the content's renewal, which allows many years of active study for the interested students.

While working with different age groups several teachers try to maintain the same educational spirit and continuity of the learning process for the students moving from group to group. Some of the programs could be named "main" (focusing on robot building and competition), others - "supporting", giving details on robotic aspects and parts (programming and electronic development being the bright examples).

While some of the youngest students (K-2, 6–8 years old) are not able to start building robots right away due to their age they are invited to introductory "supporting" programs which help them prepare for "main" programs and adapt easier later on. They make use of construction kits and specially prepared device parts to explain the basics of how robots operate. Such programs, as well as most of the "supporting" type, are limited to one year and are not meant to be taken several times as their contents is permanent.

Figure 1 shows the educational robotics lab's general equipment teachers and students use in their daily work.

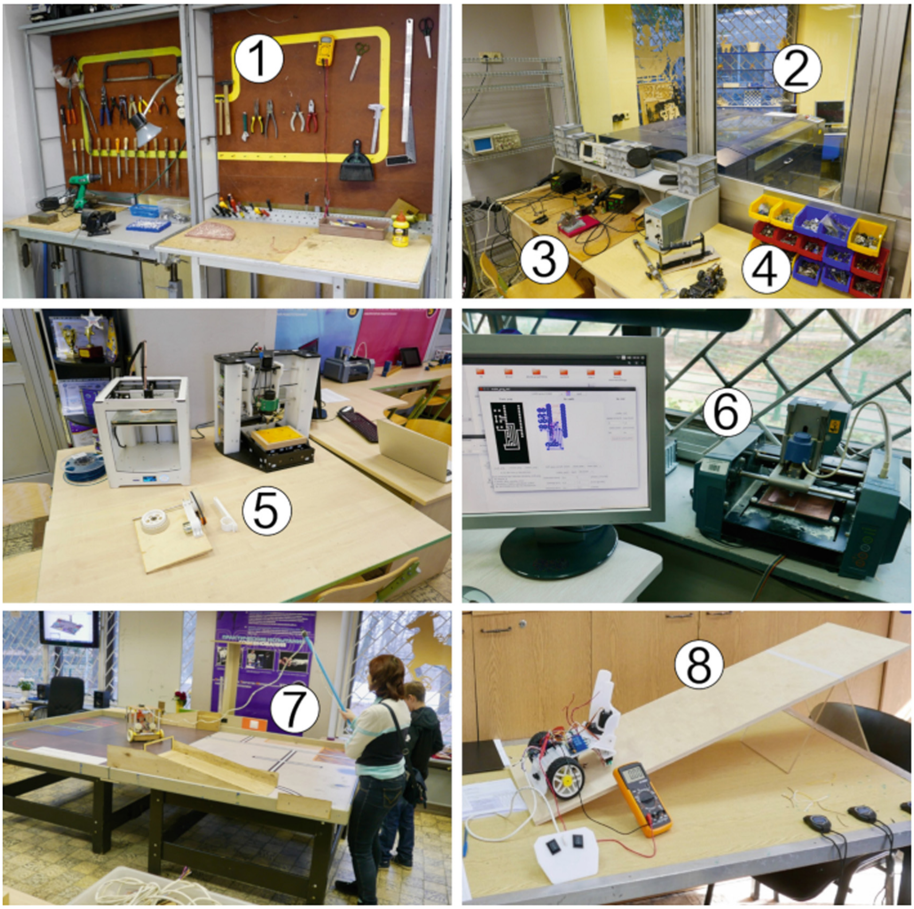

Fig. 1. Educational robotics lab's equipment: 1 - Hand tools, 2 - Laser cutter machine, 3 - Soldering and measuring equipment, 4 - Mechanical assembly parts, 5 - 3D-printers, 6 - Precise milling machine, 7 - Robotic competition table as an integrated test bench for robotic designs, 8 - Additional educational equipment for experimental tests of robotic operation aspects and parts (connects theory to practice).

Figure 2 shows the educational robotics lab's general processes all of the students take part in. Different aspects of them were previously described in [13,16,17].

Fig. 2. Educational robotics lab's student oriented processes: 1 - Interact with previously developed robots, 2 - Study basics to better connect theory to practice, 3 - Design and fabricate task solutions, 4 - Assemble manufactured parts, 5 - Measure to reveal errors and connect to theoretical description, 6 - Program and operate a robotic device, 7 - Evolution of students' results from left to right.

Debugging is a naturally implemented element of the educational process on all stages of development. While simple at first it progresses to more complicated designs and real-world applications.

Successful mastery of the main engineering competences in a competition usually takes several years to reach [13]. After which those students who decide to stay actively participate in real engineering projects. Some of such examples were reported previously by the authors in [30]. Similar work was reported by Jäggle, Merdan, Koppensteiner, Lepuschitz, Vincze et al. in [31] and [32].

3.3 Statistics and Trends

This section presents findings reflecting students' activity and behavioral trends for the previously described context in the educational robotics lab.

The method used is focused on statistics of free will attendance of students of different age. Data was gathered from all of the lab's teachers. They share same approach to education mainly resulting in a mobile robot built by the students (few preparatory classes for kindergarten and elementary school kids included do not result in a robot, those are general literacy studies) but concentrate on different aspects like age and technological focus of their classes (depends greatly on the previous teacher's experience in mechanics, electronics and programming).

The formula used for the weighted mean: $\overline{x} = \sum_{i=1}^{n} w_i \cdot x_i$. The weighted mean is used to calculate the overall resulting statistics ($\overline{x}$) from different sources (x_i) to reflect the sizes of the corresponding student groups (w_i).

The aspects under investigation are: distribution of age groups, distribution of gender groups, number of students who never show up but registered, number of students completely leaving classes after attending only several times (measured after half of the study period), number of students continuing after a year.

Figure 3 presents joint statistics for the educational robotics lab in 2019/2020 school year. The data represents the unique students. Each student can possibly

	T1: K	T1: 1-4	T2: 5-11	T3: 5-11	Grand total	Total: 1-11	Total: 5-11
Unique registered students	30	147	186	60	**423**	**393**	**246**
Percentage of grand total	7,1 %	34,8 %	44,0 %	14,2 %			
					Weighted mean	Weighted mean	Weighted mean
Boys (from the number of registered)	86,7 %	95,2 %	88,2 %	95,0 %	**91,5 %**	**91,9 %**	**89,8 %**
Girls (from the number of registered)	13,3 %	4,8 %	11,8 %	5,0 %	**8,5 %**	**8,1 %**	**10,2 %**
Dropped out students (total)	0,0 %	19,7 %	41,4 %	23,3 %	**28,4 %**	**30,5 %**	**37,0 %**
Dropped out boys	0,0 %	19,3 %	40,2 %	21,1 %	**27,4 %**	**29,5 %**	**35,6 %**
Dropped out girls	0,0 %	28,6 %	50,0 %	66,7 %	**41,4 %**	**44,5 %**	**54,1 %**
From dropped out boys, seen in class	-	0,0 %	33,3 %	50,0 %		**23,4 %**	**37,4 %**
From dropped out girls, seen in class	-	0,0 %	27,3 %	100,0 %		**28,2 %**	**45,0 %**
Students continuing from last year	-	*61,0 %*	*50,0 %*	52,9 %		**54,6 %**	**50,7 %**
Students continuing from 2 years ago	-	-	-	23,3 %			

Fig. 3. Joint statistics of the educational robotics lab in 2019/2020 school year. Note: the data in italic font was calculated from already pre-processed data from the corresponding teachers, not from raw data of the student attendance.

attend several educational programs in the lab, which brings more opportunities to track his or her behavior, but this aspect was not taken into consideration in this research. T1, T2 and T3 stand for different teachers.

The data presented shows that in all age groups girls are very poorly presented. While teachers do not give boys preference girls choose not to come into such technical field on their own. For many it happens due to the parents' decision as many view robotics and engineering in general as a "boys' subject". Given the free choice during the "open-door" registration period some of the parents tend to discourage their children though they are showing interest in what is happening in the robotic demo workshop.

The other point would be the drop out rate which is rather high. And it tends to be even higher with age increase. Here girls also show tendency to quit much more often. This could be due to a lack of females in the group or the educational processes tuned to be boy-oriented. This tendency can't be changed without special care and preparation of study sessions.

The numbers of returning students who are likely to have deep engineering interest are also very stable (also see Fig. 4 on this). Smaller children of K-4 classes show tremendous rate reaching 80% per competition oriented groups (which are possible to take more than 1 time). Though the number presented in Fig. 3 for 1–4 classes was adapted to total number of kids of that age in the lab (some of them choose to take 1-year only programs of general technological literacy nature).

Figure 4 shows year to year dynamics of students' attendance to classes in the educational robotics lab for one of its teachers. The period includes 4 years, during which the teachers' group remained same for the lab.

	2016/2017	2017/2018	2018/2019	2019/2020	Mean	Total
Unique registered students	55	52	52	60	**55**	**219**
Mean difference	0	-3	-3	5		
						Weighted mean
Boys (from the number of registered)	92,7 %	96,2 %	94,2 %	95,0 %	94,5 %	**94,5 %**
Girls (from the number of registered)	7,3 %	3,8 %	5,8 %	5,0 %	5,5 %	**5,5 %**
Dropped out students (total)	30,9 %	42,3 %	34,6 %	23,3 %	32,8 %	**32,4 %**
Dropped out boys	29,4 %	40,0 %	32,7 %	21,1 %	30,8 %	**30,4 %**
Dropped out girls	50,0 %	100,0 %	66,7 %	66,7 %	70,8 %	**70,4 %**
From dropped out boys, seen in class	73,3 %	30,0 %	56,3 %	50,0 %	52,4 %	**52,6 %**
From dropped out girls, seen in class	50,0 %	100,0 %	0,0 %	100,0 %	62,5 %	**63,7 %**
Students continuing from last year	-	68,4 %	53,3 %	52,9 %	58,2 %	**58,0 %**
Students continuing from 2 years ago	-	-	-	23,3 %		

Fig. 4. Statistics on the year to year dynamics in the educational robotics lab for one teacher.

The numbers presented in Fig. 4 prove the previously discussed facts for Fig. 3 to be actual from year to year. Despite the limited number of students the average tendency is quite the same.

It is also worth noting again that the representation was gathered in a highly competitive educational environment where children could choose potentially any educational area interesting to them. Added the ability to leave at any time gives a rather truthful picture of children's educational potential and capacity for quite specific engineering knowledge as well as the current view on such in the society.

Technical area attracted 19.83% (3513) of all supplementary students in VG (17719) in 2019/2020 educational year [24].

3.4 Educational Robotics Components, Programming

Educational robotics is highly interconnected with programming. Programming is used outside of the presented supplementary education constructivist approach at ordinary schools. It is therefore a very important indicator of how children's technological literacies form within the common educational system.

The method for this research was based on gathering answers to a number of questions among the students of the educational robotics lab. The questionnaire was randomly given to the students constantly continuing their studies in the middle of the educational year. The results were divided into several age groups of respondents, the total statistics for all is also presented.

A total of number of 59 students gave their answers. 34 of them having programming lessons at their schools. Age groups include: 30 students of 4–6 classes, 19 students of 7–8 classes, 10 students of 9–11 classes. Among all of the respondents only 1 girl (8 class, has programming) was present.

The questionnaire included several simple "yes/no/not sure" questions, several open questions as well as several simple questions on students' status at school.

Figure 5 shows the results of the questionnaire on "programming" education aspects among public school students actively participating in the supplementary technological/engineering studies at the educational robotics lab.

Questions of the questionnaire: Q1 - "Do you think programming lessons are useful?", Q2 - "Do you want to become a programmer?", Q3 - "Do you have programming at school?", Q4 - "Do you like programming lessons?", Q5 - "Do you find programming lessons easy to understand?", Q6 - "Which programming language do you study or studied at school?". Additional questions: "What's your class in school?", "If you have programming at school, how many hours a week do you study it?", "If you were a programmer what would you do?".

As already mentioned the questions answered by all 59 students included: Q1, Q2, Q3 and additional questions. The other questions were extra for the group of different age having programming (34 students): Q4, Q5, Q6.

Question 6 being open returned a number of different responses, which were divided by type of the programming language named. The 3 types include: type 1 - general computer literacy (how computer works and how to do simple office tasks with it), type 2 - visual programming, type 3 - textual programming. Quite a few of the respondents gave answers within different types (combining type 2 and type 3).

The programming language mentioned for Q6 type 2 is "Scratch", for Q6 type 3 - "Kumir/Pascal/C/C++/Python/HTML".

The questionnaire's results show that though most of the respondents think programming is useful, at the same time a rather constant number of children in any age group doesn't want to make programming their profession. This is quite an important insight taken into account that those answering are already interested in technical sciences as was described above. It is important to remember that robotics being a complex discipline attracts different people differently. One of the reasons for such picture could be that the main track for many of the given programs at the educational robotics lab is mechanics. Most students are introduced into robotics through it and they tend to practice it more as it is easier to see the immediate result.

For those who have the programming lessons at school there is an interesting curve of data for Q4. As most children are introduced to programming at the 7–8 grades, this age group shows the biggest uncertainty towards such lessons. Though younger and older are more positive. This could be because the younger still didn't have a chance to experience the lessons, and the older already know

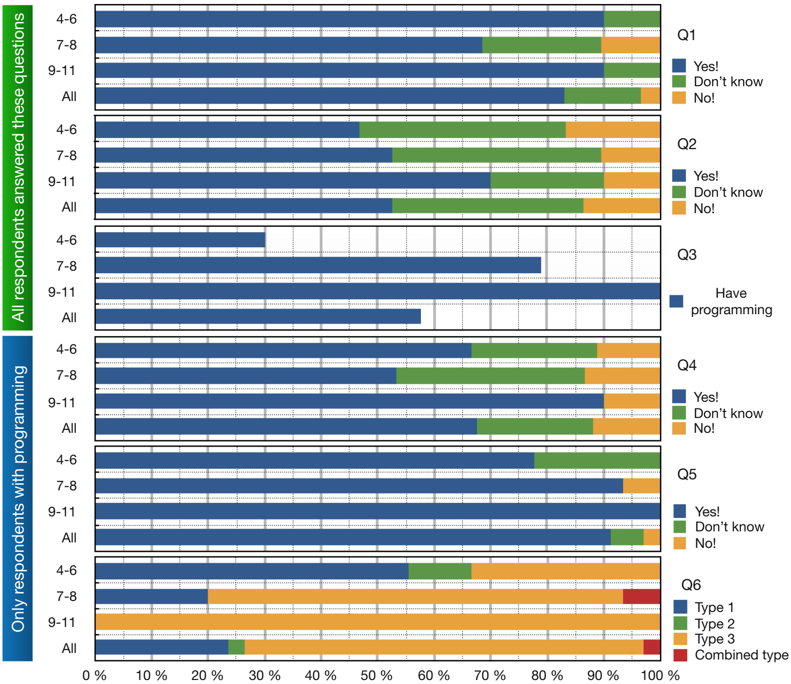

Fig. 5. Results of the questionnaire on programming education aspects among public school students receiving supplementary technical education.

enough to be confident in themselves. The insight here is that children when exposed to new knowledge (which is true for most of the educational robotics supplementary education) have natural doubt in how they do. The number of those who "don't know" could correlate to those leaving the supplementary studies as discussed earlier (they can not leave school lessons in contrast). And it is also the capacity and place to bring more children to "continued" state.

Despite the fact that programming is one of the technical subjects and not everyone is interested enough to be put in the depth of it most of schools teach textual programming languages which are much harder to master without prior experience in visual programming for example. Here it is worth to mention that there are students of different backgrounds in the lab, some are learning in specialized technically or scientifically oriented schools, but as there is no special selection the given result is universally not biased by this as the majority of the students go to common schools.

4 Conclusion

The paper presents an overview on the state of educational robotics based on the creative project-oriented approach within digital fabrication educational environment. The authors tried to reveal and prove some of the common challenges for teachers and students which form "the face" of today's educational robotics.

While having potential technological advancement teachers still need an effective tool to manage ever growing groups of children (more and more often exceeding 20 people per group for one teacher, pushed in this direction mainly for economical reasons). Educational robotics could become a natural source for such technological adaptation as most of the researchers in the field have engineering background to work on better semi-automated group management tools for teachers.

With such assistive technology in class it could become possible to track individual progress of a student and increase the statistics of non-leavers or interested children. As according to the insight of the presented questionnaire there is always a group of unsure students deciding to leave if they do not reach a certain level of understanding in the chosen field or class.

The girls-boys ratio challenge (which is very low for girls coming to the supplementary education technological classes) is impossible to beat without special actions. Partly it is on the side of parents who tend to view robotics as "boy-oriented", partly it is due to the difference in how girls tend to work and study, and partly it could be that in the presence of lack of females girls do not find their place in such a group and leave.

In the end it is important to mention that educational robotics is still emerging. After all the years of research there is still much uncertainty in how to adapt educational robotics to the existing school system. There are no doubts of the potential in it but same critics exposed in 2010 at educational robotics could still be addressed to novel research being produced. And while this paper contributes to the engineering direction of the educational robotics there is still a huge part of it which could make better use of a robot as a tool in class.

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References

1. Gershenfeld, N.: How to Make Almost Anything: The Digital Fabrication Revolution (2012). https://www.foreignaffairs.com/articles/2012-09-27/how-make-almost-anything. Accessed 9 Mar 2020
2. Kay, A.: An Interview with Computing Pioneer Alan Kay (2013). https://youtu.be/tXoSK4tLxK8. Accessed 9 Mar 2020
3. Practical Robotics Institute Austria. https://pria.at. Accessed 9 Mar 2020
4. Robinson, K.: Changing Education Paradigms (2010). https://youtu.be/zDZFcDGpL4U. Accessed 9 Mar 2020
5. New Vision for Education: Fostering Social and Emotional Learning through Technology (2016). http://www3.weforum.org/docs/WEF_New_Vision_for_Education.pdf. Accessed 9 Mar 2020
6. Bredenfeld, A., Hofmann, A., Steinbauer, G.: Robotics in education initiatives in Europe - status, shortcomings and open questions. In: Proceedings of SIMPAR 2010 Workshops, pp. 568–574 (2010). ISBN 978-3-00-032863-3
7. Alimisis, D.: Educational robotics: open questions and new challenges. Themes Sci. Technol. Educ. **6**(1), 63–71 (2013)
8. Altin, H., Pedaste, M.: Learning approaches to applying robotics in science education. J. Balt. Sci. Educ. **12**(3), 365–377 (2013)
9. Mubin, O., et al.: A review of the applicability of robots in education. J. Technol. Educ. Learn. **1**, 13 (2013)
10. Jung, S.E., Won, E.: Systematic review of research trends in robotics education for young children. Sustainability **10**, 905 (2018). https://doi.org/10.3390/su10040905
11. Anwar, S., et al.: A systematic review of studies on educational robotics. J. Pre-Coll. Eng. Educ. Res. **9**(2), 19–42 (2019)
12. Shalashova, M.M., Shevchenko, N.I., Mahotin, D.A.: Development of functional literacy of school and university students. Espacio **39**(30), 13 (2018). Cited 2 times. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85050717119&partnerID=40&md5=916960e68eca562d3366c40861703f36
13. Yudin, A., Salmina, M., Sukhotskiy, V., Dessimoz, J.-D.: Mechatronics practice in education step by step, workshop on mobile robotics. In: 47th International Symposium on Robotics, ISR 2016, pp. 590–597 (2016)
14. Sukhotskiy, D., Yudin, A.: Startup robotics course for elementary school. Communications in Computer and Information Science, vol. 156, pp. 141–148 (2011). https://doi.org/10.1007/978-3-642-27272-1_13
15. Vlasov, A., Yudin, A.: Distributed control system in mobile robot application: general approach, realization and usage. Communications in Computer and Information Science, vol. 156, pp. 180–192 (2011). https://doi.org/10.1007/978-3-642-27272-1_16
16. Yudin, A., Vlasov, A., et al.: Challenging intensive project-based education: short-term class on mobile robotics with mechatronic elements. Advances in Intelligent Systems and Computing, vol. 829, pp. 79–84 (2019). https://doi.org/10.1007/978-3-319-97085-1_8

17. Yudin, A., Sukhotskiy, D., Salmina, M.: Practical mechatronics: training for mobile robot competition. In: 6th International Conference on Robotics in Education, RiE 2015, pp. 94–99 (2016). ISBN 978-2-9700629-5-0
18. Shakhnov, V., Vlasov, A., Zinchenko, L., Rezchikova, E.: Visual learning environment in electronic engineering education. In: International Conference on Interactive Collaborative Learning, ICL 2013, pp. 379–388 (2013)
19. Vlasov, A., Echeistov, V., et al.: An information system of predictive maintenance analytical support of industrial equipment. J. Appl. Eng. Sci. **16**(4), 515–522 (2018). https://doi.org/10.5937/jaes16-18405
20. Vlasov, A.I., Juravleva, L.V., Shakhnov, V.A.: Visual environment of cognitive graphics for end-to-end engineering project-based education. J. Appl. Eng. Sci. **17**(1), 99–106 (2019). https://doi.org/10.5937/jaes17-20262
21. Yudin, A., Vlasov, A., Salmina, M., Shalashova, M.: Evolution of educational robotics in supplementary education of children. Advances in Intelligent Systems and Computing, vol. 1023, pp. 336–343 (2020). https://doi.org/10.1007/978-3-030-26945-6_30
22. Eternal youth: pages of history from the Pioneer Palace (2016). https://www.mos.ru/en/news/item/18650073/. Accessed 9 Mar 2020
23. VG website. https://vg.mskobr.ru. Accessed 9 Mar 2020
24. Public performance report for educational complex "Vorobyovy Gory" (2019). https://vg.mskobr.ru//files/public_report_2019_new_17_08_19_razvorot.pdf. Accessed 9 Mar 2020
25. Bridglall, B., Gordon, E.: The idea of supplementary education. Pedagogical inquiry and praxis (2002)
26. Outreach with educational robotics program, Automation and Control Institute, TU Wien. https://www.acin.tuwien.ac.at/en/vision-for-robotics/outreach-with-educational-robotics/. Accessed 9 Mar 2020
27. Jäggle, G., Lammer, L., Hieber, H., Vincze, M.: Technological literacy through outreach with educational robotics. Advances in Intelligent Systems and Computing, vol. 1023, pp. 114–125 (2020). https://doi.org/10.1007/978-3-030-26945-6_11
28. Lepuschitz, W., Koppensteiner, G., Merdan, M.: Offering multiple entry-points into STEM for young people. Advances in Intelligent Systems and Computing, vol. 457, pp. 41–52 (2017). https://doi.org/10.1007/978-3-319-42975-5_4
29. Eurobot: International Students Robotic Contest. https://www.eurobot.org. Accessed 9 Mar 2020
30. Yudin, A., Kolesnikov, M., et al.: Project oriented approach in educational robotics: from robotic competition to practical appliance. Advances in Intelligent Systems and Computing, vol. 457, pp. 83–94 (2017). https://doi.org/10.1007/978-3-319-42975-5_8
31. Jäggle, G., Merdan, M., et al.: Project-based learning focused on cross-generational challenges. Advances in Intelligent Systems and Computing, vol. 1023, pp. 145–155 (2020). https://doi.org/10.1007/978-3-030-26945-6_14
32. Jäggle, G., Vincze, M., et al.: iBridge - participative cross-generational approach with educational robotics. Advances in Intelligent Systems and Computing, vol. 829, pp. 263–274 (2019). https://doi.org/10.1007/978-3-319-97085-1_26
33. Lammer, L., Vincze, M., Kandlhofer, M., Steinbauer, G.: The Educational Robotics Landscape Exploring Common Ground and Contact Points. Advances in Intelligent Systems and Computing, vol. 457, pp. 105–111 (2017). https://doi.org/10.1007/978-3-319-42975-5_10

Towards a Conceptual and Methodological Framework for the Evaluation of Educational Robotics Activities

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Abstract. In schools and universities, there is currently a lack of interest in the STEM subjects (mathematics, informatics, natural sciences and technology) and well-trained teachers for these subjects in Austria and Slovakia. Particularly women are underrepresented in the STEM fields, which further leads to bottlenecks in the job market, although there is an increasing demand for STEM staff in both countries. Educational Robotics has proven to be a valuable tool for practical learning, not only for robotics itself but for STEM topics in general. The project RoboCoop encourages and engages 1800 pupils from secondary schools in Austria and Slovakia to serve as a positive example of more extensive use of educational robotics at the national level in the two countries. The robotic workshops introduce the world of robots and foster creativity and collaboration skills. A comprehensive quantitative and qualitative evaluation of all workshop activities should allow the identification of best practice activities for teachers in order to ensure systematic and long-term implementation of the robotic activities. The corresponding evaluation tool is introduced in this paper and results with 352 secondary school pupils are presented.

Keywords: Educational robotics · C4STEM-Concept · Interest in STEM · Methodology · Framework

1 Introduction

The European Commission reported that employment in STEM occupations in the EU would increase by 12.1% from 2015 to 2025 [1] while at the same time the number of graduates in the STEM education system would decrease. In this context, there is currently a lack of interest in STEM subjects at schools and universities even though there is an increasing demand for STEM staff in Austria. However, there are several strategies to foster the interest in STEM by pupils of secondary schools [2]. Educational Robotics

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has proven to be a valuable tool for practical learning, not only of robotics but also of STEM topics in general [3, 4]. But it requires pedagogical strategy, didactical design and the inclusion of four factors, which foster the interest in STEM. Consequently, all robotics activities in this paper pursue a concept (C) for (4) increasing the interest in STEM. C4STEM relates to a common conceptual framework with an evaluation tool [5] and activity plan [6]. The common pedagogical strategy is based on the constructionism approach [7] and the didactical design is based on factors (C4STEM-Factors) for sustainably increasing the interest in STEM. One factor is to increase the pupils' self-efficacy [8] through practical tasks and hands-on-activities [9]. The second factor is to establish a good relationship between tutors and pupils that will foster learning and will give pupils a feeling of success. The third factor is to foster the motivation by students during the workshop therefore is also advisable to implement constructionist activities in shared spaces to allow the pupils to express their results and ideas in and outside of the classroom [10]. Finally, the fourth factor is to have the young learners participating in out-of-school activities to increase the interest in STEM. [11] C4STEM allows to prove the benefits of robotic activities in various age groups, to develop robotic activities for all school types and to identify best practice examples for teachers and other stakeholders. In this paper, we describe three different educational robotics workshop activities in Sect. 2 and the appropriate evaluation tool for C4STEM. It measures the difference of interest in STEM before and after the workshops, the impact of the relationship between tutors and pupils, the self-efficacy, and the interest in a career in a STEM field in the future. Results with 352 students are presented in Sects. 3 and 4. The quality of the evaluation tool is proven with the Cronbach Alpha Value with a result of $\alpha > 0.8$ being good and an $\alpha > 0.7$ being still acceptable [12].

2 Educational Robotics Workshops

All Educational Robotics Workshops had the same goal of fostering the interest in STEM. However, all workshops were differently designed varying in activities, program language and robotic kits. Table 1 gives an overview of the different workshops, robotic kits, program language, number of pupils, the age group and gender mix of the pupils. The different robotic kits are depicted in Fig. 1.

Table 1. Workshop information

Workshop	Robotic kits	Program language	Pupils	Age group		Gender mix	
			N	Mean	SD	Mean	SD
A	Hedgehog	Python, Blockly	163	13,09	1,33	1,52	0,5
B	BBC Micro Bit	Python, Blockly	119	14,74	2,08	1,84	0,37
C	Thymio	VPL, Blockly	70	13,31	1,1	1,74	0,44

Fig. 1. Robotic Kits (Hedgehog, BBC Micro Bit, Thymio)

2.1 Workshop A

This workshop was designed for children who have never encountered robotics and/or programming. The required prior knowledge comprised basic reading skills and understanding of the necessary numeric values; basic knowledge of working with computers was advantageous. The workshop was suitable for children aged 8–11 years. It was used in schools in a low socioeconomic area and despite of being carried out in Austria, a large percentage of the pupils had German only as their second language. The aim of the workshop was to familiarize the pupils with the concepts of design thinking as well as robotics and programming. It consisted of two main sessions held by the workshop tutors in an open space for testing and building the robots, with notebooks or computers, and took place indoors. The first session focused on giving the pupils an introduction to design thinking and considered what type of robot they could build. The second session explained the basics of programming with the goal of moving the robot. During the activities, the pupils were expected to observe, communicate, build a robot, program a robot, discuss their ideas with a classmate and present their work in front of their peers. The workshop was divided into two phases. The following slogan for the learning process was used in the first phase: 'I can create something in a small amount of time'. In the second phase, the goal was that the pupils would try out their code and adapt it to the task. The workshop should develop collaborative skills, as pupils take roles within groups and communicate with other groups to exchange ideas and tips as well as advice, and foster presentation and argumentation skills. The pupils' learning outcomes were wither a visual or a python program for the Hedgehog Educational Robotics Controller.

2.2 Workshop B

This workshop was designed with the main goal to develop activities, which increase the interest in STEM for all pupils during learning with educational robotics tools like BBC Micro:Bit and :MOVE minirobot. The programming and coding activities happened with Python and Makecode Blockly following a guideline from Makecode. The first part needed 45 min during which the pupils got to know the BBC Micro:Bit as well as the basic commands and train their skills for creating code. The pupils got the exercises according to their individual level step by step and worked in pairs. At the end of the setting, they discussed their results (approx. 5 min). The second part needed also 45 min and involved content about the motion sensor of the BBC Micro:Bit. Again, the pupils solved the exercises in pairs and at the end discussed in 5 min their results. In the third part of further 45 min, the pupils used the BBC Micro:Bit in motion and the tilt sensor Micro. The pupils had to solve an everyday problem by developing a useful tool for festivals, events and discos, which was a solution for counting the number of visitors at events. Now, the pupils worked either individually or in pairs. At the end of the setting, the pupils discussed their results (approx. 5 min). The last setting employed the BBC Micro:Bit MicroPython, which is a version of Python that runs on the BBC micro:bit. This last part required 180 min. Python is a very popular and versatile programming language recommended for teaching the basics of programming and so the aim of this part was to introduce basic commands of this language. The traditional way to start programming in a new programming language is to teach your computer to say "Hello world!" (Fig. 2)

Fig. 2. Pictures from Workshop B

2.3 Workshop C

Workshop C lasted 4 h and was led by tutors, which acted as role-models to increase the interest in STEM careers. The workshop was divided into three parts including two breaks of each 15 min. Every part had different activity blocks and at the end of all parts the pupils presented and shared their result with the whole class during the activity block "Discussion and presentations".

The first part started with the activity block "Introduction" of the tutors, which was based on a role-model introduction guideline. The next activity block was the "Lecture about robots" [10] concerned with a robot definition, the components of a robot, different applications of robots and linking robotic technology with real-life applications. After that, the next activity block, which was called "Explore a robot" [10], was a hands-on activity for discovering the robot and its different programs. The pupils used their technology literacy to program and understand robotics and solved the problems in teams (collaboration) applying different individual ways (creativity) as researchers. Thus, the pupils developed their own goals based on their different interests and real-life problems. The next task was to link the different colors of robots with different programs.

During the second part, the pupils were able to solve problems using their own individual creative way. E.g. the robot had to drive through a maze or the robot had to draw a cycle (see Fig. 3).

The last part was to learn the program language VPL (Visual Programming Learning) and to control the robot in different settings.

Fig. 3. Pictures from Workshop C

3 Evaluation Design

The evaluation design involves a mixed method. The tutors observe the activities and record their observations on a dedicated sheet. Before and after the workshops, the pupils fill out PRE- and POST-Questionnaires and tutors conduct interviews with focus groups [5]. The data analysis is divided into two types: quantitative and qualitative data. The quantitative data from the questionnaires will be analyzed with the software SPSS 25. The questionnaires at the beginning of the workshop provide information about gender, age, the interest in STEM, and prior experience with educational robotics before the workshops. The questionnaires after the workshop provide information about the positive influence on the interest in a STEM career, provide role models, increase of the pupils' self-efficacy and motivation to work with robots during the workshops. All data will be analyzed based on the approach of design-based research [13] and mixed-method [14]. This evaluation process will give results according to the following research questions:

RQ1: Which interests have pupils regarding STEM before the robotic workshops?
RQ2: How do robotic workshops influence the interest in STEM?
RQ3: How do robotic workshops influence decisions towards STEM careers?
RQ4: How do robotic workshops foster girls regarding STEM careers?

3.1 Quantitative Evaluation Tool

Every workshop started with a PRE-Questionnaire before the workshops to evaluate the meta-data like gender mix, age, school type and migration background. The attitude and experience are measured with further five indicators like the knowledge about robots and programming, the interest in STEM, the interest in collaboration, the interest to study in the STEM field and the self-efficacy (see Table 2).

At the end of the workshop, all participants got a POST-Questionnaire to evaluate the interest in STEM, the self-efficacy, influence of the tutor as role-model, the interest in the robotic activities during the workshop, the interest to study STEM in the future, the personal understanding about the importance of STEM field after the workshop, the interest to learn with robots in the future and stars as overall rating (see Table 3).

The different indexes help to answer the research questions and to find the best practice example for teachers and other stakeholders. They are analyzed and compared in Sect. 4.

Table 2. PRE-Index-Description

Index	Description	No. Items
PRE-STEM-Index	The interest in STEM before the workshop	5
PRE-Self-efficacy	The self-efficacy before the workshop	3

Table 3. POST-Index-Description

Index	Description	No. Items
POST-STEM-Index	The interest in STEM after the workshop	5
POST-Self-Efficacy	The self-efficacy after the workshop	3
POST-Role-Model	The influence of tutors as role-models during the workshop	3
POST-Robot-Activities	The interest and fun of working with robots during the workshop	3
POST-Study-STEM	About more interested in studying in the STEM fields after the workshop	3
POST-STEM-Imp	The understanding of the importance of STEM after the workshop	3
POST-Robotic-Future	The interest to build, program and learn with robots in the future	3
Stars	The pupils can give feedback with stars. The best score is five stars	1

3.2 Items to Compare the Interest in STEM and Self-efficacy Before and After the Workshop Activities

The STEM-Index is developed to compare the interest in STEM before and after the workshop activities. The hypothesis is that the robotic workshop influences the interest in STEM positively; therefore, the STEM-Index should be higher after the workshop than before the workshop.

The STEM-Index is the sum of the 5 items from Table 4. The statistical analysis shows an $\alpha = 0.639$ at the PRE-Test and an $\alpha = 0.731$ at the POST-Test.

The self-efficacy-index [15] is a standard test and measures the confidence and resilience of pupils by solving problems. The goal is to increase the self-efficacy during the workshop sustainably to encourage pupils towards a more active interest in the STEM fields and thus to empower them as makers and developers.

The Self-Efficacy-Index is the sum of the 3 items from Table 5. The statistical analysis shows an $\alpha = 0.721$ at the PRE-Test and an $\alpha = 0.815$ at the POST-Test.

Table 4. STEM-Index

Items	Statement	Datatype
STEM-1	I like using a computer	Ordinal (5-Likert)
STEM-2	I like to research and discover	Ordinal (5-Likert)
STEM-3	I like math	Ordinal (5-Likert)
STEM-4	I like science	Ordinal (5-Likert)
STEM-5	I want to understand how technical things work	Ordinal (5-Likert)

Table 5. Self-Efficacy-Index

Items	Statement	Datatype
SELF-1	In difficult situations, I can depend on my abilities	Ordinal (5-Likert)
SELF-2	I can master most problems well on my own	Ordinal (5-Likert)
SELF-3	Usually I can also solve difficult and complicated tasks well	Ordinal (5-Likert)

3.3 The Items to Prove the C4STEM-factors of Positive Influence of Role-models with the Role-Model-Index and Achievement During the Robotic Activities with the Robotic-Activity-Index.

The Rolemodel-Index measures the impact of the tutors as role models regarding the pupils' thoughts on following a STEM career.

The Rolemodel-Index is the sum of the 3 items seen in Table 6. The statistical analysis shows an $\alpha = 0.782$.

Table 6. Role-Model-Index

Items	Statement	Datatype
Rol-1	The tutor is a role model for me	Ordinal (5-Likert)
Rol-2	The tutor has motivated me towards more interest in technology	Ordinal (5-Likert)
Rol-3	The tutor motivated me to go for technical education	Ordinal (5-Likert)

The POST-Robotic-Activity-Index [5] measures how it was for the pupils to work with robots (see Table 7).

The statistical analysis of the POST Robotic-Activity-Index shows an $\alpha = 0.450$. This Cronbach alpha value is too weak to sum it for an index, which is why the items have to be evaluated separately (as done in Sect. 4.5).

Table 7. POST-robotic-activities

Items	Statement	Datatype
Rob-1	Working with robots during the workshop was interest	Ordinal (5-Likert)
Rob-2	Working with robots during the workshop was difficult	Ordinal (5-Likert)
Rob-3	Working with robots during the workshop was fun	Ordinal (5-Likert)

4 Results/Findings

This section shows the results of the explained indexes of Sect. 3. The results of the three different workshops are compared for identifying best practice examples.

4.1 Findings of the Interest of the Participants Before the Workshop

The first step was to evaluate the Meta-Data and the pupils' interest in STEM before the workshop activities (see RQ1 in Sect. 3). Therefore, we designed different statements and questions for PRE-Questionnaires to answer the research question RQ1: "Which interests have pupils regarding STEM before the robotic workshops?".

The best gender mix is shown in workshop group A (see Table 8). The participants of workshop B had most experiences with robots and programming. Most of all did not build a robot, but most of the pupils that have programmed before, were in group B.

Table 8. Gender mix and experience before the workshops

		Workshop A N = 163	Workshop B N = 119	Workshop C N = 70
Gender	Girls	48,2%	16,1%	25,7%
	Boys	51,8%	83,9%	74,3%
Did you build a Robot?	School	0,7%	5,9%	2,9%
	Workshop	7,7%	12,6%	1,4%
	At home	10,6%	9,2%	12,9%
	No	74,6%	69,7%	80,0%
Did you program?	School	19,7%	69,7%	28,6%
	Workshop	3,5%	0%	24,3%
	At home	14,8%	20,2%	5,7%
	No	54,2%	9,2%	40,0%

4.2 Comparison of STEM-Index and Self-Efficacy-Index Before and After the Workshops

Table 9 shows the comparison between the interest in STEM before the workshops (PRE-STEM-Index) and the change after the workshop (POST-STEM-Index). Consequently, this result gives us an answer to RQ2 (i.e. interest in STEM).

Table 9. Compare-STEM-Index

Index	Group A		Group B		Group C	
	Mean	Std.	Mean	Std.	Mean	Std.
PRE-STEM	18,7	3,747	19,31	2,946	19,33	3,594
POST-STEM	18,1	4,661	20,35	3,63	19,65	3,382

The mean of the PRE-STEM-Index in groups B and C is similar and higher than the mean in group A. The interest in group B increased more than in group C but in group A the interest in STEM decreased during the workshops. However, most of the pupils in group B had experience with programming (seen Sect. 4.1) and therefore a more clearly imagination about STEM before the workshop, which could make them better receivers for the workshop content. On the contrary many of the pupils in group A had their first experience with robots and programming in the workshops. Besides, group A had best gender-mix and therefore significantly more girls in the workshop than group B. Due to these different participants in the workshops a direct comparison is not significant. Nonetheless, the results are important for every individual workshops to identify best practices.

The PRE-Self-Efficacy-Index shows the empowerment of the participants before the workshop and the POST-Self-Efficacy-Index shows the empowerment of the participants after the workshop (Table 10).

Table 10. PRE-Self-Efficacy-Index

Index	Group A		Group B		Group C	
	Mean	Std.	Mean	Std.	Mean	Std.
PRE-Self-Efficacy	11,17	2,17	10,69	1,959	10,84	1,742
POST-Self-Efficacy	10,75	3,149	N/A	N/A	12,06	2,098

The PRE-Self-Efficacy-Index is highest in group A and lowest in group B. The Self-Efficacy-Index decreased in group. A but increased in group C (no data available for group B). Pursuing a STEM career is more likely through increasing the self-efficacy [8], which is linked to a positive STEM task performance [16].

4.3 Findings After the Workshop

Table 11 shows the different results after the workshop. The Rolemodel-Index was evaluated with a five point Likert scale. The other indexes were evaluated with yes and no. If the result involves more yes, the mean is close to 1, and if the result involves more no, it is close to 2.

Table 11. POST-Index-Results

Index	Group A		Group B		Group C	
	Mean	Std.	Mean	Std.	Mean	Std.
Role-Model	9,21	3,139	11,51	2,691	9,64	3,014
More-Study-STEM	1,52	,302	1,36	,331	1,51	,312
STEM-Importance	1,25	,297	1,13	,216	1,24	,302
Robotic-Future	1,6	,384	1,34	,340	1,47	,411
Stars	4,08	1,061	4,36	1,953	4,17	,851

The impact of the role-model is highest in group B. The mean of the More-Study-STEM index with 1,36 in group B is closer to Yes than the mean of the other groups. This is likewise with the mean of the STEM-Importance with 1,13, the Robotic-Future with 1,34 and the stars rating with 4,36. However, all groups show a result close to yes in STEM-Importance. This result is significant for answering RQ3: "How do robotic workshops influence decisions towards STEM careers?"

4.4 Interest in STEM Career by Girls

Table 12 shows the results from girls after the workshop and helps to get an answer for the RQ4: "How do robotic workshops foster girls regarding STEM careers?"

Table 12. POST-Index-Results with girls

Index	Group A	Group B	Group C			
	Mean	Std.	Mean	Std.	Mean	Std.
Role-Model	8,73	2,962	9,59	2,551	9,8	2,551
More-Study-STEM	1,6	,284	1,49	,356	1,44	,362
STEM-Importance	1,26	,285	1,14	,279	1,27	,275
Robotic-Future	1,74	,327	1,51	,321	1,54	,430
Stars	4,01	1,052	3,95	1,224	4,06	,802

The best impact of a role-model for girls was in group C. The answers for More-Study-STEM and the STEM-Important-Index were closer to yes (nearer to 1) by group

B than the ones of the other groups. The highest mean concerning the stars for overall rating was in group C.

4.5 The Interest in Robots by Girls

Figure 4 shows how working with robots during the workshop was perceived by girls.

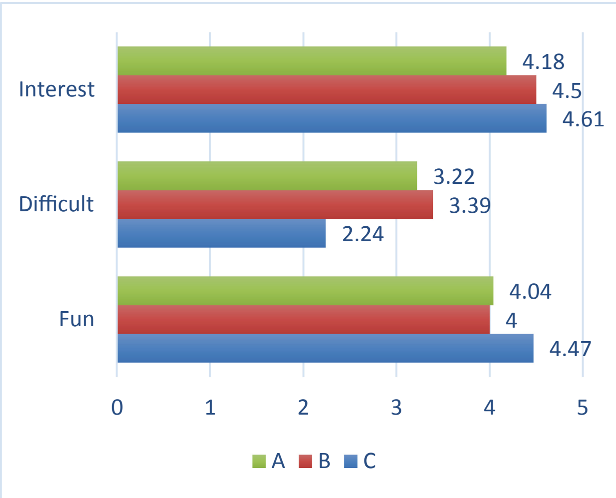

Fig. 4. How it was for girls to work with robots

The results show that the highest mean regarding interest was at group C with 4,61 and regarding fun with 4,47 also at group C. Besides, the mean of 2,24 in the category difficulty at the group C was the lowest result. These results show a clear best practice for increasing the motivation of girls to learn and work with robots.

5 Conclusion and Outlook

The results show the positive influence of essential factors to increase the interest in STEM by different workshops. Therefore, we can identify best practices in regard of different factors. The evaluation tool focuses on the interest of the pupils before the workshops and after the workshops, and gives a better understanding concerning the comparison of results between different educational robotic workshop designs. However, more detailed information about the activities and their different pedagogical intervention and goals of the workshops are required for a better understanding of the different workshops designs. This would allow a better comparison of the results in order to identify best-practices. In this context, a better workshop template with activity blocks, which includes the goal, pupil activities and tutor activities, based on the AVIVA-Model [17] is recommended. This model splits educational activities in five explicitly described phases. Generally, the activity blocks should include both constructivist-oriented and instructionism-oriented approaches. Moreover, we plan to modify the Self-Efficacy Index of the evaluation tool to a specific Robotic-Self-Efficacy (RSE) evaluation tool for workshop activities [18], because it offers a better Cronbach Alpha Value ($\alpha = 0.842$) and allows a better interpretation of the educational robotics context. The tried and tested evaluation presented in this work is accurate, but the evaluation needs to reflect the different participants to identify suitable activities for the workshops. Consequently, further work on C4STEM will support the sharing of educational robotics activities and facilitate the comparison and proof of the quality of educational robotics activities for identifying best-practice examples for a sustainable increase of interest in STEM of young learners.

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References

1. European Comission: Does the EU need more STEM graduates? (2015)
2. EU STEM Coalition: STEM Skills for a future-proof-europe Fostering Innovation, Growth and Jobs by bridging the EU STEM Skills Mismatch (2016)
3. Mead, R.A., Thomas, S.L., Weinberg, J.B.: From grade school to grad school: an integrated STEM pipeline model through robotics. In: Robots in K-12 Education: A New Technology for Learning, IGI Global, pp. 302–325 (2012)
4. Bredenfeld, A., Leimbach, T.: The roberta initiative. In: Gehalten auf der Workshop Proceedings of International Conference on Simulation, Modeling and Programming for Autonomous Robots (SIMPAR 2010), pp. 558–567 (2010)
5. Carina, G., Todorova, C.: Evaluation Tool Kit (2018)
6. Yiannoutsou, N., Nikitopoulou, S., Kynigos, C., Gueorguiev, I., Fernandez, J.A.: Activity plan template: a mediating tool for supporting learning design with robotics. In: Robotics in Education, Cham, pp. 3–13 (2017). https://doi.org/10.1007/978-3-319-42975-5_1
7. Stager, G.S.: A Constructionist Approach to Teaching with Robotics, p. 12 (2010)
8. Kramer-Bottiglio, R.: Intersecting Self-Efficacy and Interest: Exploring the Impact of Soft Robot Design Experiences on Engineering Perceptions
9. Honebein, P.C., Duffy, T.M., Fishman, B.J.: Constructivism and the design of learning environments: context and authentic activities for learning. In: Designing Environments for Constructive Learning, pp. 87–108. Springer (1993)
10. Jäggle, G., Lammer, L., Hieber, H., Vincze, M.: Technological literacy through outreach with educational robotics. In: Robotics in Education, pp. 114–125 (2020)
11. Jäggle, G., Lepuschitz, W., Girvan, C., Schuster, L., Ayatollahi, I., Vincze, M.: Overview and evaluation of a workshop series for fostering the interest in entrepreneurship and STEM. In: 2018 IEEE 10th International Conference on Engineering Education (ICEED), pp. 89–94 (2018). https://doi.org/10.1109/iceed.2018.8626980
12. Blanz, M.: Forschungsmethoden und Statistik für die Soziale Arbeit: Grundlagen und Anwendungen. Kohlhammer Verlag (2015)
13. Baxter, P., Jack, S.: Qualitative case study methodology: study design and implementation for Novice researchers. The Qualitative Report, Bd. 13, Nr. 4, pp. 544–559, December 2008

14. Leech, N.L., Onwuegbuzie, A.J.: A typology of mixed methods research designs. Qua. Quan. **43**(2), 265–275 (2009). https://doi.org/10.1007/s11135-007-9105-3
15. Beierlein, C., Kovaleva, A., Kemper, C.J., Rammstedt, B.: Ein Messinstrument zur Erfassung subjektiver Kompetenzerwartungen: Allgemeine Selbstwirksamkeit Kurzskala (ASKU) (2012)
16. Britner, S.: Sources of science self-Efficacy beliefs of middle school students. J. Res. Sci. Teach. **43**(5), 485–499 (2006)
17. Städeli, C., Städeli, C.: Kompetenzorientiert unterrichten-das AVIVA-Modell: fünf Phasen guten Unterrichts. hep, der Bildungsverl (2013)
18. Jäggle, G., Lammer, L., Wiesner, J.-O., Markus, V.: Towards a Robotics Self-Efficacy-Test in Educational Robotics Contexts (2020)

Placemat Instructions for Open-Ended Robotics Challenges

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Abstract. This research documents our investigation of alternative forms of written instructions for robotics education. Currently, instructions that accompany educational robotics kits often provide students with step-by-step directions leading them to one "correct" solution. This research explores alternative forms of written instructions called placemat instructions. Placemat instructions are a one-page (double-sided) representation of an open-ended robotics challenge. They give students a few images of example builds and some code snippets to get them started, but they do not provide step-by-step instructions or dictate the creation of a single solution. The goal of this study is to investigate what type of learning experiences unfold when placemat instructions are used to facilitate open-ended robotics challenges in K–12 classrooms, and how these learning experiences differ from those when no placemat instructions are used. We analyzed classroom video data to look for ways students did or did not use the placemats, where students became stuck or required the assistance of a peer or instructor, and the time it took each group to reach an initial testable prototype. Based on these data, we found that the use of placemat instructions to support open-ended robotics challenges in an 8th grade science classroom was successful in: (1) helping students quickly and easily get started with open-ended design challenges, (2) supporting students and teachers when questions arose during the activity, and (3) inspiring a diverse set of student-generated solutions to a problem.

Keywords: Educational robotics · Learning support tool · Instructional tool

1 Motivation

Research has shown that open-ended design-based inquiry is in some ways more effective than traditional lecture-based instruction [1]. K–12 classrooms have begun to incorporate more open-ended learning instruction combined with educational technology to empower their students to learn science, technology, engineering, and mathematics by doing instead of simply by watching and listening [2–4]. This has proven, in many cases, to have a positive impact on students' attitudes towards learning as well as their overall academic achievement [4]. However, there are many challenges that make open-ended robotics learning experiences difficult to implement [5–8].

In general, the problem-based learning environment is structured differently than a traditional classroom environment. This means that students and teachers are fulfilling

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different roles than they are used to in a more traditional learning setup [5]. This transition can be difficult for students, and it sometimes brings out coping behaviors that hinder their ability to extract full value from the learning experience. Some students assume a passive role and simply do not participate in the activity, or require frequent one-on-one support from the teacher. Other students engage in distracting and off-task behaviors, while still others seize control of the problem and refuse to cooperate with groupmates [6]. The different coping behaviors that students exhibit when engaging in problem-based learning puts added strain on the teacher as they try to motivate students, all with unique needs, to meaningfully engage with an open-ended task.

Teachers are also faced with adjusting to a new role during open-ended activities, as well as dealing with additional issues related to using robotics technologies with their students [6]. Lack of teacher training for the technologies being used, high student–teacher ratios, and poor classroom infrastructure are just some of the logistical challenges many teachers face when trying to use technology in classrooms [7]. Open-ended problem-based learning requires teachers to create different types of scaffolds and supports for students than are typically used [8]. Teachers understand that scaffolds are beneficial, and in some cases necessary, for students to be successful in a problem-based learning environment, but creating a scaffold that is useful without being too constraining is a major challenge. While using step-by-step instructions that come with many robotics kits might alleviate some of the challenges of using technology in the classroom, it eliminates the benefits of allowing students to come up with their own ideas and explore multiple solutions to one problem [9].

Finding this balance between showing and telling vs. inspiring and supporting is challenging, especially in a classroom context. Often times, any examples shown to students will wind up being internalized as a “correct” answer and be replicated by the majority of a class. Paulo Blikstein [10] describes his experience teaching students how to use a laser cutter. His introductory activity was to have students design and fabricate a personalized key chain. He was excited about the open-ended nature of the challenge, and while students did enjoy making their own keychains, they then became stuck on the idea that the laser cutter was only for making keychains and couldn’t come up with anything else for which they wanted to use it. This “keychain syndrome” can happen with open-ended design challenges too [10]. As soon as students see one solution to a problem, even if they are told that they can and should come up with their own idea, it will be much harder for them to see outside of the initial idea that their teacher has presented. This is problematic, as the most important kinds of engineering and critical thinking happen when students stop trying to replicate the knowledge of others and start thinking for themselves [11].

The question then becomes: *What kinds of support resources for open-ended challenges can educators use with their students that won’t hinder independent thinking?* Placemat instructions were designed with that purpose in mind: to help students get started and give them ideas (both for coding and constructing their robot), without dictating one “correct” answer. Educators and education companies have long been designing their own scaffolds for open ended learning in classrooms using robotics [12]. One example is the LEGO Subassembly Constructopedia which was a one-hundred page document providing inspirations and hints on building with the original LEGO Robotics platform (the LEGO MINDSTORMS RCX) [13]. However, despite the availability of these resources, research on teacher perceptions still shows that a lack of instructional resources is a major barrier faced by teachers trying to bring robotics into their classrooms [14]. While literature analyzing the benefits and shortcomings of using existing open-ended robotics scaffolds is limited, we believe that the placemat instructions are of a novel format and length and have the potential to lower barriers to entry for conducting open ended robotics challenges in the classroom. The goal of this study is to investigate what type of learning experiences unfold when placemat instructions are used to facilitate open-ended robotics challenges in K–12 classrooms and how these learning experiences differ from those where no placemat instructions are used. We are particularly interested in investigating how placemat instructions (1) facilitate students quickly and easily getting started with open-ended design challenges, (2) support students and teachers when issues or questions arise during an activity, and (3) inspire a diverse set of solutions to single challenge.

2 Study Design

2.1 Study Context

To investigate the impact that placemat instructions have on students participating in robotics challenges, we tested them in an 8th grade science class. The study site was a private school in the northeastern United States serving pre-kindergarten through 8th grade students. The study site has a six to one student–teacher ratio with an average class size of fourteen. Twenty percent of students receive financial aid and thirty-six percent of the student body are students of color. The study was conducted in four sections of an 8th grade science class, with each section containing between ten and fourteen students. All four sections of this 8th grade science class had previously used LEGO MINDSTORMS Education EV3 robotics kits as a data logging tool during their most recent physics unit. The LEGO MINDSTORMS Education EV3 robotics kit includes the EV3 Intelligent Brick, a small programmable computer that makes it possible to collect sensor data and control motors. The kit also contains LEGO Technic building components that students can use in conjunction with the EV3 Intelligent Brick, motors, and sensors to create their own robots [15]. For these physics activities, each pair of students built an identical car using step-by-step instructions that the teachers had provided. This group of students had not yet participated in any open-ended robotics challenges as part of this class, but they had done more open-ended projects with LEGO robotics in other classes. Each class block lasted forty-five minutes per the standard schedule at the study site. There were two different teachers for the four sections, each teaching two sections, and one observer taking notes and facilitating the video recording.

2.2 Activity Design

For this study, students in each section participated in two different robotics challenges. The first challenge was a “silly walks” challenge, where students were asked to build a robot that moves forward but does not use wheels as the main method of locomotion

[16]. The second challenge was a "tug-of-war" challenge, where students were asked to build a car that could pull another car over a line. In two of the sections, one taught by each educator, students were given the placemat instruction for challenge one (silly walks) but not for challenge two (tug of war). The other two sections were not given the placemat for challenge one, but they were given a placemat for challenge two. Since it is impossible to ensure that each challenge is of the exact same difficulty/complexity, switching placemat assignment across the sections was done in an effort to help remove difficulty as a variable in the analysis of the efficacy of the placemat instructions. Each challenge lasted one class block (forty-five minutes). Students worked in groups of two with the same partner for each challenge.

The teacher of each class introduced the challenge to their students just as they would any other robotics challenge or activity. They briefly explained the challenge, the constraints, and then let students begin building. For challenges where students were given placemat instructions, the teacher passed them out with the LEGO MINDSTORMS Education EV3 robotics set and explained to students that the placemat instruction could be used as a reference if they wanted it, but could be ignored if they didn't want to use it or didn't feel they needed any help.

2.3 Placemat Instructions Design

The placemat instructions for each activity (shown in Fig. 1 and Fig. 2 below) were designed intentionally to be sources of inspiration without dictating a correct answer. The placemat instructions depicted three potential solutions. The hope was that students who didn't want or need any assistance would simply bypass the placemat and proceed through the robotics challenge independently, naturally iterating and experimenting to produce a solution of which they are proud

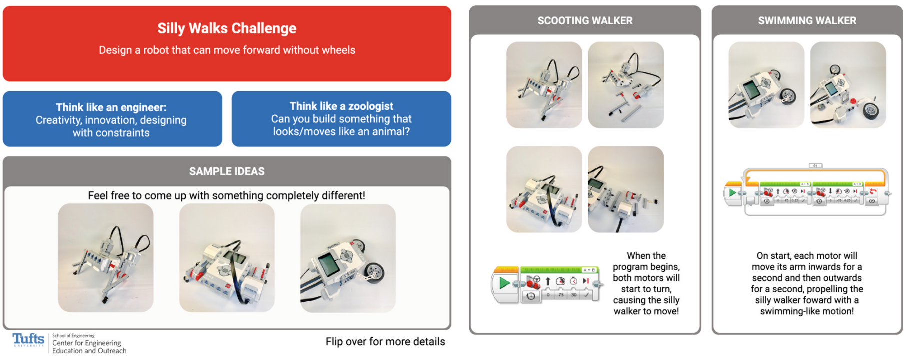

Fig. 1. Silly walks challenge placemat instruction (Left – Front Page, Right – Back Page)

Students who just need a little help getting started or were simply looking for inspiration would be able to leverage just the front page (left-hand image in Fig. 1 and Fig. 2) to see some images of example robots and some tips for brainstorming ideas. For example, in the silly walks placemat, students were prompted to "think like a zoologist" and

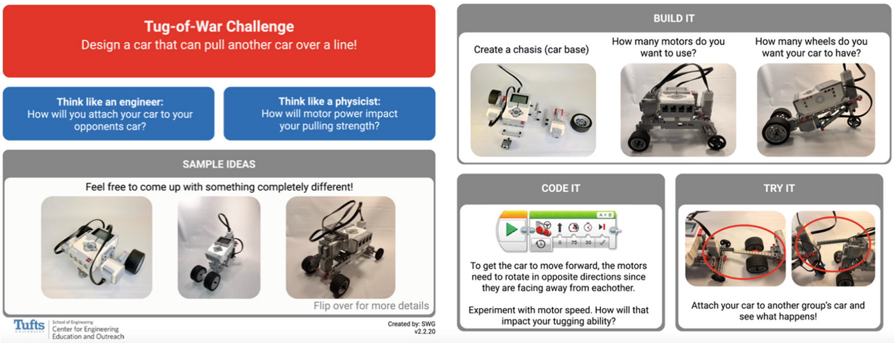

Fig. 2. Tug-of-War challenge placemat instruction (Left – Front Page, Right – Back Page)

brainstorm ways that different animals move to come up with an idea for how to get their robot to move forward without wheels. For some students, the inspiration on the front page would be enough to get them started. However, some students may still feel lost or not know where to start with actually constructing a robot. The back of the placemat was therefore designed with those students in mind. The back page (right-hand image in Fig. 1 and Fig. 2) contains some example code as well as more in-depth depictions of example robots. Students could use these images to get started with building the robot from the picture. However, these images were intentionally small to make it possible, but challenging, to copy the idea exactly. The hope was that these images would get students started towards assembling pieces but then encourage them to have their own ideas and instead build a unique solution.

The power of using placemat instructions is that students have the agency to choose the level of assistance they want or need to use and when they want to use it. Realizing that some students will be more (or less) willing to take risks in their learning [17], we designed the placemat instructions so that students who are willing to engage in the open-ended challenges independently and with-out supports can do so by simply ignoring the placemat instruction altogether. Without the use of placemat instructions, the teacher would be the main source of support for any student needing assistance. The placemat instructions will hopefully act as another support system and alleviate some of the demand on the teacher during robotics design activities.

3 Methods

3.1 Data Collection

Each pair of students was video recorded as they completed the design challenges. There was also a camera placed in the front of the classroom to capture students as they collaborated with other groups and moved about the classroom testing their robot and asking the teacher questions. Photographs of the students' robotic solutions to each challenge were also taken. Additionally, one member from the research team was present during each class session to take field notes and facilitate the video recording.

3.2 Data Analysis

The video recordings of students working on the robotics challenges were analyzed and qualitatively coded. We looked specifically for instances when students referenced or used the placemat instructions and the impact it had on their learning experience. We also looked for situations in the classes where placemat instructions were not used and where students became stuck, frustrated, or required the additional assistance of a peer or instructor.

Additionally, we recorded how long it took students to create a testable prototype, and how much iteration they were able to complete in the forty-five minute class period. The goal of looking at this timing data is to see if the use of placemats helped students get started more quickly and therefore helped facilitate more testing and iteration in the same amount of class time.

While the study population size of approximately fifty students is too small for substantial quantitative analysis, the results below qualitatively describe the impact that the placemat instructions had on the learning experiences of this small population of students as they engaged in open-ended robotics challenges.

4 Results

4.1 Overall Results

The results revealed that the majority of students did not leverage the placemats at all (Fig. 3). Students that did use the placemats did so for a variety of reasons. Only six of the thirteen groups who received a placemat instruction for the silly walks challenge and five of the twelve groups who received a placemat for the tug-of-war challenge referenced the placemats in a way that sparked some kind of conversation between partners or incorporated one of the ideas on the placemat instruction into their robot build or code.

The majority of the groups who referenced the placemat instructions did so for help with coding. Many students were unfamiliar with the LEGO MINDSTORMS Education block-based software. As the students began trying to code their robot many of them raised their hand to ask for help finding the correct blocks to use. This happened in all four of classes during the silly walks activity, as it was the first time students were opening up the software in several weeks. In both of the sections where the placemat instructions were used for silly walks, the teachers used the placemat instructions as a way to point out which blocks to use to the whole class.

There was a large diversity of solutions to both challenges across all of the sections. There were only four total instances out of twenty-five total groups (three in the silly walks challenge and one in the tug-of-war challenge) where students built the exact model shown on the placemat. This was encouraging to see, as it illustrates that the presence of the placemat did not perpetuate the idea that there was one correct answer.

We also analyzed the time it took students to complete a first testable prototype with and without the placemat instruction. Across the eleven groups that used the placemat instructions, there was no trend in the time it took students to reach a first testable prototype compared to when they did not have access to a placemat instruction. There was also no trend in how quickly students who chose to use the placemat instructions

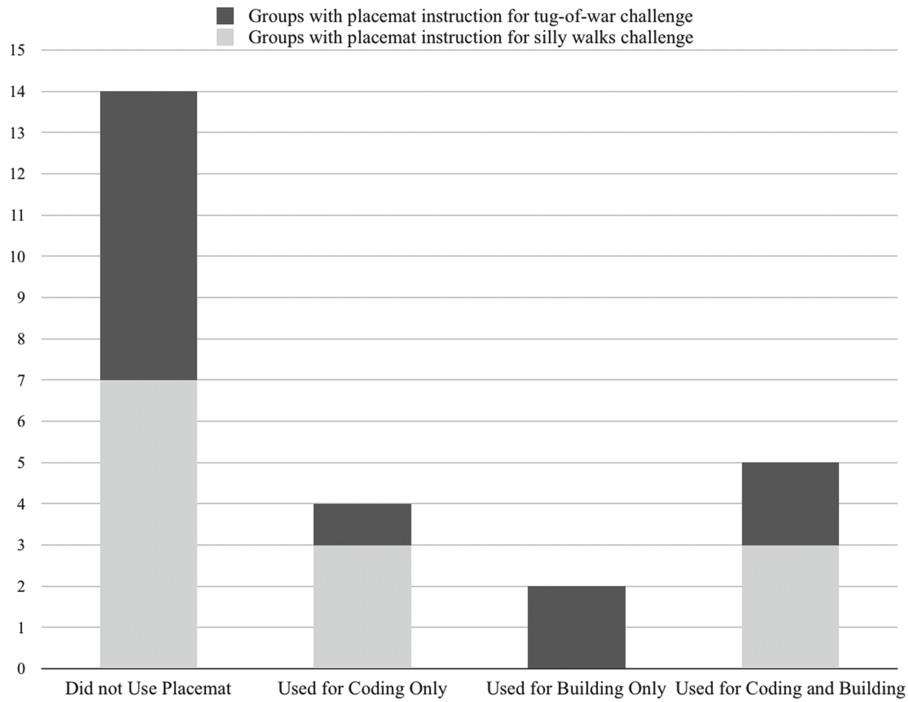

Fig. 3. Usage summary of placemat instructions among the twenty-five students pairs in the study population

reached a testable prototype compared to their peers who chose not to use the placemat instruction. This validates the idea that placemats are a support for students who feel they need them, but not a tool that needs to be leveraged by every student. In a select case documented below, the placemat instruction was key in helping a group get started on building their first prototype, which in turn enabled them to have enough time to test and iterate. The sooner students were able to complete the first prototype, the more testing and iteration they were able to engage in, which is a valuable part of the engineering design process.

4.2 Specific Use Cases

There were three cases in particular that exemplified situations where the placemat instruction was particularly helpful for both the students and the teacher. These three instances are described below.

The case of "We don't have any ideas." Anna and Matt (pseudonyms) spent the first minute of their silly walks challenge silently staring at the placemat instruction in front of them. The conversation below followed:

Matt: Do you, um, have any ideas of what we should make?
Anna: Uh…no. Do you?

Matt: Not really, I … no I don't have any I don't think
Anna: [opens LEGO MINDSTORMS Education EV3 kit and picks up a few of the pieces without saying anything] Should we make it walk or something?
Matt: Yeah OK. How would we do that.
Anna: We could make it like this [points to back of placemat instruction where there is an exploded view of the scooting walker robot]

These two students seemed to have trouble coming up with initial ideas and on their own were hesitant to start experimenting. They then leverage the placemat instruction by using one of the provided ideas to get started. They both worked together to build the scooting robot and then modified the code multiple times to get it to move forward by moving one leg at a time instead of two as depicted in the placemat example code.

During the next class period, Anna and Matt were then presented with the tug-of-war challenge. A similar conversation occurred, with neither of them offering up an idea or starting to build. After approximately three minutes the teacher went over and helped Matt and Anna brainstorm ways of attaching the motors to the EV3 brick to create a driving base. While Anna and Matt still had time to build a functional tug-of-war robot and test it against two different opponents, it took them almost twice as long to get started and required their teacher to notice them struggling and appropriately intervene. This is just one case where students benefitted from having the placemats available to help them get started.

The case of "We want to build it this way." Kevin and Eric (pseudonyms) were very excited about the silly walks challenge and immediately decided that they were going to build a robot that had legs and could walk. However, after twenty minutes of building they still hadn't succeeded in building anything close to a robot that could walk. They began to get frustrated and lose interest and started making silly faces into the camera. The teacher noticed and went over to ask them about their design. They told her that they wanted to make a robot that could walk but didn't know how. The teacher then flipped the placemat over and showed them the scooting walker. "This one kind of has legs, why don't you give that a try?" she prompted. Kevin and Eric got back on task and were able to finish their silly walker in time to test it out with two different leg configurations.

In the tug-of-war challenge, where Kevin and Eric did not have a placemat, they initially had the idea of making a braking system. Their idea was to add brakes to their car so that if it started getting pulled by the opposing car the brakes would activate and stop the car from moving forward. After tinkering with the pieces for a few minutes, Kevin and Eric decided that they didn't know how to build brakes, so instead they would use the USB cord included in their robotics kit to tie their robot to the leg of the table and use that as a mechanism for keeping their robot from being pulled over the line. This caused some disruption in the classroom and other students viewed using the USB cord as cheating. The teacher then had to speak with Kevin and Eric multiple times about coming up with other ideas in an effort to prevent them from becoming off task and disruptive to the rest of the students.

In this case, the placemat instruction was a helpful tool for students who had a very set idea of what they wanted to build but weren't sure how to achieve it. While the placemat instruction for the tug-of-war challenge did not offer any ideas for how to build a brake system, it did offer other ideas that may have inspired Kevin and Eric to stay more on topic, just as the silly walks placemat instruction was able facilitate them getting back on track with building their walking robot.

The case of "What if we do it wrong?" Alexa and Samantha (pseudonyms) struggled initially with the silly walks challenge. They did not have a placemat for this challenge and Alexa in particular was having a hard time picking an idea or even just trying something out. Samantha asked her if she had any ideas and she responded that she didn't really have any. Samantha started pulling pieces out of the LEGO MINDSTORMS Education EV3 kit and started to build, explaining to Alexa that she thought they could build a robot that used a rotating beam to move forward instead of a wheel. Samantha continued building the robot and Alexa remained un-engaged. The teacher later explained to us that Alexa struggled significantly with anxiety and often was unable to attempt problems that didn't have a defined correct answer. Her fear of being wrong prevented her from engaging in the activity altogether for most of the challenge. Only towards the end did she help Samantha try out a few different beam configurations after she saw that the robot did in fact move forward successfully.

When it was time for the tug-of-war challenge, Alexa and Samantha looked at the placemat together. Having the opportunity to see some different examples gave Alexa an entry point into engaging in the activity. Samantha told Alexa that she wanted their car to have four wheels and Alexa confirmed that she was okay with that. Samantha began attaching the motors to the EV3 brick. Alexa looked at the placemat some more and then started getting out the pieces needed to add the caster wheel onto the EV3 Brick as depicted in the placemat instruction (Fig. 2, top left of back page). Samantha and Alexa collaboratively built a three-wheeled car and tested it against two components. Having the placemat seemed to give Alexa a feeling of security and a sense that she was "doing it right", despite there being no "right" answer to the tug-of-war challenge. For students like Alexa who are afraid to fail, having a scaffold that helps them feel as though they are on the right track throughout the problem-solving process is helpful. The placemat instruction served this purpose here, enabling Alexa to be an active participant in the activity without needing constant teacher encouragement and support.

5 Conclusions

Based on the case study presented in this paper, the placemat instructions were successful in: (1) helping students to quickly and easily get started with an open-ended design challenge, (2) supporting students and teachers when issues or questions arose during the activity, and (3) inspiring a diverse set of solutions to single challenge. While the placemat instructions were only used by a minority of the groups in this study, they did have a clear positive impact on some of the use cases described above. The idea of students self-selecting the level of support they extracted from the placemat instruction proved effective and the learning experiences that unfolded in the classroom were positive. In the case of this study population, the placemat instructions did not limit the diversity of student solutions to a design problem, and in specific cases were instrumental in helping students get started, stay on task, alleviate frustration, or engage meaningfully with the challenge. In an ideal classroom, free from many of the challenges typically found in open-ended robotics challenges, placemat instructions would not be needed. The fact that we saw so few students leveraging them is an aligned with the fact that this study population was not dealing with many of the traditional problems that placemat instructions help to alleviate (such as high student to teacher ratios and teachers that are unfamiliar with the technology).

In future studies, we hope to investigate the use of placemat instructions with younger students and with a more diverse study population. We also hope to conduct research on how the teachers' experiences change when they are able to use a placemat to support an engineering design challenge. In this study, we saw preliminary indicators that the placemat instruction supported not only the students, but also the teacher. This discovery does not come from thorough research but rather from this one case study and therefore can only suggest potential directions for a more comprehensive study. In the future, we hope to explore this idea further to find out how to optimize the design of the placemat instructions to best support positive learning processes and outcomes for students and educators alike. We also plan to continue to iterate on the format and structure of the placemat instructions and conduct studies to analyze how variations in the placemat design effect usage outcomes.

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References

1. Mehalik, M.M., Doppelt, Y., Schuun, C.D.: Middle-school science through design- based learning versus scripted inquiry: better overall science concept learning. J. Eng. Educ. **97**(1), 71–85 (2008)
2. Stager, G.S., Ph, D.: A constructionist approach to teaching with robotics four case studies of robotics projects. In: Constructionism (2010)
3. Barreto, F., Benitti, V.: Computers & education exploring the educational potential of robotics in schools: a systematic review. Comput. Educ. **58**(3), 978–988 (2012)
4. Korkmaz, Ö.: The effect of Lego Mindstorms Ev3 based design activities on students' attitudes towards learning computer programming, self-efficacy beliefs and levels of academic achievement. Balt. J. Mod. Comput. **4**(4), 994–1007 (2016)
5. Liu, M., Lee, S., Chang, H.M.: Examining how middle school science teachers implement a multimedia-enrched problem-based learning environment. Interdiscip. J. Probl. Learn. **6**(2), 46–84 (2012)
6. Gertzman, A.D.: A case study of problem-based learning in a middle school science classroom: lessons learned. In: Proceedings of the 1996 International Conference on Learning Sciences (1995)
7. Johnson, A.M., Jacovina, M.E., Russell, D.G., Soto, C.M.: Challenges and solutions when using technologies in the classroom. In: Adaptive Educational Technologies for Literacy Instruction, pp. 13–29 (2016)

8. Ertmer, P.A., Simons, K.D., Simons, K.D.: Jumping the PBL implementation hurdle: supporting the efforts of K – 12 teachers. Interdiscip. J. Probl. Learn. **1**(1), 40–54 (2006)
9. Odden, T.O.B., Russ, R.S.: Defining sensemaking: bringing clarity to a fragmented theoretical construct. Sci. Educ. **103**(1), 187–205 (2019)
10. Blikstein, P.: Digital fabrication and 'making' in education the democratization of invention. In: FabLabs: Of Machines, Makers and Inventors, no. September, pp. 203–221 (2015)
11. Rogers, C.: Learning STEM in the Classroom, LEGO Engineering (2014). http://www.legoengineering.com/learning-stem-in-the-classroom/. Accessed 06 Jan 2020
12. Chambers, J., Carbonaro, M., Rex, M., Grove, S.: Scaffolding knowledge construction through robotic technology: a middle school case study. Electron. J. Integr. Technol. Educ. **6**, 55–70 (2007)
13. The LEGO Group: Subassembly Constructopedia. In: LEGO Group (1999), LEGO MINDSTORMSTM set for Schools # 9790, Billund, Denmark, pp. 1–109 (1999)
14. Khanlari, A.: Teachers' perceptions of the benefits and the challenges of integrating educational robots into primary/elementary curricula. Eur. J. Eng. Educ. **41**(3), 320–330 (2016)
15. Bringing Best-in-Class STEM and Robotics Tools to the Classroom with LEGO MINDSTORMS Education EV3 for High School (2019). https://education.lego.com/en-us/middle-school/intro/mindstorms-ev3. Accessed 06 Jan 2020
16. Torok, R.: Silly Walks (2019). http://www.legoengineering.com/silly-walks/. Accessed 06 Jan 2020
17. Vygotsky, L.S.: Mind in Society: The Development of Higher Psychological Processes, Cole, M. (ed.), pp. 79–91 (1978)

Technologies and Platforms

Maera: A Hybrid Wheeled-Legged Robot Designed for Research and Education

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Abstract. In this paper, *Maera*, a low-cost open-source hybrid legged-wheeled robot, is presented. The robot is designed to be used as a teaching platform and a hands-on introductory example in the field of robotics. To this end, the paper describes in detail the design and manufacturing methods used, along with the main specifications and capabilities of the robot. Two educational use-cases are presented and evaluated by taking into account student feedback. It is shown how Maera can be used as a complete project that brings to the surface the most important topics in robotics, namely, design, dynamics, manufacturing, embedded systems, and control. Most importantly, it is described how the project bridges the gap between theoretical knowledge and practice throughout the development stages of a complex robotic application.

Keywords: Legged robots · Educational robotics · STEM education · 3D printing · Open source · Low cost

1 Introduction

In the rapidly advancing technological era, the field of robotics is experiencing accelerating growth. Statistics show that by the year 2023 the robotics market will have doubled in size, indicating a Compound Annual Growth Rate of 10.9% [1]. This growth raises the need to educate students in the field of robotics so that they can adapt to the involvement of robots in their career and everyday life. In addition, the introduction of robots in the education curriculum to assist with STEM, as well as non-STEM, subjects has proven to have great potential [2,3]. In the field of Engineering, robotics courses are taught at the undergraduate level, and more students are actively engaging in the design and control of robotic platforms. However, the knowledge acquired from university courses usually is at a theoretical level. It is essential that the students are able to apply the theoretical knowledge they gain to real-life applications.

To be able to do that, Additive Manufacturing (AM) methods can help significantly. Recently, AM machines have become more accessible and inexpensive.

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Following the RepRap Initiative, prices of 3D Printers have been decreasing exponentially, finding their way in amateur makers' homes and various labs [4]. In addition to the ease of manufacturing functional parts, various robotics tools have become more accessible. Open-source microcontroller/computer boards, prototyping platforms, as well as off-the-shelf components and actuators, can be acquired at low cost. Clearly, a trend towards the decentralization of the production process is taking form. The above lay the ground for bridging the gap between STEM Education and Applied Sciences, by introducing the design and manufacturing of simple and low-cost robots to be used inside the classroom.

Recent years have shown extensive research in the field of legged robots, but little attention has been given to the educational value of such mobile robotic systems. Legged robots such as Spot Mini by Boston Dynamics [5], StarlETH [6] and ANYmal [7] by ETH, Cheetah by MIT [8], Jelly by UC Berkeley [9], etc., are robots that are mostly optimised for industrial purposes. Robots such as Stag Mk2 [10] and OpenDOG [11] are low cost and accessible, but are essentially hobby projects. Other platforms like Bobcat [12] and Cheetah-Cub [13] by EPFL are small and low cost, but are mainly focused on research purposes. Some educational legged robots do exist, such as the PUT Hexapod Family and the RMIT Walking Robots Family [14]. However, these robots are mostly arachnids, utilizing only quasi-static locomotion methods. Furthermore, a large number of educational robots on the website Thingiverse [15] exist, which are mostly focused on primary school teaching. To sum up, existing educational approaches focus on control methods and using wheeled and manipulator robots to accomplish various tasks, leaving aside the process of design and manufacturing, especially regarding legged robots.

In this paper, the hybrid robot *Maera* is presented as a teaching platform, combining wheeled and legged locomotion, thus highlighting the educational value of both types of mobile robots. *Maera* has been used as an educational tool during the DAAD Summer School, a joint project of the National Technical University of Athens (NTUA) and the University of Duisburg-Essen (UDE), and during a short educational event. The robot served the purpose of a hands-on example for various lectures and workshops. In this way, teaching various theoretical concepts through real-life hardware was possible; the outcomes of this work and experience are presented in this paper.

In Sect. 2 the proposed design is presented and the various mechanical and electronic components are documented. In Sect. 3 educational use-cases and the way *Maera* robot was utilized as a teaching platform are conferred. The student feedback is presented in the form of a Likert Scale Evaluation [16] and discussed in Sect. 4. The conclusion of this paper and future work are given in Sect. 5.

2 Maera Specifications: Designing for Education

The first step of the design process was to set guidelines aligned with our goal, i.e. to develop a mechatronic physical system, aimed to facilitate the understanding of complex theoretical concepts through an interactive hands-on learning activity. To this end, a set of specifications has been defined and is listed next. (a)

To be an easy-to-use teaching platform. Therefore it must be designed in a way that it can be treated as an educational tool. (b) To incorporate both wheels and legs, to combine the advantages of the two most important locomotion mechanisms. (c) To be relatively small, so it can be carried around in the classroom or to short educational events. (d) To be relatively inexpensive to show that a fully functional robot can be built using off-the-shelf components and accessible manufacturing methods. (e) To incorporate different actuation technologies. The use of rotary and linear servos has been proposed to introduce the different advantages of using each actuation method. (f) To incorporate 3D printed parts so that the students can get acquainted with the technology as well as the various constraints when designing for AM. (g) To be easy-to-assemble so the whole procedure can be completed during one week long workshops. (h) To be modular so the students can test the effect each design parameter has on the robot's capabilities.

2.1 Hardware Architecture

Maera incorporates a number of actuation technologies and materials. The robot is based on a standard quadruped design, extended in a way to include actuated wheels at its toes. It features four two-segment 3D printed legs and a lightweight body frame consisting of 3D printed parts and two carbon fibre tubes as shown in Fig. 1. The 3D printer filament used is Acrylonitrile Butadiene Styrene (ABS) plastic due to its good mechanical properties and popularity as a printing material. The design is modular, in a way that several design parameters can be modified and that the effect each one has on its capabilities can be observed (payload capacity, stability, etc). Modules can also be added or removed (different microcontrollers, sensors, etc). Most of the parts are designed so they can be built using a 3D Printer and most of the components can be bought at a hobby store. The prototype robot has been built using mostly elements from an online shop [17]. *Maera* has been designed to be open-source. The part files are available upon contact with the lead author.

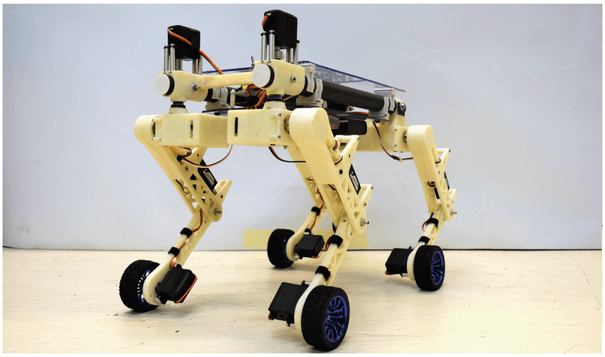
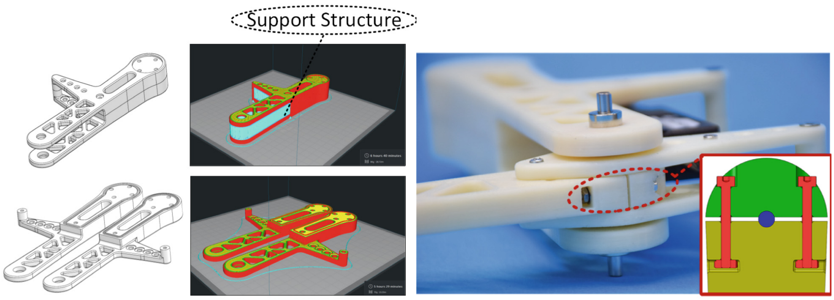


Fig. 1. *Maera*: A Hybrid Legged-Wheeled Robot.

The design of the current platform can be used as an example, assisting lecturers on teaching 3D Printing design principles. It is essential to teach students the limitations when designing for AM. One of the most challenging problems is the need for support structures when parts are built with a bottom-up approach. To tackle this constraint, one needs to cleverly adjust the designs to bypass the need for support structures. It is important to correctly orient the parts during the pre-processing stage or split the parts for post-printing assembly. By preparing the print jobs and orienting the parts themselves, students can understand the cost of using support structures in AM as shown in Fig. 2a.



(a) Split to Assembly. (b) Nut Pockets.

Fig. 2. 3D Printing Design Principles showcased using the robot *Maera*.

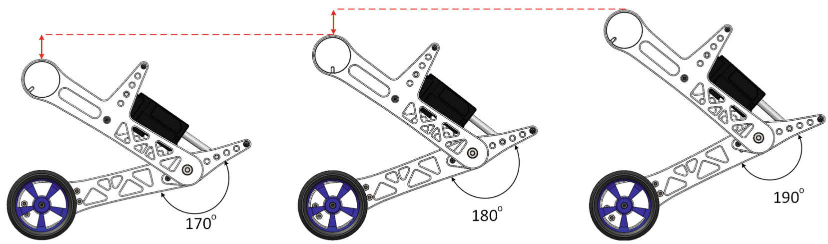
Other important design principles showcased by the platform itself, include joining methods suitable for 3D printed parts (such as nut pockets, Fig. 2b), as well as methods to orient the parts correctly, before printing, to receive tension loading. AM processes produce orthotropic parts, meaning that they display different mechanical properties along different axes. By preparing and printing the robot's legs, students can get acquainted with the importance of designing a part with layers parallel to the loading direction.

Another important aspect of teaching the principles of legged robots, concerns alternative actuation methods. Using this platform one can focus on the differences of using rotary and linear electric servo actuators. A rotary RC servo motor was used for actuating the hip joint and a linear actuator was used to actuate the knee joint. By using the servo motors, the students can realise the advantages of each method when actuating legged robots. For example, by placing the end effector of each leg below the corresponding hip joint during stance, students realise that the current consumption is close to zero ($\approx$0.05 A). This way one can showcase the advantage of actuating static loads with linear actuators that use lead screw-nut mechanisms. These mechanisms, due to their inner frictional forces, can hold static loads with the motors drawing almost zero currents. In our case, static loading occurs due to the weight of the robot while moving on wheels, making linear lead screw actuators perfect candidates.

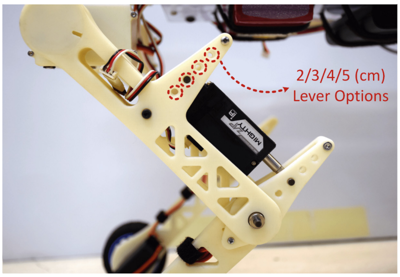
On the downside, such systems have lower efficiency (0.3–0.5), so while actuating dynamic loads different actuation methods (e.g. RC servos) are recommended.

In addition, *Maera* incorporates three core modular mechanisms. These can be used to change parameters of the robot and consequently affect its capabilities, or even add different modules, e.g different microcontrollers, sensors, etc. The basic modular mechanisms of the robot are the following:

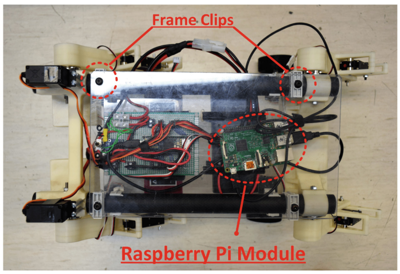
– **Adjustable Lever-Bottom Limb Angle:** By adjusting the relative angle between the actuation lever and the bottom limb, one can achieve different configurations. As a result, the robot can extend its legs in greater lengths or crouch even more. Students can see how the robot is able to carry bigger loads at the expense of reduced stability (closer to singular configurations) or smaller loads with increased stability while crouching (Fig. 3a).
– **Different Lever Options**: By adjusting the lever length, one can focus on the effect of either higher speed or force. By placing the linear actuator further or closer to the knee joint, students can observe in real time the trade-off between force and speed, and the effect of the robot's legs on the active workspace (Fig. 3b).
– **Carbon Tube Frame:** A lightweight body of adjustable length is designed, which also gives the instructor the ability to add or remove modules from the robot using clip-on components (Fig. 3c). These modules include alternative microcontrollers, sensors, cameras or even different motor housings.



(a) Adjustable Lever Angle.



(b) Different Lever Options.



(c) Carbon Tube Frame.

Fig. 3. The three core modularity mechanisms of the robot. By incorporating these mechanisms into the design, the robot is becoming more versatile on how it can be used in a lecture.

Finally, to steer the robot when moving on wheels, it was decided to simulate the Ackermann Steering method [18] by incorporating two vertical Degrees of Freedom (DOFs) into the two front legs. In this way, one can control the Yaw angle of each leg independently. These two DOFs give the students the opportunity to program a virtual Ackermann Steering mechanism and experience the importance of achieving the no-slip condition proposed by this steering method. This method is widely used when driving wheeled vehicles such as mobile robots or even more commonly commercial cars.

2.2 Electronics and Control

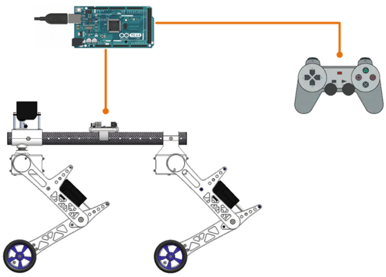
The robot incorporates 14 Hobby Servo Motors: 4 RC servos for the hip joints, 4 linear actuators for the knee joints, 4 continuous rotation servo motors for the wheels, and 2 RC servos for the steering DOFs. All the robot's actuators share the same control protocol using Pulse Width Modulation (PWM) signalling. The entire system is powered by an 8V Li-Po battery mounted on the body.

Maera is a teleoperated robot, which means that there are no sensors mounted on the robot's body or the limbs, providing feedback for autonomous functions. The students can control the robot's movement by programming an appropriate microcontroller. In detail, they can control the robot's posture, driving speed and steering angle by sending PWM signals to the corresponding actuators. The current version of the robot can be teleoperated using two different methods.

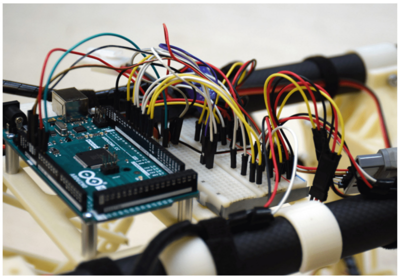
1) **Arduino Mega:** The Arduino Mega [19] is a popular microcontroller board, very common amongst hobby makers and educational robotics instructors. It features 14 Output Pins capable of producing PWM Signals, 16 Analog Input Pins, 16 MHz Clock Speed, 256 kb Flash Memory (current sketch uses 5 kb) and 8 kb of SRAM (current variables use 0.5 kb). Each motor's signal cable is connected to one of the 14 PWM pins and the students can send commands to the microcontroller using a Playstation Controller [20]. Prototyping tools such as a breadboard and jumper cables are used so that the students can see how everything is wired on a basic circuit or experiment with alternative connections themselves (Fig. 4a, 4b).
2) **RPi & Teensy 3.5:** The Raspberry Pi (RPi) [21] is a complete Linux-running micro-computer, or better known as a Single Board Computer (SBC). The students can connect to the Raspberry Pi using WiFi and Secure Shell (SSH) Network Protocol and send commands using their computers or smartphones. The Raspberry Pi then runs a Python program to communicate with a microcontroller board called Teensy 3.5 [22] using the UART (Universal Asynchronous Receiver/Transmitter) protocol (Fig. 4c, 4d). The Teensy is a powerful, feature-rich, Arduino-programmable microcontroller board, which is also tiny and of low cost. Here, the Teensy replaces the Arduino used in the first setup, since it is able to produce the PWM signals necessary to drive the actuators. Using this control framework the students can work with a setup

widely used in complex robots that typically need the combined power of one (or more) Linux-based computer(s) for computationally intensive tasks, and one (or more) microcontroller(s) for low-level signal handling.

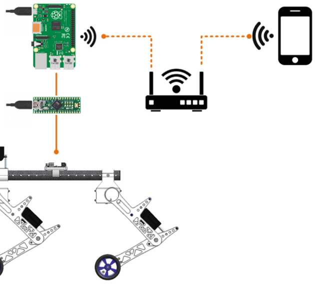
The programming scripts used in the aforementioned setups are based on a simple input/output open-loop logic and can be made available upon request.



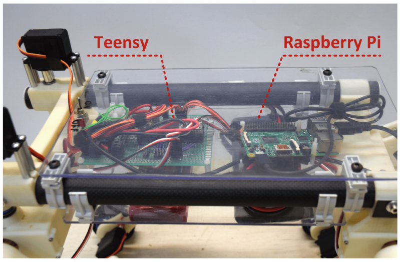
(a) Arduino Circuit.



(b) Arduino Mounting.



(c) Raspberry Pi Circuit.



(d) Raspberry Pi Mounting.

Fig. 4. (a), (b) The students can either use an Arduino board and drive *Maera* using a controller or (c), (d) they can use a Raspberry Pi SBC and a Teensy 3.5 board to drive the robot wirelessly by connecting their smartphones to a registered IP Address.

To conclude, *Maera* has been built in a way that allows an instructor to explain the different stages of the design process and the principles of legged robots. For example, during a lecture one can showcase kinematic principles through the leg design. The different stages of the development of the legs, from idea to final product, can be explored and the conceptual design process validated, by presenting different simulation and experimental results.

3 Educational Use-Cases

In this section, the different use-cases proposed for the robotic platform *Maera* are discussed. The robot can be used as an educational platform for Design and Robotics courses, a simple and easy to control platform on which students can work their thesis on, as well as a tool to communicate the field of legged robotics to the general public through short educational events. The use-cases in which the robot has been used already include the following.

3.1 NTUA-UDE Summer School

The NTUA-UDE Summer School was the final project of a 3-year collaboration between the NTUA and the UDE. It took place at the premises of NTUA's School of Mechanical Engineering from 2/9/2019 to 11/9/2019. The summer school was attended by 23 engineering students (13 German and 10 Greek). During the summer school, *Maera* was used as an educational aid for the lectures (L) and workshops (W) as presented in Table 1.

Table 1. Robotic platform usage in lectures (L) and workshops (W).

Title		Description
MSC Adams	L	Used part files to simulate the dynamic behaviour of the robot on MSC Adams
Design of a Hybrid Legged Robot	L	Used the robot as an example of how to design legged robots and what are the main principles of such systems
Introduction to 3D Printing	L	3D Printing principles and design rules showcased on the robot's structural parts
Introduction to Embedded Systems	L	Using Microcontrollers to control robots and their main principles
3D Printing the Robot	W	The students prepared the files and printed the necessary parts for the robot
Assembling the Robot	W	The students assembled the printed legs so they would be functional. During that time they tackled real-life manufacturing constraints while using different tools and joining/fitting methods
Controlling the Robot	W	Together with the lecturer, the students programmed and controlled the robot.

The lectures were taught in a sequence that presented the entire design process of the robot. During the lectures, the students would delve into the theoretical knowledge needed to complete each design phase and with the help of the physical robot see how each principle was implemented. Firstly, the students attended a lecture in which the MSC Adams simulation software was presented. During that lecture, CAD files of the robot were used to represent the different links and joints. In this way, students could simulate the dynamic behaviour of the robot in a real-life operation scenario (Fig. 5a). Next, a lecture was given on the principles of hybrid legged robots, where the students had the chance to see the effect of each decision made during the design process, e.g. popular ways to mount wheels or the importance of leg length in legged robots. During the Introduction to 3D Printing lecture, major 3D Printing principles were presented. The students could inspect the robot and identify which principle was used while designing each part, for example layer orientation, joining methods, etc. Finally, the students attended a lecture on Embedded Systems, where they learned how to use different computing platforms to control their own robots.

After the lectures, the students attended three workshops where they used the knowledge gained to 3D print, assemble and control the robot *Maera*. The workshops followed the sequence presented next.

1) The students were instructed on how to use the lab's 3D Printer and prepared the printing jobs for two legs. They oriented and arranged the parts and then initiated the printing process.
2) After printing was finished, students were divided into two groups to assemble the legs under the supervision of staff. Each group was given printed instructions, blueprints, and the necessary tools and components to fully assemble one robotic leg (Fig. 5b).
3) After assembling the legs, the students mounted them on the existing robot and in cooperation with the lecturers, managed to drive the robot. This was done in two ways. One way was to use the Arduino module where they assessed the code and drove the robot around the classroom using a joystick. The other way was to use the Raspberry Pi module where 3 students connected their smartphones to the robot and managed to drive it by sending separate commands (Fig. 5c). One student was responsible for propulsion, one for steering, and one for controlling the leg configurations.

(a) MSC Adams simulation. (b) Assembling the robot. (c) Controlling the robot.

Fig. 5. (a) After simulating the robot's dynamic behaviour, (b) students worked together to 3D Print and assemble a working set of legs. (c) By mounting the legs and controlling the robot, they were able to be part of the design and control process as well as apply their knowledge to a hands-on project.

3.2 Researcher's Night - Short Event

Researcher's Night is an annual short educational event organized by NTUA, where research labs and teams inform the general public about their field of research and their advances. During the Researcher's Night 2019, *Maera* was presented to the public as a working prototype and a hands-on example for the field of legged robotics. The robot was controlled wirelessly and could adjust its height while rolling on the team's desk (Fig. 6). During the event, lab members were using the platform to introduce concepts like leg kinematics, the necessity of legged robots, actuation methods and more to the audience. Primary School, High School, and University Students as well as parents, enthusiasts, and National Television covering the event, were really intrigued by the robot.

Fig. 6. *Maera* can be used for short educational events as it is easy to carry and can be controlled wirelessly while a Li-Po battery powers the whole system.

4 Student Feedback

The students who participated in the NTUA-UDE Summer School Workshops were given an anonymous questionnaire that measured their overall appreciation of the teaching methods involving *Maera*. They were asked 14 closed-type questions and each student provided their answer on a 7-level Likert scale. Furthermore, the students were asked one open-type question about their opinion of this teaching method, its strengths, and ideas for improvement. The questions used in the questionnaire were adapted from previous research [23] and modified accordingly (Table 2).

Table 2. Questions given to students to answer on a 7-level Likert scale.

No	Question
1	...helped me better understand theoretical Engineering concepts
2	...increased my level of familiarity with Mechatronics
3	...increased my desire to pursue Mechanical Engineering as a profession
4	...helped me decide which area in Mechanical Engineering I want to pursue...
5	...helped me apply theoretical knowledge to real-life applications
6	...helped me better understand the Engineering Design process
7	...helped me gain knowledge I was initially unfamiliar with
8	...increased my level of attention during the lectures I attended
9	...helped me develop my abilities and skills for the subject of Mechatronics...
10	...helped me develop my ability to think critically about Mechatronics...
11	...encouraged me to work as part of a team in the spirit of cooperation
12	...to complete the various tasks I collaborated with my teammates/instructor...
13	Overall, my team worked effectively together on this project
14	Considering both the limitations and possibilities of the subject matter and the course, how would you rate the overall effectiveness of this teaching method?

The answers provided by the students are summarized in Fig. 7. The mean value and the corresponding standard deviation for each question are calculated and presented in the form of a histogram. On a scale of 1 to 7, the students graded this teaching method very positively and this attitude was evenly distributed among them. With a mean value of 6.17 and a standard deviation of 0.76, it is clear that *Maera* was well received by the students as an educational platform.

From the lecturers' perspective, the students were more actively engaged in the theoretical concept whenever a hands-on stimulant was introduced in the teaching process. During the summer school, the students could easily apply the theoretical knowledge they gained on real-life problems and systems that they were presented with. This heightened their interest to pursue further study as they were really intrigued by the robot and seemed eager to learn more about its working principles.

When asked about their opinion on this teaching method's strengths and ideas for improvement, most of the students highlighted the fact that during their everyday university courses, they do not have the opportunity to tackle real-life problems. An example of answers received for the open question is presented next, as quoted by one of the students.

"You will forget 90% of theory you get from lectures, but practical knowledge provided by this teaching method will remain." (Anonymous, NTUA-UDE 2019)

Some of the students proposed a more robust control framework so that the robot could achieve more tasks. Indeed, that would let the students better understand what is required by the robot to tackle each task separately and is something that we are working on for future courses.

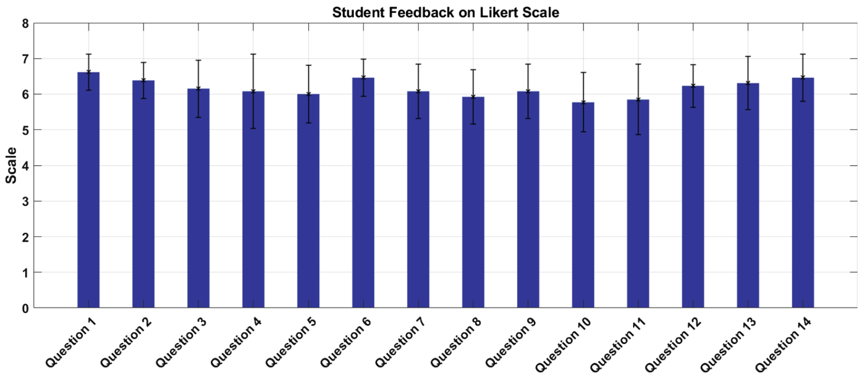


Fig. 7. The average answers provided by the students on a 7-level Likert scale show that the robot was successful as an educational platform and helped the students better realize theoretical concepts taught during the summer school.

5 Conclusion and Future Work

This paper presented the robotic platform *Maera* as a quadruped robot aimed for education and research. The robot can be used as a teaching tool in the education curriculum, as well as a research platform for students to work on. The design is focused on the educational aspect, as it incorporates various features aiming to engage the students in an interactive learning experience. The robot can work as a hands-on example to accompany different engineering lectures, taking students through all stages of a legged robot's life. Great emphasis is given on the design and manufacturing of the robot, as opposed to the almost exclusive use of educational robots as examples for control methods for completing various tasks. In this way, students interested in different fields of engineering can obtain useful practical knowledge. By using the robot in two separate use-cases, we reached the conclusion that *Maera* is a successful platform in introducing legged robotics to the general public. When *Maera* was used as a teaching tool, students showed increased interest in the theoretical knowledge derived from each lecture. Thus, proving to be a very efficient method of inviting students to further explore the field of mechatronic systems such as legged robots.

As the first prototype of the robot was used successfully in the curriculum, we plan on making the robot completely open-source, with instructions so that anybody can replicate it. Furthermore, a more robust teaching framework in the form of a course plan will be designed to accompany the robot in the educational process. Finally, we are thinking about utilizing sensors to introduce autonomy in the teaching process, as well as modifying the leg design so that the robot can be built by using only conventional hobby servo motors. Such a design can lower the cost and broaden the audience that can adapt *Maera* as a teaching tool. With this platform, we hope to introduce legged robotics to the educational community and bridge the gap between practical application and theoretical knowledge.

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References

1. BCC Research: Global market for robotics to reach $64.0 billion by 2023, 26 March 2019. https://www.prnewswire.com/news-releases/global-market-for-robotics-to-reach-64-0-billion-by-2023--300818211.html
2. Kubilinskiene, S., et al.: Applying robotics in school education: a systematic review. Baltic J. Mod. Comput. **5** (2017). https://doi.org/10.22364/bjmc.2017.5.1.04
3. Benitti, F.B.V.: Exploring the educational potential of robotics in schools: a systematic review. Comput. Educ. **58**(3), 978–988 (2012). https://doi.org/10.1016/j.compedu.2011.10.006
4. RepRap (n.d.). https://reprap.org/wiki/About
5. Spot®. (n.d.). https://www.bostondynamics.com/spot

6. Hutter, M., et al.: StarlETH: a compliant quadrupedal robot for fast, efficient, and versatile locomotion. In: 15th International Conference on Climbing and Walking Robot (CLAWAR 2012), Maryland, USA, 23–26 July 2012, pp. 483–490 (2012). https://doi.org/10.1142/9789814415958_0062
7. Fankhauser, P., Hutter, M.: ANYmal: a unique quadruped robot conquering harsh environments. Res. Features **126**, 54–57 (2018). https://doi.org/10.3929/ethz-b-000262484
8. Bledt, G., et al.: MIT Cheetah 3: design and control of a robust, dynamic quadruped robot. In: 2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS) (2018). https://doi.org/10.1109/iros.2018.8593885
9. Jelly: The walk & roll robot. (n.d.). https://www.youtube.com/watch?v=9sITXoZu2gY
10. Quadruped robot (Stag Mk2) - autonomous navigation and trotting. (n.d.). https://www.youtube.com/watch?v=oYSkWIvlyp8&list=PLHaZiGeGdMsVxc3_rmS9a95RtSr2FP6VV&index=5&t=1s
11. Wulff, A.: Meet openDog-The Open-Source Robotic Dog, 15 March 2019. https://medium.com/@Alex_Wulff/meet-opendog-the-open-source-robotic-dog-fdb8a070c763
12. Khoramshahi, M., et al.: Benefits of an active spine supported bounding locomotion with a small compliant quadruped robot. In: 2013 IEEE International Conference on Robotics and Automation (2013). https://doi.org/10.1109/icra.2013.6631041
13. Rutishauser, S., et al.: Passive compliant quadruped robot using central pattern generators for locomotion control. In: 2008 2nd IEEE RAS & EMBS International Conference on Biomedical Robotics and Biomechatronics. https://doi.org/10.1109/biorob.2008.4762878
14. Belter, D., et al.: Affordable multi-legged robots for research and STEM education: a case study of design and technological aspects. In: Progress in Automation, Robotics and Measuring Techniques. Advances in Intelligent Systems and Computing, pp. 23–34 (2015). https://doi.org/10.1007/978-3-319-15847-1_3
15. Thingiverse.com. Digital Designs for Physical Objects (n.d.). https://www.thingiverse.com/education
16. Mcleod, S.: January 1). Likert Scale Definition, Examples and Analysis (1970). https://www.simplypsychology.org/likert-scale.html
17. Servocity (n.d.). https://www.servocity.com/
18. Ackermann Steering (n.d.). http://datagenetics.com/blog/december12016/index.html
19. Arduino (n.d.). https://www.arduino.cc/
20. PlayStation® Official Site - PlayStation Console, Games, Accessories (n.d.). https://www.playstation.com/
21. Teach, Learn, and Make with Raspberry Pi – Raspberry Pi (n.d.). https://www.raspberrypi.org/

22. Teensy USB Development Board (n.d.). https://www.pjrc.com/teensy/
23. Mclurkin, J., et al.: Using multi-robot systems for engineering education: teaching and outreach with large numbers of an advanced, low-cost robot. IEEE Trans. Educ. **56**(1), 24–33 (2013). https://doi.org/10.1109/te.2012.2222646

Andruino-R2: Android and Arduino Based Low-Cost ROS-Integrated Educational Robot from Scratch

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Abstract. This work presents the design of a modular, extensible, open and low-cost mobile robot (35–40 euros) based on Android and Arduino, and compatible with ROS. It is intended to be used as an educational tool in vocational training labs and classrooms, or in engineering courses, as well as in e-learning or massive open online courses (MOOCs) as an alternative or complement to virtual laboratories, according to "BYOR: Bring [Build] Your Own Robot" educational policy, equivalent to "BYOD: Bring Your Own Devices" in the world of computers.

Keywords: Educational robotics · Vocational training · ROS · Android · Arduino

1 Introduction

In the 1980s, the launch and expansion of the IBM PC, easily expandable by hardware and a relatively low price compared to the computers of its time, marked a change in the implementation of automated and robotic systems. Similarly, the ubiquitous use of smartphones, with their numerous sensors, touchscreen, high connectivity, and relatively low price, is supposed to transform the implementation of automated and robotic systems, as shown in [1–4]. In educational settings, almost all students have an advanced cell phone, even in some disadvantaged social areas, so using it as an educational tool could be a motivating element for students.

To use smartphones for the implementation of automated and robotic systems that operate in the real world, it is necessary to connect or link the smartphone to an input-output microcontroller board, such as Arduino, IOIO, ESP8266 or similar.

The use of Arduino is increasing in education in electronics, control and robotics labs [5–8], and even in automation and industrial applications, as Arduino has become a de facto 'open standard' microcontroller board. In robotics, Arduino is used as an everyday tool in many schools, universities, and robotics enthusiasts, with a large community of roboticists around it, so it would be appropriate to take advantage of the educational results of existing knowledge enhancements.

On the other hand, Robot Operating System (ROS) [9] is an open robotics software framework that has become a standard interface for robots in the academic world with

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exponential growth from the beginning, and even with uses in industrial robotics. Several ROS-integrated educational robots have been developed in recent years [10, 11].

ROS is defined as "an open-source meta-operating system for your robot. It provides the services you would expect from an operating system, including hardware abstraction, low-level device control, implementation of commonly used functionalities, message passing between processes, and package management. It also provides tools and libraries to get, create, write, and run code on multiple computers". Some ideas behind ROS are:

- Software reuse, avoiding wasting time "reinventing the wheel" and coding it.
- ROS naturally integrates robots into networks, facilitates the communications of various robots and makes the robotic cloud possible.
- A middleware to hide and abstract the heterogeneity of hardware and communications for programmers. So ROS uses concepts like nodes, themes or services.
- A language independent architecture, although C++ and Python are the preferred languages, a ROS implementation in Java was also developed.

Beyond the technical aspects, one of the biggest advantages of using ROS is its open character, which has a large and active community of developers and users.

In a previous work [12], a low-cost educational mobile robot, called Andruino-A1 (see Fig. 1) based on Android and Arduino as an open system (hardware and software) was introduced. It was created to be used as a robotic educational tool to enable vocational education for adults (VET) and undergraduate students who perform learning tasks with real robots, in the laboratory, in the classroom or even as homework, according to the educational policy "BYOR: Bring [Build] Your Own Robot".

As indicated in [12], some future development lines from the Andruino-A1 were to provide the new robot with an interface compatible with ROS, the need to increase the integrated sensors to improve the measurement of the environment and complement the available sensors on the phone. Finally, the need to strengthen remote processing and remote access to functions and data, as is typical for cloud robots, was also noted as the future developments of the Andruino family of robots. This aspect became essential in the face of advances in the development of public clouds and the Internet of Things (IoT). The implementation of these new features, maintaining the cost limit of 35–40 euros, led to a new model in the Andruino family, called Andruino-R2 (shown in Fig. 2), which is presented in this paper.

The article begins by reviewing the design criteria for Andruino robots, according to their educational purpose. After that a description of the hardware and software components is given. In the final part, some simple developments and didactic activities are presented, that could be implemented and improved by VET or undergraduate students.

2 Design Criteria

The design and construction criteria for low-cost educational Andruino robots are as follows:

- **Simplicity:** Must contain the minimum number of hardware components, with a simple mechanical construction using easily accessible tools and simple assembly

Fig. 1. Andruino-A1 mobile robot.

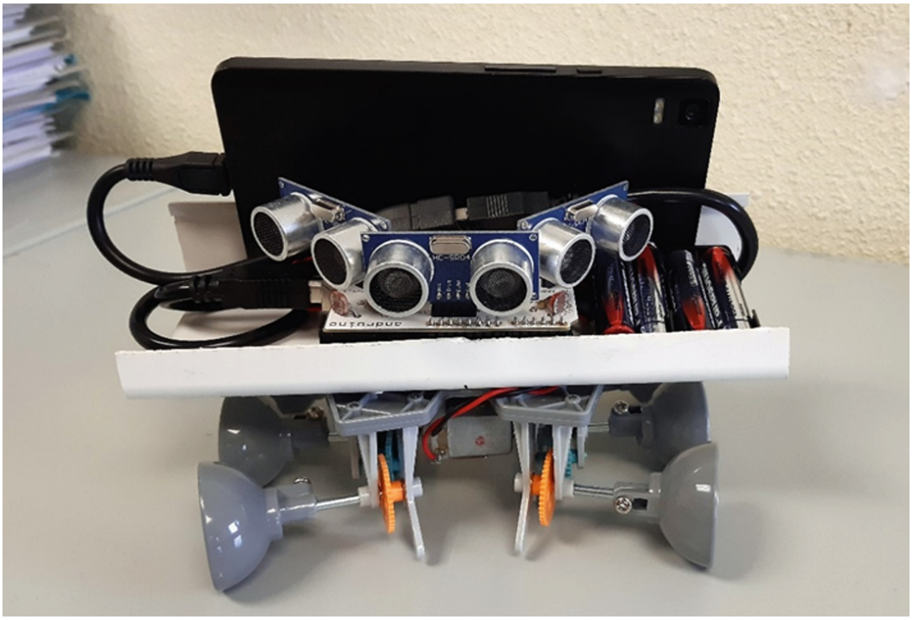

Fig. 2. New Andruino-R2 mobile robot.

techniques, and with the minimum number of lines of code. Sensors added to improve robot characteristics should be inexpensive.

- **Open:** students must be able to build it from parts that are easy to find (local stores or popular web stores) and must be modular and extensible. All information must be published, so that students or others can easily repeat and improve the design of the robot, using open tools. Preferring open source will not imply a prohibition on the use of other tools accessible to students, in the event that there is no open alternative, so as not to limit the creativity of students. Like a robotic system, the robot could be operated using a common robotic framework tool.
- **Low cost:** the robot should be as cheap as possible, considering the use of student-owned smartphones. A limit of 35–40 euros is defined.
- **Educational:** the construction of the robot and the improvements made by the students must implement the knowledge of the procedure in several areas, in a holistic vision of the development of the product, including hardware, communications, programming, robotics, IoT, artificial intelligence, networks, social skills and teamwork. Its educational purpose is the motto that inspires the project: "All doing is knowing/All knowing is doing".
- **Autonomous, cooperative and cloud robotics oriented:** the robot must have sufficient capacity to act as an autonomous robot, but must have the capacity to act on the orders of others or in cooperation with other robots (computers) that use networks for communication and the Internet, especially public cloud resources. Therefore, the robot must be able to remotely use the processing and services offered by the cloud, especially to take advantage of IoT and artificial intelligent evolution, which it often offers in the public cloud at no charge to students.

3 Andruino Hardware and Sensors

In accordance with the general design principle stated above, the robot should be built with the minimum hardware components to make the assembly process as simple as possible. As shown in Fig. 1 and Fig. 2, the complete robot has a mobile base, an Arduino with a specially designed shield, batteries, and an Android device. We discuss each of these parts in the following lines.

The mobile base includes 3–6 V DC motors and gearboxes. This base can easily be replaced by any other base purchased on the market or, better still, if possible, as is the case with mechatronics courses, the students themselves could design and build their own bases. We must draw attention to the fact that the absence of encoders or other electronic elements in the robotic base makes this much simpler, interchangeable and economical, so only 4 cables for DC motors connect the electronics to the selected base.

As we mentioned earlier, the system should allow you to take advantage of manufacturers' experience with Arduino. Whereas in Andruino-A1 [12] a one-way audio connection (using simple and asynchronous low-bit-rate communication with frequency shift modulation) was used in order to communicate Arduino with Android, in Andruino-R2 it is now done by using a bidirectional serial communication via USB On-The-Go (OTG). In this way, the Android phone acts as a host on the USB bus, in a role similar to that of a PC in standard Arduino communication. Also, the use of USB OTG makes the

Arduino and shield sensors work with Android batteries (usually a lithium-ion battery with more than 2000 mAh). Therefore, there is another system power supply only for motors, which are based on AAA batteries. This separation of power sources makes it easier to reuse development on other larger autonomous vehicles, so replacing the motors and batteries would be enough to drive either 12 V or 24 V DC motors.

A new Andruino shield has also been developed for Andruino-R2, as shown in Fig. 3. It is designed on a standard size Arduino board for compatibility and integrates three light sensors (LDR) and three ultrasonic sensors. Two LDRs were placed in the left and right side corners of PCB in a symmetrical configuration, under the shadow of ultrasonic sensors, this location is intended to detect the sidelight of doors and windows in an indoor environment. There is also a central upward LDR, which tries to detect ceiling light indoors.

Fig. 3. New Andruino shield.

The shield also supports three ultrasonic sensors for a low-cost range of sensors. An ultrasonic sensor is placed parallel to the cell phone, while the other two are in the left and right position, rotated 45°, to obtain a front range sensor from 30º to 150º. In addition to avoiding collision in a 2D environment, it is possible to obtain the metric distance, so ultrasonic sensors are also used in the calibration process to obtain an estimate of linear speed. The shield also supports a dual in-line integrated circuit to implement the H-Bridge to control the DC motors.

The design of a shield makes it easy to assemble the hardware for the robot, reducing failures in hardware construction. However, since the number of components is very low and no SMD components are used, it could also be mounted on a breadboard. The electronic design, from the schematic to the PCB, was done with the free tool Fritzing [13], and it is published as open hardware, so that students can improve the design or modification of the hardware to meet the requirements of their own projects, and easily produce their own electronic shields.

In summary, the Andruino-R2 robot is equipped with 3 ultrasonic sensors and 3 light sensors and those provided by the smartphone (camera, accelerometer, gyroscope, magnetometer, GPS, etc.). Table 1 shows the total cost of Andruino-R2 hardware parts from popular web stores, within the range of 35–40€.

Table 1. Andruino-R2's Hardware parts and cost.

Part	Cost
Chassis, UNO board and L293D H bridge	13,57€
Andruino PCB	13,00€
3 Ultrasonic Sensors	3,21€
3 LDR, resistors, cables and connectors	4,23€
TOTAL COST:	34,01€

Thus, Andruino's hardware development contributes to the following learning objectives, among others [12]:

- Basic knowledge of electronics, such as soldering, use of multimeters, identification and use of electronic parts, resistors color code and pin identification, among others.
- Construction of electronic prototypes, mainly Arduino shields.
- Knowledge of the DC motor control through the H-bridge.
- Knowledge of the Arduino open hardware architecture with its numerous hardware scalability options across shields.
- Basic skills in computer-aided electronic design and the use of CAD/CAE

4 Andruino Software

Andruino software is mainly made up of two parts: The Android software driver and the Arduino firmware. This section presents a brief description of them.

4.1 Android Software Driver

As a basic idea, the Andruino robot is considered a unique system, so Arduino is seen as an Android peripheral device that uses a USB bus to communicate, similarly inside the phone or tablet an integrated sensor connects to the core via of an I2C or SPI bus.

Using the RosJava libraries [14], the Andruino driver implements multiple ROS nodes in Java that run on separate threads. Running the robot's functionality on several separate nodes makes it more adaptable and configurable, and more computationally efficient. Some Java codes were originally implemented for Andruino, and other functionalities are adapted third-party codes, as is the case with IMU [15].

Figure 4 shows the nodes and topics in a visual line-tracking task using the image from the Android camera. As shown in the figure, the namespace for each Andruino-R2 node and topic is preceded by the word Andruino plus a number, which corresponds to the last byte of the IPv4 address, to easily allow cooperation between various Andruino robots that use the same master.

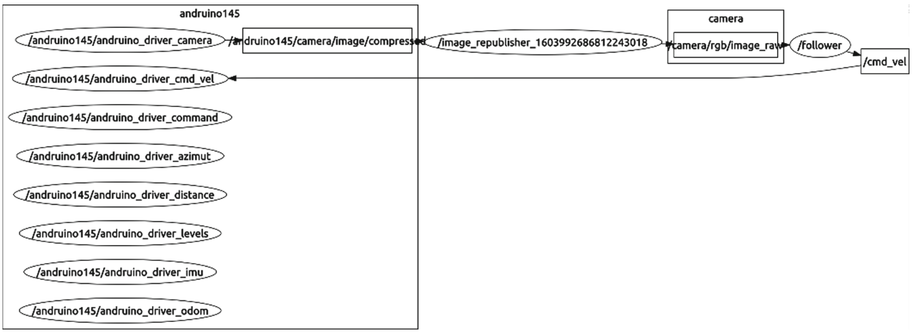

Fig. 4. Andruino-R2 nodes and topics in a visual line-tracking task.

Instead of Rosserial [16], the approach used in Andruino-R2 to communicate Android and Arduino is to use simple serial communication using USB On-The-Go (OTG) [17]. By using this serial communication, it becomes easier for the large number of students and hobbyists already using the Arduino to easily switch to using ROS. On serial communication, a character-based communication protocol was defined, so that students can understand in practice the concept of protocol and define their own protocols in their own robots.

4.2 Arduino Firmware

The Arduino code, written in a C-like language called Processing, runs a continuous loop, where it reads and sends data sensors, and performs the appropriate control actions based on the state of the robot.

The transition between states could be caused by serial incoming messages from the Android device, such as a yaw angle from the Android sensors or an order of movement from another ROS node on the network. In particular, two types of commands were defined to be received in Arduino: i) test commands used for calibration, initialization or specific tasks, and ii) standard commands to control the robot indicating linear and angular velocities.

In this part of the project, students could develop their low-level programming skills from a real-time perspective, and understand the link between hardware and software, gaining a complete overview of the system.

Therefore, Andruino software development (including Android and Arduino components) contributes to the following learning objectives, among others [12]:

- Use of Object-oriented programming languages (Java, Python,..) for mobile devices with professional developer tools as Eclipse or AndroidStudio, which they will most likely be exposed to during their working life.
- Administration of Android operating system (process, command-line interface, logs, threads, sockets, etc.).
- The ability to work with robot networks (cooperative robots), founded on the huge communications capabilities of smartphones: 4G, TCP/IP, WiFi, and Bluetooth.
- Knowledge of Pulse Width Modulation (PWM), to control the speed and direction of rotation of DC motors, both implemented by interrupts or in the main loop.
- Programming with Processing, a language like C, for performing low-level tasks. Using the programming and debugging environment of Arduino. Loading and running programs from the PC to the Arduino.
- Knowledge and use of threads in application programming using the Thread class to schedule tasks in the background that send messages to the main thread using Handler class.
- Knowledge and use of Android sensor framework, which allows us to monitor the motion, environmental and position sensors, which are the robot sensors.
- Knowledge of HTTP protocol and headers, to send images or other MIME types.

5 Examples of Tasks with Andruino-R2 in the Classroom

One of the main advantages of ROS is that it greatly facilitates integration with tools for computer vision or 3D modeling and simulation, such as OpenCV or Gazebo, among others. This section illustrates a couple of examples of tasks that can be performed with Andruino-R2 in classroom leveraging such as integration.

5.1 Understanding Computer Vision and Feedback Control

The first task is intended for students to acquire the basic notions of image processing and feedback control. To do this, using the smartphone's camera, the robot must detect a line of a given color on the ground, stand on it and start following it.

Figure 4 shows the ROS computation graph for this task. Thus, the ***/follower*** task subscribes to the image from the camera (which was previously converted into raw format, ***/camera/rgb/image_raw***). With this input, it has to compute the desired linear and angular velocities (***/cmd_vel***) that are sent to the Andruino-R2, and translated into actual PWM signals for each DC motor.

Figure 5 shows an experiment with Andruino-R2 starting separate from a green line, approaching it and keeping moving centered on it. Image from the on-board camera can also be seen on the smartphone screen. Notice that, due to the location of the camera on the left side of the smartphone, the center of the image does not correspond to the center of the robot, so an axis transformation must be performed in order for the robot's reference point moves actually centered on the line.

Image processing is done by using basic commands from the OpenCV library. Therefore, students learn how to acquire an RGB image and convert it to the HSV color space where it is easier to represent a color. They then threshold the HSV image for a range of

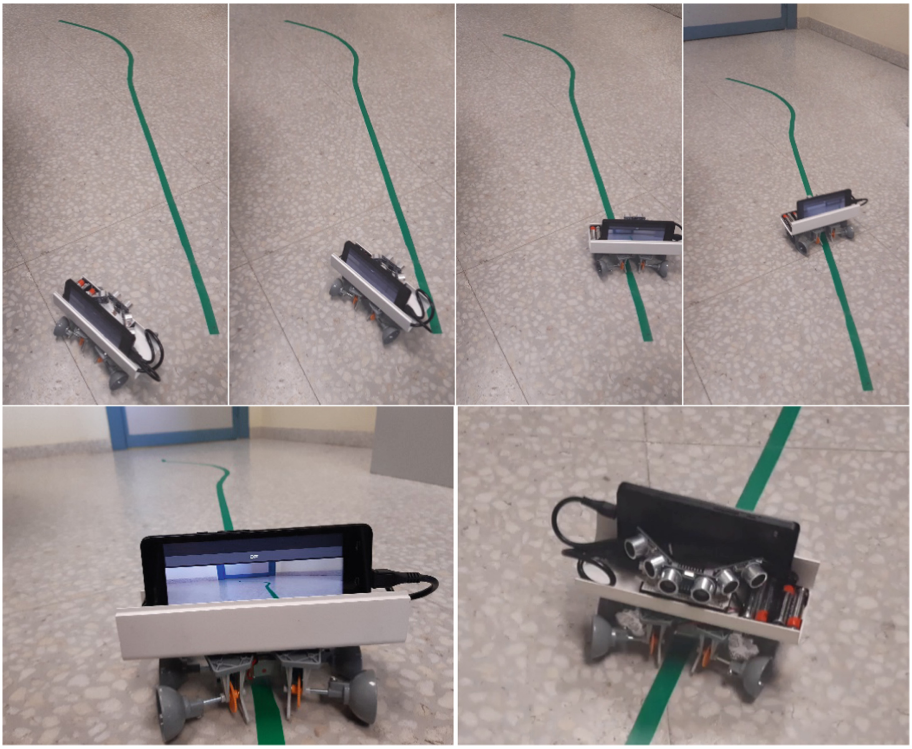

Fig. 5. Andruino-R2 performing a visual line-tracking task using Android camera.

the line color and apply the resulting mask to the original image. The mask is also used to calculate the target point on the line at a forward distance. The axis transformation is performed, and the lateral error is fed back into a proportional controller to calculate the desired linear and angular velocities. Figure 6 shows the control screen with the different steps.

5.2 Understanding Modeling and Simulation with Gazebo

It was desirable to have a simulation model of the Andruino-R2 robot so that students could become familiar with a simulation environment like Gazebo [18, 19]. First, using Blender [20], each part of the Andruino-R2 robot was modeled in 3D in detail. Later, the URDF model [21] was created to describe the physical elements of robots that contain details of dynamic and kinematic properties, and also includes plugins, with the appropriate parameters, to generate the behavior of the sensors in the environment of simulation (see Fig. 7).

Finally, with the use of Gazebo as a simulation tool integrated with ROS, the model was verified with several simulation tests in different scenarios and control tasks. Figure 8, for example, shows AndruinoR2 performing an obstacle avoidance navigation based on the smartphone camera image (also shown at the left) and their ultrasonic sensors, using the simulation tool and models.

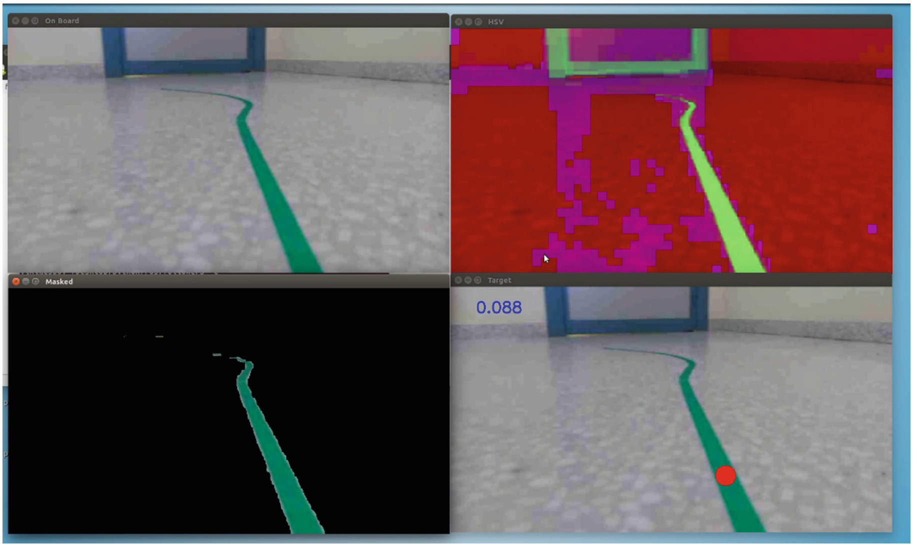

Fig. 6. Control screen showing the different stages (from top to left): a) Original image from Android camera; b) HSV conversion; c) Original image masked with the detected line; d) Original image with the selected target point marked on the line.

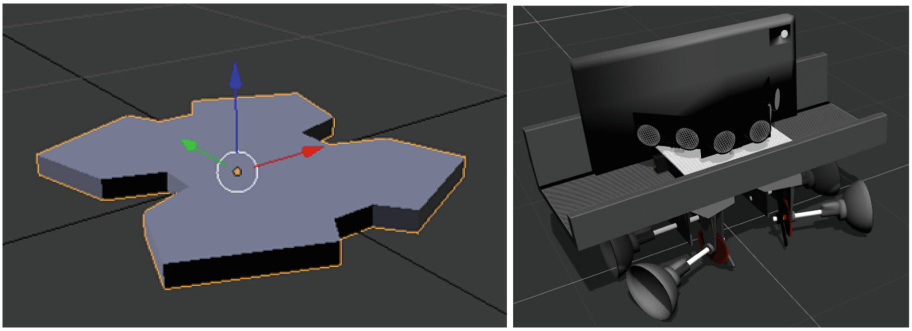

Fig. 7. Andruino-R2 3D model.

6 Conclusions

In this document we described the design of a low-cost ROS-integrated educational robot based on Android and Arduino, called Andruino-R2, for less than 35–40 euros (not including the cost of the smartphone), with a large number of sensors and communication resources: light sensors, ultrasonic sensors, GPS, camera, accelerometer, compass, Bluetooth, WiFi, etc. It can be easily built, programmed, and enhanced from scratch by students in the lab, in the classroom, or at home in e-learning courses.

Its initial purpose was to extend the characteristics of the Andruino-A1, so that the new robot could be integrated into the ROS environment and also allow taking advantage

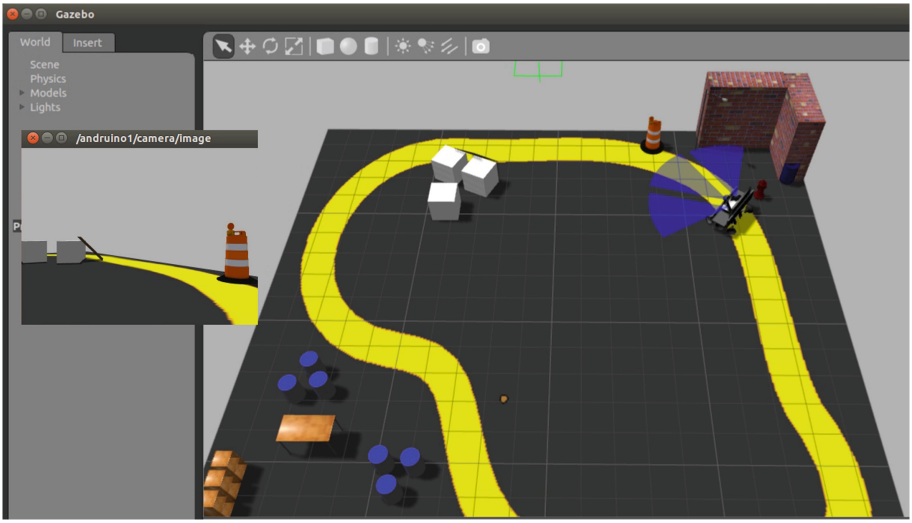

Fig. 8. Andruino-R2 simulation in Gazebo.

of the latest innovations in cloud robotics and artificial intelligence for robotics. Therefore, Andruino-R2 is a tool for education, research and innovation, but it maintains its simplicity, its low price and its open source. All in accordance with the educational policy "BYOR: Bring [Build] Your Own Robot", which encourages every vocational student to create or improve their own robots from scratch, and not just operate commercial robots or use simulation environments.

Future developments, which are already being implemented, involve tasks such as integrating Andruino-R2 into the IoT network, using artificial intelligence for object recognition in unstructured environments, or developing a biologically inspired robotic architecture for Andruino-R2.

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References

1. Hiraki, T., Narumi, K., Yatani, K., Kawahara, Y.: Phones on wheels: exploring interaction for smartphones with kinetic capabilities. In: Proceedings of the 29th Annual Symposium on User Interface Software and Technology, pp. 121–122 (2016)
2. Moazzami, M., et al.: ORBIT: a platform for smartphone-based data-intensive sensing applications. IEEE Trans. Mob. Comput. **16**(3), 801–815 (2017)
3. Diano, D.A., Claveau, D.: A four-legged social robot based on a smartphone. In: Robot Intelligence Technology and Applications, vol. 3. Springer (2015)
4. Alepis, E., Sakelliou, A.: Augmented car: a low-cost augmented reality RC car using the capabilities of a smartphone. In: 7th International Conference on Information, Intelligence, Systems & Applications (IISA), pp. 1–7 (2016)

5. D'Ausilio, A.: Arduino: a low-cost multipurpose lab equipment. Behav. Res. Methods **44**(2), 305–313 (2012)
6. Barber, R., Horra, M., Crespo, J.: Control Practices Using Simulink with Arduino as Low Cost Hardware. IFAC Proc. Vol. **46**(17), 250–255 (2013)
7. Grover, R., Krishnan, S., Shoup, T., Khanbaghi, M.: A competition-based approach for undergraduate mechatronics education using the arduino platform. In: Fourth Interdisciplinary Engineering Design Education Conference, pp. 78–83 (2014)
8. Sarik, J., Kymissis, I.: Lab kits using the Arduino prototyping platform. In: IEEE Frontiers in Education Conference (FIE), pp. T3C-1–T3C-5 (2010)
9. Quigley, M., et al.: ROS: an open-source robot operating system. In: ICRA Workshop on Open Source Software, vol. 3, no. 3.2, p. 5 (2009)
10. Araujo, A., Portugal, D., Couceiro, M.S., Rocha, R.P.: Integrating arduino-based educational mobile robots in ROS. J. Intell. Robot. Syst. **77**(2), 281–298 (2015)
11. Barbosa, J.P., et al.: ROS, android and cloud robotics: how to make a powerful low cost robot. In: 2015 International Conference on Advanced Robotics (ICAR), pp. 158–163 (2015)
12. López-Rodríguez, F.M., Cuesta, F.: Andruino-A1: low-cost educational mobile robot based on android and arduino. J. Intell. Rob. Syst. **81**, 63–76 (2016)
13. Knörig, A., Wettach, R., Cohen, J.: Fritzing: a tool for advancing electronic prototyping for designers. In: Proceedings of Third International Conference on Tangible and Embedded Interaction (2009)
14. Kohler, D.: Rosjava core. http://rosjava.github.io/rosjava_core/. Accessed 15 Jan 2020
15. Rockey, C.: Android Sensors Driver. https://github.com/chadrockey/android_sensors_driver. Accessed 15 Jan 2020
16. Ferguson, M.: Rosserial. http://wiki.ros.org/rosserial. Accessed 15 Jan 2020
17. Suzuki, K.: FTDriver. https://github.com/ksksue/FTDriver. Accessed 15 Jan 2020
18. Koenig, N.P., Howard, A.G.: Design and use paradigms for Gazebo, an open-source multi-robot simulator. In: IEEE International Conference on Intelligent Robots and Systems, vol. 3, pp. 2149–2154 (2004)
19. Gazebo. http://gazebosim.org. Accessed 15 Jan 2020
20. Blender. https://www.blender.org/. Accessed 15 Jan 2020
21. URDF at wiki ROS. http://wiki.ros.org/urdf. Accessed 15 Jan 2020

An Exploratory Study About the NAVS Robot Emotional Effect in Educational Contexts

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Abstract. Robots can have different appearance to foster the learning process. The ability of robots to show emotions could be related to the anthropomorphic and non-anthropomorphic characteristics. Learners can use the robot's emotions in order to improve their learning process. The main idea is exploring the conditions to show emotions by mediational tools with emotional characteristics. This paper presents the result of our research process about the design and validation of a non-anthropomorphic robot called NAVS which expresses emotions. The experience involved 363 children ranged 9 and 14 years old. They come from the Public School called *Compartir* of the municipality of Soacha in Colombia. The results are simple, but it contributes to understand the recent phenomena about use emotional tools without human appearance in learning contexts.

Keywords: Emotional robots · Non-anthropomorphic robot · Education with technology

1 Introduction

In the educational field, the devices are considered mediation tools. This means that students use them as representation systems for developing knowledge. The relation established between the subject and the tool affects the learning process. Robots have been the mediational tools with the closer characteristics to humans. In education, robots have evolved through the Intelligent Tutoring Systems and actually robots have two ways for enhancing learning: virtual and physical. But, emotional characteristics either virtual or physical claim to be explored. The document begins with a literature review description in order to highlight some technical characteristics of the robots used in educative contexts. After that, a design process of the robot NAVS is presented. Finally, but not less important, the validation process is carried out.

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2 Literature Review

This section describes the articles review associated with the use of anthropomorphic and non-anthropomorphic robots in education. Since the integration of robots in educational environments have appeared different technological proposals. The first robots in scholar environments were no-anthropomorphic and they were equipped of basic sensors that allow the robot navigate in known and unknown environments but they can not interact with humans through educative emotional-expression. Until some years ago humanoid robots have started to be used in school environment where one of the advantages has been the ability to establish social relationship through emotional expression. From the integration of the two types of robot mentioned before has appeared an interest for designing non-anthropomorphic robots that also have the emotional expression ability to establish better emotional bonds with the students during learning. The implementation of non-anthropomorphic robot has made students interaction easier with these pedagogical tools because they help to create learning environment that develop their physical knowledge of the things no longer through gestures or actions of anthropomorphic bodies, but by movements, reproduction of sounds and light effects; creating another emotional communication language that allows improve their teaching-learning process. On the other hand, the non-anthropomorphic robots have helped in a meaningful way teaching process in schools and universities by means of their kits because they were the first implemented in the robotics training and not education with robotics. A summary of appearance designs is presented in [1]. The appearance considers human-like anthropomorphic robots such as Nexi, KOBIAN, Meet Milo, KASPAR, Kismet, NAO, iCub, Pepper, Roboy, non-humanoid anthropomorphic robots such as Nabaztag, Robovie, PARO, Leonardo, Pleo, iCat, Mamoru, BAXTER, and robots Non-anthropomorphic such as Keepon, BUDDY, JIBO, Romibo, Romo, Sphero, Quemes. The appearance of the robot affects the recognition of the abilities of the robots while there is a relationship between appearance with features such as functionality, experience, and will, [2,3]. It also affects human non-verbal behavior, [4]. Even robots can convey the need to be touched and thus establish kinesthetic communication channels, [5]. The emotional behavior of robots promote feedback about learning and social interaction between the user and the robot. The emotions transmitted by the robots allow establishing, maintain, change or terminate relationships that guide the thinking processes during learning.

3 Design Process

The design contains considered aspect as size, non-anthropomorphic appearance, lights and sound skills. The main requirement was the capacity to express emotions. Due to, the non-anthropomorphic appearance, the options to express emotions are joined to aspects such as velocity, sound and color. From the emotional perspective, velocity is a physical phenomenon which has evolved as a

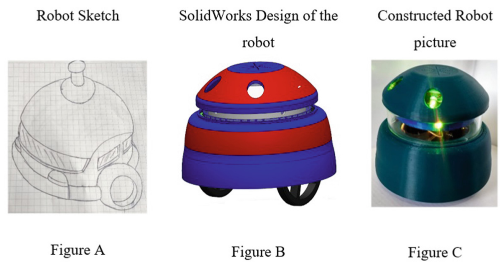

Fig. 1. The figure describes the design process of NAVS robot. The figure A presents a sketch of the basic characteristics for the emotional expression of NAVS. The figure B illustrates the design of the robot NAVS and the figure C the constructed robot and showed in the validation.

resource either to show emotions or understand emotions. Humans emotions have used the velocity of movements to transmit messages about their emotional state. This phenomenon is showed by other agents as animals. For example, dogs show emotional states through their tail movements which include velocity. To design NAVS, the speed of the two wheels and the speed in the trajectory of the robot were considered. From the emotional perspective, sounds are physical resources which are joined to body and cognitive capacity. Humans create emotional patterns to understand emotional behavior of other living beings. While the language of human beings is supported in centuries of evolution, humans understand the sounds of animals through a relationship with their behavior. To design NAVS, a sound effect library named Bleep was used. The library includes 211 sounds about emotions as Activation, Affection, Anger, Arousal, Confusion, Dying, Drunk, Exertion, Falling/Descending, Epiphany, Grumbling, Hurt, Jumping, Laughing, etc. From the emotional perspective, colors are physical resources. Although, the human body has a small variety of colors to express its emotions, from the field of psychology, color codes have been proposed to understand emotions. Some of these codes are already well recognized by the Human-Machine Interaction and Human-Robot Interaction fields. To design NAVS, the range of colors that results from the combination of the colors Red, Blue, Green was used. Finally, structure is a resource with phenomenological implications. That is, physical appearance defines behavior patterns. Based on experience, humans interact with other humans and animals. However, the interaction with unnatural devices such as robots, allows the appearance to be used as the first form of prediction of the robot's behavior, which is complemented during the interaction. To design NAVS, a CAD software was used. The robot's electronic is simple. The electronic design was inspired by the capabilities of the Arduino board. Then, Arduino MEGA, bluetooth module, micro SD module, a couple of servomotors, and RGB leds were used. The structure is composed by an external casing with a tool to put a pencil or pen as a support, a circular base where the servomotors are placed, the audio module, the battery and the Bluetooth module, an intermediate base where the Arduino board goes, a circular support for the lights of the robot, an acrylic cylinder and at the top (cover) there are leds for the eyes and mouth, and the support of the speaker that plays the audio. (see Fig. 1.) Finally, to show emotions a multimodal fusion-method needed be considered. The theoretical framework to control the emotional behavior of NAVS is based on the work of Brackett who analyzes the Implications for personal, social, academic, and workplace success of teachers [6]. According to the model, Control and Acceptance axis are related to learner's behavior while the learning process. Then, the NAVS variables as velocity, sounds, and color are joined to the variables. To present this research experience, the Control and Acceptance values were calculated by a teacher and send to NAVS through a bluetooth. Next, NAVS' emotional behavior depend on the values sent by the teacher.

4 Validation Process

The validation process was carried out with 363 students of fourth and fifth of basic elementary school of the Educative Institution Compartir Soacha - Bogotá - Colombia. During the experience, NAVS was exposed with 10 emotional routines which included movement, sounds and lights. To validate the robot's emotional expressions, children observed to NAVS and identify the emotions. For the experimentation of the expressed emotions by NAVS robot, it made a short introduction of 3 min where it carried out a demonstration of the robot and its operation through the presentation of a trajectory. Then, it explained to children they had to identify the emotion showed by the robot in the survey submitted, there appeared 10 emotions and they had to value them from one to five stars, being five the highest expression and one the least expression. At the end of the exploration for identifying which was the emotion that caused most impact, children wrote on a sheet the emotion they liked most and the reason they liked it so much. The experimentation was carried out in each classroom of the surveyed children of the Educative Institution Compartir, children were organized in a round table in order they could have a better visibility of the robot, which was located in the middle of each classroom.(see Fig. 2.) Before to start the experiment, an informed consent was signed by the parents for taking photos and video-recording. At time of making the experimentation it was submitted to the students a survey where they have to fill in some personal information, observe and listen to the movements made by the robot and explain which was the emotion that most impacted them. The way how children interacted with NAVS was initially through observation where they noticed the robot was moving, produced sounds and changed of color. Afterwards, children and robot interacted when they perceived those movements which were representing an emotion or mood, seeing this, the students expressed their pleasure because they felt they identify themselves with the way how they show their emotions, in addition to being an innovative and tender object for them. To tabulate the information collected in the validation, they typed the values in Excel program, afterwards, a histogram were made according to the identification and non-identification level of the emotions in NAVS. The result is show in Table 1.

Fig. 2. The stage of the research presents the population and the robot NAVS. It was developed in the Educative Institution Compartir Soacha. (Colombia)

Table 1. Results of the survey about how children recognized the robot emotions.

Emotion	Recognition	Non-recognition
Doubtful	89%	11%
Boredom	74%	26%
Joy	95%	5%
Sadness	93%	7%
Dissatisfied	52%	48%
Fear	88%	12%
Tiredness	85%	15%
Interested	64%	36%
Exhorting	93%	7%
Neutral	56%	44%

Confusion (Doubtful) was expressed through an erratic trajectory moving from forward to backward, with fast and slow movements, with a related audio, a light in its mouth with linear shape and light purple color eyes. *Boredom* was expressed through a trajectory where went forward and turned to the sides, it stayed quiet for few seconds and went forward slowly with a paused audio as complaining, a light in its mouth and magenta eyes color. *Joy* (Guiding) was expressed through a trajectory that started turning to the left, went forward a little and then turned to the right with medium speed, it had an audio with laughter, a light in its mouth with a semicircular shape and green color eyes. *Sadness* was expressed through a slow trajectory turning back and forth, it returned and in all the movements were reproduced a paused audio as a lamentation and a light in its mouth with a semicircle shape down and purple color eyes. *Frustration* (Dissatisfied) was expressed with short rectilinear movements and medium speed in its trajectory making a triangular displacement in which reproduced a complaint and a grief sound, the light of its mouth and dark gray eyes. *Fear* was expressed through with a zigzagging trajectory and rectilinear at the end. The movement was slow with an audio of wailing and a light with brown color in its mouth and eyes. *Tiredness* was expressed with a straight and circular trajectory with a big diameter with a low speed at the beginning and medium speed at the end, it presented an audio with sounds of fatigue and dissatisfied, a light in its mouth and dark yellow eyes. *Surprise* (Interested) was expressed through rectilinear movements, describing a ladder shape and returning to its initial point, doing in a medium speed and with an audio with sighs and anxiety. In its mouth and eyes had a light purple color. *Anger* (Exhorting) was expressed through a straight trajectory at the beginning, with fast speed and then many circulars with low speed, at the end with a straight fast movement. It reproduced an anger and fury audio. It had a light in its mouth and its eyes are red. *Neutral* was expressed through a straight trajectory all the time, that had a trapezoid shape with a medium speed. It had an audio that represented the basic sounds that produces a robot, with a light in its mouth and eyes of blue color.

5 Conclusion

In the educational context, the emotions of robots must be associated with the learning needs. Exploration with non-anthropomorphic robots is a research path oriented towards the integration of tools with agentivity without human appearance. Resources such as speed, sound and light are useful to foster the learning through non-anthropomorphic tools.

Notes and Comments. The authors express gratitude to Universidad Distrital Francisco José de Caldas, Bogotá, Colombia.

References

1. John, P.R.: Interacción Humano-Robot: Consideraciones de implementación en ambientes escolares. Noria, Investigación Educativa. Universidad Distrital Francisco José de Caldas. Volumen 3. Número 1. 2019. Bogotá (2019)
2. Gray, K., Wegner, D.M.: Feeling robots and human zombies: mind perception and the uncanny valley. Cognition **125**(1), 125–130 (2012)
3. Hegel, F., Lohse, M., Wrede, B.: Effects of visual appearance on the attribution of applications in social robotics. In: ROMAN 2009-The 18th IEEE International Symposium on Robot and Human Interactive Communication, pp. 64–71. IEEE, September 2009
4. Kanda, T., Miyashita, T., Osada, T., Haikawa, Y., Ishiguro, H.: Analysis of humanoid appearances in human–robot interaction. IEEE Trans. Rob. **24**(3), 725–735 (2008)
5. Yohanan, S., MacLean, K.E.: The role of affective touch in human-robot interaction: human intent and expectations in touching the haptic creature. Int. J. Soc. Rob. **4**(2), 163–180 (2012)
6. Brackett, M.A., Rivers, S.E., Salovey, P.: Emotional intelligence: implications for personal, social, academic, and workplace success. Soc. Pers. Psychol. Compass **5**(1), 88–103 (2011)

Easy Controlling a Robot Using Voice for Hobbyists

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Abstract. We present a tool for the easy implementation of the robot control via voice, which we have developed. It is based on an application for mobile phones with Android OS which employs Google cloud for Speech-To-Text translation. The application records voice by the mobile phone microphone, calls the cloud service via the Internet and transmits the resulting text command to the robot using TCP protocol. The system can be combined with any robot board equipped with WIFI, e.g. Raspberry Pi. This is an easy way to make robot control much more attractive for students of robotics or hobbyists while its implementation on the robot is still as easy as text parsing. Moreover, it is a zero-cost solution, since no additional hardware except an ordinary mobile phone (which is vastly available) is required.

Keywords: Robot · Voice control · Cloud service · Text-to-speech · Mobile application · Robotics education

1 Introduction

Devices controlled via voice commands are becoming usual. Moreover, students often meet advertisement of novel products or news about breaking technologies which can be significantly overrated. As a result, students, who have music box equipped with Cortana at home, expect at least the same from robots they meet in the educational process and could think of their technology as not up-to-date. How to persuade them that they are dealing with useful technology if the capabilities of the robots they create in school are so far from their expectation? We need to show them that the content of education is relevant to the production of robots with capabilities they expect.

Particularly we can show that remote control of robots via keys on a keyboard is not so different from analogical control based on voice commands. Students develop almost the same control program, but finally, they can speak to their robots. And that is the AI which nowadays everybody talks about!

We have designed and developed a zero-cost solution to turn an ordinary remote control to voice control in an easy way. It is suitable for any robot control board with WIFI. We discuss its design and implementation in Sect. 2 and Sect. 3. We have tested the solution on the robot based on Raspberry Pi3 and Parallax Boe-bot gear [2] (Sect. 4).

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Finally, we would like to share our solution, so we present how to get it and how to use it in Sect. 5.

Our idea follows multiple trends of involvement of mobile phones into robotics education due to their high computational power and interesting sensors. Mobile phones are used as control board of robots [1] and also remote controllers of robots, e.g. by movement of smartphone monitored by the embedded gyroscope sensor [4].

Our solution follows also from the idea of cloud service involvement. Here we employ the fact that calling of Google cloud from Android on mobile phones is neither restricted nor charged. (The same strategy applied on PC would encounter several troubles.) Cloud services provide better quality and their response is fast enough.

2 Our Approach to Easy Voice Control

We suppose our robot is controlled by a board equipped with WIFI, so the robot connects to wireless LAN and gets an IP address. Nowadays plenty of such boards are available, e.g. Raspberry Pi3 [3] and they are becoming more popular than Bluetooth. When we aim to implement their remote control, we need to code a TCP server or UDP receiver of text commands. Typically, we develop a program in Python programming language which handles the text commands like follows:

```
boebot = Boebot(port= '/dev/ttyS0')
tcp = tcp_server(port=7171)
while True:
    command = tcp.recv()
# ------------ to be designed by students -------------
    if command == 'l':
        boebot.rotateLeft()
    elif command == 'r':
        boebot.rotateRight()
    elif command == 'f':
        boebot.forward()
    elif command == 'b':
        boebot.backward()
    elif command == 's':
        boebot.stop()
# ----------------------------------------------------
    time.sleep(0.1)
```

Then we launch the program on the robot and from a suitable client like Putty on the PC we get a connection to the employed TCP port on the robot and send commands by pressing keys on keyboard.

If we would like to control the robot via voice commands, it would be pretty difficult to implement it on-board. Typically, we even have no microphone on the board and the only way how to record voice is to connect a camera with an integrated microphone via USB. Even then significant troubles can be caused by the low sensitivity of the microphone, by the noise in the classroom or by limited computational power of the voice recognition system on board. As a result, the impression of students is that such voice control is not fully operational.

A much better approach involves smartphone (Fig. 1). In that case, the distance between student and microphone is short, thus the recording is less sensitive to noise and there are no troubles with microphone sensitivity. The mobile phone can connect to the local wireless LAN via WIFI, e.g. in the same way as the robot. Without any modification of the program running on the robot, we can install TCP client on the mobile phone and then when we enter the IP address of the robot and the port of the control service to the client, we can perform the same control via keys in the same way as on a PC. To achieve more, we need to implement our own application, which enables the user not only to enter the IP address of the robot and port of the service but also records voice, turns it into text and transmits the recognized text to the robot in the same way as the keys have been transmitted before.

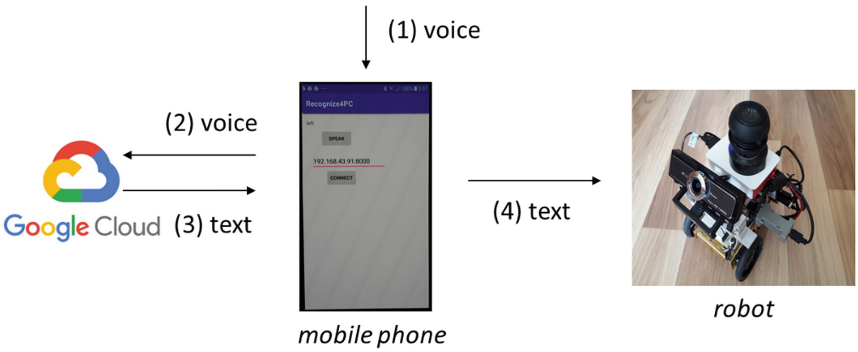

Fig. 1. Schema of our approach to voice control of robots. We employ the microphone in the mobile phone from where the recorded voice is sent to cloud to be translated into text. Then the text is sent to the robot in the same way as of control keys from a remote PC. (Handling of the text commands is up to the developer of the robot, but it is a task almost as simple as the handling of the control keys.)

The remaining task is to provide Speech-To-Text translation on the mobile phone. Though there are some solutions for this task which could be installed on the mobile phone, they usually require to use a particular language, record voice samples and cause certain issues during the setup. Much better quality and no setup can be achieved if we employ the huge power of the cloud. Particularly, in our case, we use a mobile phone with Android OS, so we call Google cloud. Google cloud is remote but extremely powerful. It responds typically within 40 ms in the USA, 80 ms in the EU and Japan, which is a better response than we would get by calling the recognition process locally. With a proper setup of the call we do not need to specify the language (mobile phone knows already a lot of information about us) and no details from the speaker is required. The quality of the recognition varies from language to language, but in our experience, it works sufficiently well for languages like Slovak. Thus, students can speak with the robot in their native language. Even, more languages can be implemented at the same time and their support requires no special treatment in the mobile application setup.

Just the onboard program has to handle text commands in more languages. In the same way, we can handle lower quality of recognition which could appear. If a command is sometimes recognized as a different word, the robot will obey both the correct word and the wrong one. From the beginning, we handle just the correct words and the wrong ones are added later when they are detected as a cause of failures. Of course, this can help us only if we are lucky and the wrong words do not interfere with the correct ones.

This solution works fine while the wireless LAN is available for us. It is granted in the classroom, however, sometimes we would need e.g. to present the robot at an exhibition or to run it under outdoor conditions, where wireless LAN is not necessarily available. In this case, we can start access point in mobile phone and let the robot to connect to WIFI created by the mobile phone. In this way, the WIFI interface of the mobile phone is used for connection to the robot and Mobile data interface is used for connection to the Internet and the cloud. Thus, we can employ the solution everywhere mobile network signal is present.

3 Implementation Details of Our Solution

As already mentioned, we have developed an application running on an Android-based mobile phone. To achieve this, we have used the Android studio IDE platform [5, 6]. It is not a difficult job since Android OS has strong support for recording voice and its translation to text using the cloud. Another task is to implement a TCP client which connects to the robot and transmits any recognized text to it. Individual texts need to be separated somehow so we put each text to an individual line.

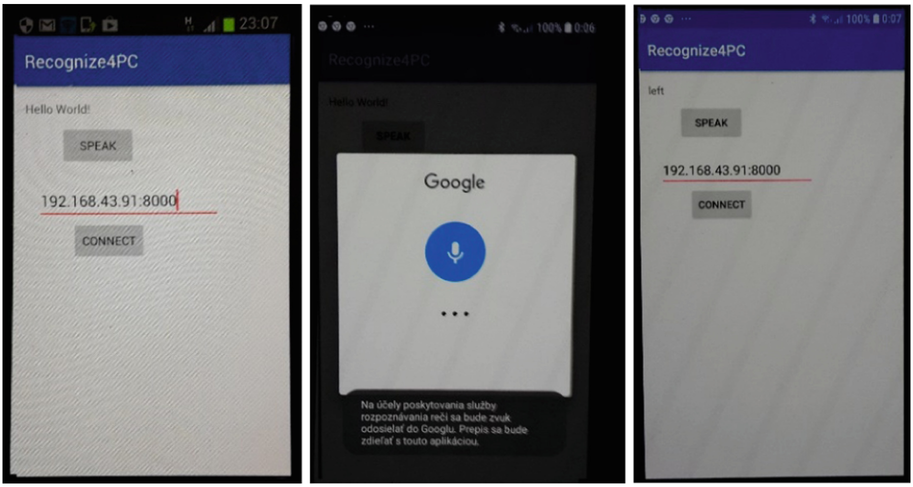

Fig. 2. Application for mobile phone which turns voice commands to text and sends it via TCP to the robot board.

Finally, we employ the IDE for the definition of the graphic user interface. There are just four items in the GUI: the last recognized text, button invoking voice recording and recognition, IP address and port of the robot service (entered in form IP:port, e.g. 192.168.43.91:8000) and a button for initialization of connection (see Fig. 2).

The server on the robot side is almost the same as in the case of the remote control via the keyboard. Just the handling of the received data is more complicated now since we have the text of natural language instead of key codes. However, having a few prepared matching functions, it is relatively easy for students to implement it in the following way:

```
import re, time, os
from boebot import Boebot
from Recognize4PC import Recognize4PC
boebot = Boebot()
tcp = Recognize4PC()
while True:
    try:
        command = tcp.command()
        if len(command) > 0:
# ------------ to be designed by students -------------
            if tcp.match(r'type (.*)',command):
                print(tcp.matched[0])
            elif tcp.match(r'left'):
                boebot.rotateLeft()
            elif tcp.match(r'right'):
                boebot.rotateRight()
            elif tcp.match(r'forward'):
                boebot.forward()
            elif tcp.match(r'backward'):
                boebot.backward()
            elif tcp.match(r'stop'):
                boebot.stop()
# -----------------------------------------------------
        time.sleep(0.1)
    except:
        os._exit(1)
```

A great effect can be achieved if we equip the robot with a speaker. Then the robot can respond to our voice commands by voice reaction. The best hardware solution for such speaker is the speaker for mobile phone. Though it is not so common as mobile phones, it is still very popular among young people who use it for music production from their mobile phones.

Having a speaker on the robot we can employ tools like *espeak* for speech synthesis which is less complicated than speech recognition and can be effectively performed on the robot. The robot is then able to confirm command reception by saying “OK” or “I see”. On the other hand, the robot can say “I do not understand”, when the received command is not recognized:

```
from speak import speak
…
/* ------------ to be designed by students ------------- */
             if tcp.match(r'say (.*)',text):
                 speak(tcp.matched[0])
/* ----------------------------------------------------- */
…
```

We can implement also new commands dealing just with language communication, e.g. “say X” will be responded by X, e.g. “say I am a robot” is responded by “I am a robot”. In this way the communication overcome set of commands corresponding to capabilities of the robot actuators and students can easily implement behavior as “Let me introduce X” responded by “Hi X, how do you do?”.

We can also combine remote control from mobile with other clients, e.g. notebook equipped with a joystick. In this case, we do not need to launch another service on the robot, we just have to support more clients at the server running on the robot and on the client side we use natural language as communication protocol: e.g. turning joystick to left, we transmit command “turn to left”, clicking joystick button 1, we transmit command “say eee” and so on.

4 Test of the Implemented Control

For testing of our solution, we have implemented it on a robot named PingPong V (see Fig. 3). It is based on Raspberry Pi3 control board connected to older Boebot gear (with Javelin processor board). We have powered it from power bank (also very common, cheap and powerful component provided to robotics by mobile phone industry). Raspberry Pi3 has WIFI which we can set up to connect to a local wireless LAN or mobile phone access point. We have implemented a TCP server which receives text commands in natural language, in both English and Slovak. Commands enable to control the movement of the robot and a few additional language conversations. This robot is equipped with a speaker, it can hence respond to commands using synthesized by voice.

Testing our solution proved that it is not only fully functional but is also very easy to use. The only problem found was related to the Android recording procedure which does not stop recording when there are significant sounds in the room where we are located, e.g. rock music in the exhibition hall or shouting students in the classroom. The recording procedure is also responsible for delay in the voice command execution. Though the delay caused by the calling cloud is minimal, the recording procedure needs about 1s of quite just to stop recording. Unfortunately, this behavior is a part of the Android OS, and it is not open for modifications.

Image of the robot for Raspberry Pi3 including support of opencv and dlib libraries is available at www.robotika.sk/raspberryPi3/raspberryPi3-opencv-dlib-image.zip.

Teaser video is available at https://youtu.be/tFvfGI9swDM.

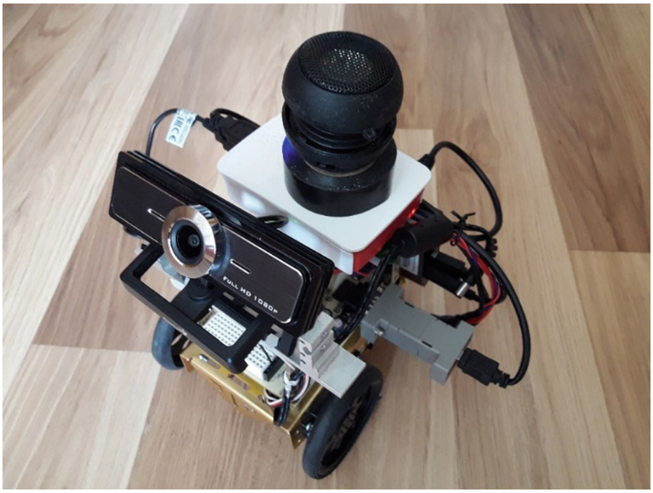

Fig. 3. Robot controlled via commands

5 Where to Get and How to Use Our Solution

We have prepared a page on Github for download of both deployment and source codes: https://github.com/andylucny/Recognize4PC.

The source codes of the apk are written in Java, while the examples of the robot side are coded in Python or C++.

The minimal content for download is Recognize4PC.apk which can be transferred to mobile phone and installed. The easiest way to manage it, is to transfer the apk file somewhere on mobile phone filesystem and then open the file by Total Commander application (installed to the mobile phone from Google Play).

One can also download a demo program of the TCP server running on the robot.

Finally, Android studio project could be downloaded if there is a requirement to modify the application.

When the application is installed, it can be launched at any time. After the robot is started, the user has to enter the address and the port of the service on the robot and click on the button Connect. Before that, the user has to reveal the IP address of the robot (the port is selected by him). In the classroom, it is easy to connect a monitor, a keyboard and a mouse peripheral to the robot board and find the IP address from a command line using the *ifconfig* utility. Outside the classroom, we would prefer to connect the robot to an access point of the mobile phone and in this case, we can employ user interface of the mobile phone to list the connected hosts and show their IP addresses. Either way the user has to know IP address not just because of the voice commands, since but because he also needs a way to start and stop the program in the robot (e.g. he has remote access to the robot via ssh or VNC, so he needs to enter the IP address to ssh or VNC clients).

6 Conclusion

We have developed a zero-cost solution for extension of robot control via voice commands. We have provided it for free download together with a demo of the robot program to make its deployment as easy as possible. Its employment is easy and can make students' robotics projects much more attractive and just a little bit more difficult for implementation. On the other hand, though it is very good for students' inspiration, it is not dedicated to building practical applications – hence user needs to hold a smartphone in the hand, so the main advantage of voice control is not addressed.

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References

1. Aroca, R., de Oliveira, A., Goncalves, L.: Towards smater robots with smartphones. In: 5th Workshop in Applied Robotics and Automation (2012)
2. Balogh, R.: Basic activities with the Boe-Bot mobile robot. In DidInfo 2008, 14th International Conference. FPV UMB, Banská Bystrica, Slovakia (2008)
3. Kearney, K., Freeman, W.: Creative Projects with Raspberry Pi. Harry N. Abrams, New York City (2017)
4. Lemus, D., van Frankenhuyzen, J., Vallery, H.: Design and evaluation of a balance assistance control moment gyroscope. J. Mech. Rob. **9**(5) (2017)
5. Meier, R., Lake, I.: Proffesional android 4th edition, Wrox (2018). https://github.com/retomeier/Wrox-ProfessionalAndroid-4E
6. Android Notes for Proffesionals, Stack Overflow. Free Programming Books, GoalKicker.com (2018). https://books.goalkicker.com/AndroidBook/

Programming Environments

Physical Bits: A Live Programming Environment for Educational Robotics

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Abstract. The use of physical computing devices as teaching tools presents several challenges for educators and learners. Most introductory programming environments help to learn programming by removing the possibility of syntax errors, usually by using a visual programming language. However, understanding syntax is just one aspect of the learning process. One of the most challenging tasks for students is to build a correct mental model of the underlying machine model and its execution dynamics. Additionally, visual programming languages present issues when transitioning to text-based languages. In this paper we present Physical Bits, a web-based programming environment for educational robotics that attempts to solve these issues by providing a live programming experience using both visual and textual programming languages.

Keywords: Educational robotics · Live programming · Block-based · Introductory programming

1 Introduction

In the last couple of decades, the use of physical computing devices as teaching tools has increased all over the world. Experts agree on the importance of introducing children to computational thinking, programming, and technology. Using robots in the classroom encourages students into learning these concepts.

Teaching programming to young children is not a recent trend, there have been experiences designing and implementing educational programming environments since the 1970 [1, 2]. Most educational programming environments developed in recent years share the same visual programming style, usually in the form of blocks that snap together when they form valid constructs (inspired by Scratch [3]). Studies show that visual programming environments help to learn programming by removing the possibility of syntax errors and simplifying the programming language, which allows students to focus on understanding the underlying concepts [4, 5]. However, some studies reveal that learning the syntax is not the principal problem because the students only struggle

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with it at an early stage. One of the most challenging tasks for students to assimilate is to correctly predict the impact of the source code they are writing on the actions performed when the program is executed. Teaching programming presents a dichotomy that is not easy to grasp for beginners: the source code is explicit and visible while the execution dynamics are implicit and harder to understand. Studies show that most student misconceptions are related to an imprecise perception of the execution model presented by the programming language [6].

In order to solve this problem, some studies propose to design educational programming environments in a way that makes the relationship between the source code and its effects more explicit. Most virtual introductory programming environments provide the impression of changing a program while it is running, a feature often described as liveness [7]. In a live programming environment, the users change the program and receive immediate feedback on the effect of the change, without requiring any manual compilation steps and minimizing the time wasted waiting for the code to begin executing. Live programming shortens the feedback loop and encourages experimentation and programming by “Trial & error” [4]. Some environments also support monitoring the internal state of the program by showing the value of the variables as well as highlighting the currently executing blocks. These features, however, are rarely seen in educational programming environment for physical devices [8] and the ones that support it usually do so in detriment of the autonomy of the robot, requiring a computer connected at all times in order to run the programs and send the commands to the robot as they are executed. Due to the latency of the communication, these environments are limited to projects that do not require precise timing and cannot be used in many robotics competitions.

Another common problem identified with teaching using visual programming environments is the eventual transition to text-based languages. Most block-based programming environments do not aid the learner in the transition to text-based languages, instead they are more concerned with simplifying the programming language and hiding the complicated syntax rules. This has led to a perceived “lack of authenticity”: some students tend to think of block-based programming as not “real programming”, potentially damaging their effectiveness in introductory courses [4]. Another problem found when using visual programming environments is referred to as “syntax overload” [9]. In a study performed by Powers et al. [10] a CS0 course started using the Alice visual programming environment and then moved to a text-based programming language (either Java or C++). The authors report the transition was unsuccessful. Students were overwhelmed and frustrated by the strict syntax requirements of the text-based languages. Furthermore, some students ended up acquiring poor programming habits that damaged their ability to work with text-based languages. A few different solutions have been proposed to alleviate this problem, such as: using blocks that look like text, automatic placement of syntax, and helpful syntax errors instead of removing the syntax altogether [9].

In this paper we present our attempt at solving these problems.

2 Proposed Solution

We have developed Physical Bits, a web-based programming environment for educational robotics. All the code for the system is open source[1] and, at the time of this writing, we have made five public releases with varying levels of functionality. We have decided to initially target the Arduino platform because of its low cost and popularity but we have designed the system with portability in mind and we plan to support other hardware platforms in the future.

Physical Bits was designed to solve the above-mentioned problems; thus, it supports a set of features that distinguish it from other similar tools. In this section we will briefly describe those features in relation to the problems identified above.

2.1 Live Programming and Autonomy

The programming environment is supported by a virtual machine responsible for executing the user programs. This virtual machine is installed on the robot, allowing Physical Bits to provide a live programming experience without sacrificing the autonomy of the robot, which is required for most projects. The programming tools connect to the robot through a serial port and every change made to the user program is automatically compiled, verified, and transmitted to the virtual machine, taking less than 100 ms, after which the robot will start to execute the new program. This allows to shorten the feedback loop, encouraging experimentation and programming by "trial and error". Furthermore, if the robot is connected to the computer, the environment displays all the values of the sensors as well as the global variables declared in the program. Making the data concrete and visible helps the user understand the underlying machine model [6]. Finally, the environment also supports classic debugging features such as breakpoints at arbitrary instructions and step-by-step execution. Apart from aiding the user in the process of fixing programming errors, this feature makes the underlying machine model visible, thus helping the students make the correct mental model.

2.2 Block-Based and Text-Based Programming

Recognizing the benefits of visual programming, Physical Bits includes a block-based language suitable for beginners. However, in order to avoid the above-mentioned issues Physical Bits also supports text-based programming using a custom programming language designed specifically for educational robotics. We decided to develop our own programming language instead of using an already established one for a simple reason: we can control its syntax and ensure it is minimal while also providing useful constructs for the robotics domain. This custom language is inspired by the C programming language but it is much more simple and limited, focused only on educational robotics. The carefully chosen syntax is designed to avoid the "syntax overload" problem experienced by beginners while at the same time being recognizable for experienced programmers. This language is not a goal in itself, instead we consider it as a tool to help the student learn more powerful and useful languages.

1 https://github.com/GIRA/UziScript.

In order to provide a smooth transition from block-based and text-based programming the Physical Bits environment allows programming in either mode or both at the same time. The user can start programming by assembling blocks, not worrying about syntax, and the environment will automatically generate the corresponding textual code and display it alongside the blocks. Once the user has become so proficient using the visual programming language that he starts to feel its limitations, he can write textual code and the environment will update the blocks accordingly, allowing to compare the semantics of the written code with the equivalent blocks the student already knows. If, at any moment, the student starts to feel overwhelmed by the syntax he can go back to program with blocks without losing what he already wrote. The environment takes care of keeping both representations of the user program (visual and textual) automatically synchronized. This lets the student go back and forth between them as he pleases while learning about the relation between the language syntax and the blocks, helping smooth the transition without making the experience frustrating.

3 Related Work

We have reviewed some programming environments for educational robotics in order to compare their features with Physical Bits. This is not an exhaustive list, as there are many more programming environments available and including them all would exceed the scope of this paper. We have selected these environments based mainly in their relative popularity and our own familiarity with their implementations.

In order to compare functionality, we have selected a small number of features each environment can either support or not. The features we will be comparing are:

1. Liveness: The ability to change the program while it runs and see the changes immediately without manual user intervention (like clicking a button).
2. Monitoring: The ability of the environment to automatically inspect the state of the running program and let the user see the value of all variables as well as the state of all pins or sensors in the robot.
3. Debugging: The ability to pause the execution at any time in order to visualize the program execution step-by-step.
4. Autonomy: The ability to run the programs inside the robot without being connected to a computer.
5. Programming interface: Whether the environment supports block-based programming, text-based programming, or both.

The result of our analysis is presented in the table below (Table 1).

Although the list is not exhaustive, this selection offers a representative picture of the most commonly found strategies for developing programming environments for educational robotics. A majority of environments support visual programming in the form of blocks but only a few provide textual code generation.

The most notable programming environment we reviewed is microBlocks. What distinguishes it from all the alternatives is that it took the same approach as Physical Bits: using a virtual machine in order to run programs autonomously in the robot while

Table 1. Programming environments comparison

	Liveness	Monitoring	Debugging	Autonomy	Programming interface
Physical Bits	✔	✔	✔	✔	Blocks + Text
MicroBlocks [8]	✔	✔	✗	✔	Blocks only
Physical Etoys [11]	✔	✔	✔	✗	Blocks + Text
Lego Mindstorms [12]	✗	✔	✗	✔	Blocks only
Scratch4Arduino [13]	✔	✔	✗	✗	Blocks only
Snap4Arduino [14]	✔	✔	✗	✗	Blocks only
XOD [15]	✗	✔	✗	✔	Blocks only
Ardublock [16]	✗	✗	✗	✔	Blocks only
MakeCode [17]	✗	✗	✗	✔	Blocks + Text
Arduino IDE [18]	✗	✗	✗	✔	Text only

still providing an interactive and dynamic experience. However, microBlocks does not implement any debugging tools and it does not support text-based programming (the authors expressed it is one of their goals for the future). Apart from that, microBlocks target a different set of devices. The microBlocks virtual machine is designed for 32-bit microcontrollers while Physical Bits works on 8-bit microcontrollers. Moreover, microBlocks requires at least 12 Kb of RAM and 50 Kb of Flash memory while Physical Bits requires 2 Kb of RAM and 24 Kb of Flash memory.

Another interesting environment is XOD. In contrast to all other environments in this list, XOD is a data flow language. It uses blocks to represent nodes in a directed graph, in which each node can represent an input (typically a sensor), some computation, or an output (typically an actuator). The programs are built by linking nodes together, which are then used to generate the actual native program that the user can upload to the board.

MakeCode caught our interest mainly because it is a web-based programming environment that supports both blocks and text-based programming using Javascript, and it provides bidirectional code generation. Although the MakeCode environment does not provide a live programming experience, it compensates this limitation by providing a virtual simulator, making it possible to test programs without a physical device.

Finally, Physical Etoys is an extension to Etoys we developed in order to interact with a wide range of physical devices such as LEGO NXT, Arduino boards, innovative joysticks like Microsoft Kinect or Leap Motion, etc. It allows to program robots using either blocks or a text-based programming language (Smalltalk). However, once the user has modified a script using the textual mode it does not support going back to the blocks without losing the changes. This problem, together with its lack of autonomy, led us to develop the Physical Bits environment.

4 Implementation

4.1 Architecture

The system is composed of three distinct components: the IDE, which is a web application containing all the programming tools; the middleware, which is a desktop application that handles the communication with the robot; and the firmware, which contains the virtual machine (Fig. 1).

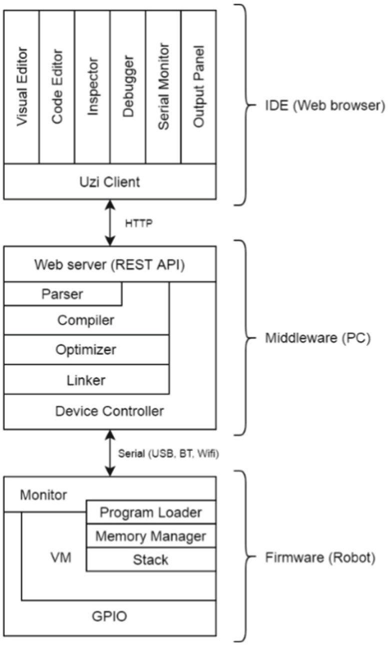

Fig. 1. Physical Bits architecture diagram

This architecture has several benefits. On the one hand it is flexible. The IDE, being a web app, could be used from any device with a web browser, such as a laptop or a mobile phone. It could be installed as a native app or accessed through a web browser. Both the middleware and the firmware are portable: although the only implementation of the latter currently supports Arduino boards, the code could be ported to other types of robots without changes to the middleware or IDE. It is fast: compiling, verifying, and uploading programs using the Physical Bits IDE takes a fraction of the time required to compile an Arduino sketch, mostly because of the small size of the programs. And finally, the communication to the robot can be done wirelessly either using bluetooth or a network socket (although the current implementation has only been tested using a USB cable).

4.2 Firmware

The firmware is a regular Arduino sketch written in C++ that can be uploaded using the Arduino IDE. We have tested the firmware using several different boards, including: Arduino UNO, Micro, Nano, MEGA 2560, and Yun. We have also received reports of it working successfully on other compatible boards such as DuinoBot [19], Educabot [20], and TotemDUINO [21]. The firmware contains a stack-based high-level language virtual machine that executes user programs using a decode and dispatch bytecode interpreter [22]. This implementation was chosen mainly because of its simplicity. Apart from the virtual machine, the firmware also contains a monitor program that allows it to interact with the middleware in the host computer. Periodically, this monitor program will send the status of the Arduino and receive commands, allowing the middleware to fully control the virtual machine, including directly manipulating the variables and the pin state, debug the current user program, or download a new one. By having these two components running on the Arduino we can provide a live programming experience with a short feedback loop without sacrificing autonomy.

The firmware also contains a GPIO class that simplifies working with the Arduino pins. It takes care of setting the pin modes according to its usage; it stores the pin values in order to access them later; and it handles PWM, square wave generation, and servo control. This GPIO class is designed to be configurable using compile-time macros in order to support other pin layouts, enabling the use of different boards.

4.3 Middleware

The middleware contains a small set of tools that allow to compile, debug, and transmit the programs to the Arduino board through a serial connection. All these tools were originally developed using Squeak, an open source version of Smalltalk [23]. We decided to use Smalltalk to build the first prototype of the middleware mainly due to of our familiarity with the language. We later ported this code to the Clojure programming language for performance and ease of deployment [24].

In order for the IDE to interact with these tools the middleware exposes a REST API containing endpoints to: connect and disconnect from the robot; compile, run, and install programs; and to retrieve the state of the robot, which includes the sensor and global data. The compiler takes the source code of a program in our custom programming language and generates bytecodes in a format that the virtual machine can decode and execute. The language includes common syntactic constructs typically found in structured programming languages, such as: conditionals (if-then-else), loops (while, until, for, repeat, etc.), procedures and functions with positional arguments, variables (both local and global scope supported). Additionally, we added the “task” syntax for defining concurrent processes.

4.4 Ide

The Physical Bits IDE is a web-based programming environment that supports both visual programming (using the Blockly library [25]) as well as textual code using a custom programming language loosely inspired by C. Even though the middleware needs to run locally in order to access the serial port, the IDE, which is composed of HTML and Javascript files can either be hosted locally, on a web server, or even on the cloud (as long as the client browser has access to the middleware's API) (Fig. 2).

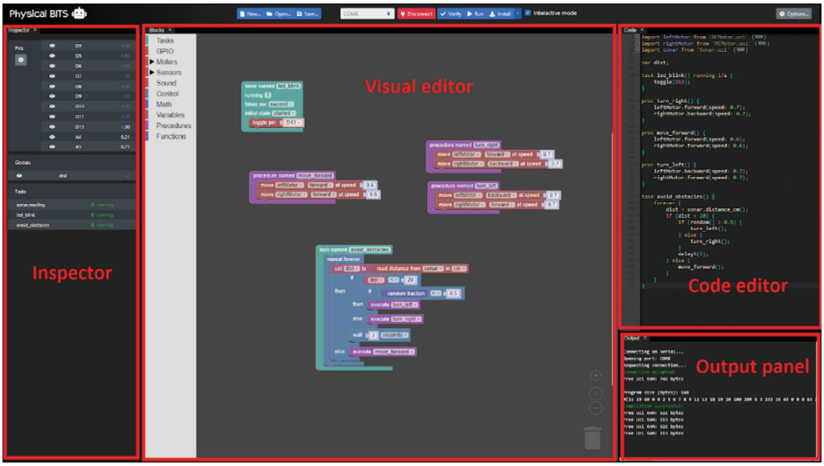

Fig. 2. Screenshot of the IDE and its panels

The environment is designed to provide a smooth transition from block-based programming to text-based programming. In order to do this the student can choose to work on his programs using either mode or both at the same time. The environment takes care of translating automatically from blocks to code and back, this helps with the transition by showing how each block is representing in code while the user edits the program.

Every time the user makes a change in the program (independent from the mode) the program is sent to the middleware, which compiles it, looks for syntax errors, and if the program is correct and the robot is connected it sends it to the robot to be executed immediately. Since the entire compilation process finishes within 35 ms on average, effectively every change in the program is automatically transmitted to the robot, which immediately starts executing it.

Apart from the instant compilation and execution, the IDE also supports inspection of the pins in the arduino and the variables in the program. The inspector panel is automatically configured to show the current values of each pin and variable referenced in the program, this allows users to see the values of any sensor immediately without requiring any extra code. This feature allows to make the process of programming a robot much more transparent and helps to understand the behavior of the program.

Finally, if a program doesn't behave as expected the user can stop the execution at any point (breakpoint) and execute it step-by-step, observing how the state of the program changes at each step.

5 Code Example

In order to demonstrate the programming language we made a small example program consisting of a robot car that autonomously wanders in a room while avoiding obstacles.

The robot is made of two DC motors that provide movement and an ultrasonic sensor in the front to detect obstacles. This type of robots is very common in robotics competitions such as the Roboliga, the Argentinian Robotics Olympics and the Robocup Junior, an international competition where students from around the world gather to share their experiences in educational robotics.

The expected behavior of the robot is simple: it should move forward until an obstacle is detected, in which case it should turn left for a second (Fig. 3).

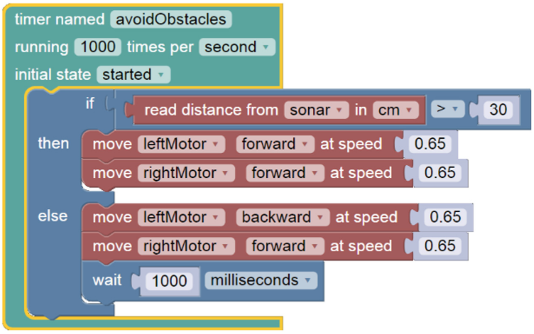

Fig. 3. Blocks-based version

The block-based program consists of a single “timer” block. This block allows to specify behavior that should be executed periodically. Inside the “timer” block we have an “if-then-else” block that represents a conditional statement. It reads the value of the ultrasonic sensor, called “sonar” in this example. If the reported value is greater than 30 cm, it will activate both motors forward at a constant speed. Otherwise it will move the “leftMotor” backward and the “rightMotor” forward (making the robot turn counter-clockwise) for 1000 ms.

The autogenerated textual code is a direct translation of the blocks above, with the only exception of the “import” statements at the top of the program. These statements allow to include external libraries in the user program. In the interest of brevity, we have omitted the source code for these imported libraries but they can be found in github[2].

2 https://github.com/GIRA/UziScript/tree/master/uzi/libraries

```
import leftMotor from 'DCMotor.uzi' {
  enablePin = D5; forwardPin = D7; reversePin = D8;
}
import rightMotor from 'DCMotor.uzi' {
  enablePin = D6; forwardPin = D11; reversePin = D9;
}
import sonar from 'Sonar.uzi' {
  trigPin = A5; echoPin = A4; maxDistance = 100;
  start reading;
}

task avoidObstacles() running 1000/s {
  if (sonar.distance_cm() > 30) {
    leftMotor.forward(speed: 0.65);
    rightMotor.forward(speed: 0.65);
  } else {
    leftMotor.backward(speed: 0.65);
    rightMotor.forward(speed: 0.65);
    delayMs(1000);
  }
}
```

Just for reference we have included the same program written in the Arduino language. In this case, we also decided to omit the source code of the external libraries used but they can be found online[3].

As we can see, except for a few syntactic differences, the Arduino code is very similar to the code generated by Physical Bits. This is by design. We have chosen the language syntax to be very easy to understand for any experienced programmer and very similar to Arduino code. Our goal for this language is to be just a learning tool, an intermediate step before moving to more powerful languages.

```
#include <L293.h>
#include <NewPing.h>

L293 leftMotor(5, 7, 8);
L293 rightMotor(6, 11, 9);
NewPing sonar(A5, A4, 100);

void setup() {}

void loop() {
  delay(50); // Wait between pings to avoid echo issues
  int dist = sonar.ping_cm();
  if(dist == 0 || dist > 30) {
    leftMotor.forward(165);
    rightMotor.forward(165);
  } else {
    leftMotor.back(165);
    rightMotor.forward(165);
    delay(1000);
  }
}
```

One important difference, however, is the “task” construct, which just like the “timer” block allows to specify behavior that the robot should execute periodically. It can be seen

[3] L293: https://github.com/qub1750ul/Arduino_L293NewPing: https://bitbucket.org/teckel12/arduino-new-ping/wiki/Home

as the equivalent of the loop() procedure in Arduino but with the possibility of declaring multiple tasks instead of just one.

Since this capability does not exist in the Arduino language without the inclusion of a third-party library it can be a source of confusion for beginners. However, we feel that since any programming language for robotics needs to support concurrency in order to be effective [26], the benefits of moving away from the Arduino execution model outweigh its disadvantages.

6 Future Work

Although we have reached a point in development in which we feel confident enough to start using this tool with students, this project is still a work in progress.

Some of the features described in this paper, while working in previous releases, are not fully integrated in the latest version of the IDE yet. These include: the watchers, the debugger, and the text-to-blocks translation. The latter remains an open issue due to the lack of a 1:1 mapping between the textual language constructs and the blocks. We have discussed extending the block-based language by introducing more complex blocks but we fear we might overwhelm the users if we provide “too many” blocks to choose from. Even though the discussion is still open we have decided, for the moment, to translate as much code as we can using the existing high-level blocks and, for any statement that can’t be translated, provide a special block (hidden from the user) that simply represents this untranslatable code.

Apart from that, we have plans for porting the Uzi VM to other hardware platforms like ESP8266 and ESP32. We also plan to improve the robustness of the communication protocol with the robot. We have observed some issues that can leave the robot in an inconsistent state and force the user to reset the connection, interrupting the live experience we are trying to reach. We expect to be able to optimize the virtual machine in order to provide faster execution.

Finally, some related projects we hope to develop are: a cloud repository for users to share their creations and discover other people’s projects; and a designer tool to help teachers to plan activities for their classroom.

7 Conclusions

We have described the more common problems found when using visual programming languages for teaching robotics.

Our proposal consists of Physical Bits: a web-based programming environment for educational robotics that attempts to solve these issues by providing a live programming experience as well as bidirectional blocks to code generation. These features make Physical Bits a suitable introductory environment for teaching programming using robots. We have reviewed popular alternative programming environments and compared its characteristics with Physical Bits. We also described the implementation of the system as well as a small code example to demonstrate the language features.

Although this is still a work in progress, we believe this project is a step towards our vision of what educational robotics should be in the future.

References

1. Feurzeig, W., Papert, S., Bloom, M., Grant, R., Solomon, C.J.: Programming-languages as a conceptual framework for teaching mathematics. ACM SIGCUE Outlook **4**(2), 13–17 (1970)
2. Kay, A.C.: The early history of Smalltalk. In: History of Programming Languages---II, pp. 511–598. Association for Computing Machinery, New York (1996)
3. Meerbaum-Salant, O., Armoni, M., Ben-Ari, M.: Habits of programming in scratch. In: ITiCSE 2011 Proceedings of the 16th Annual Joint Conference on Innovation and Technology in Computer Science Education, pp. 168–172 (2011)
4. Weintrop, D., Wilensky, U.: To block or not to block, that is the question: students' perceptions of blocks-based programming. In: Proceedings of the 14th International Conference on Interaction Design and Children, pp. 199–208 (2015)
5. Kelleher, C., Pausch, R.: Lowering the barriers to programming: a taxonomy of programming environments and languages for novice programmers. ACM Comput. Surv. (CSUR) **37**(2), 83–137 (2005)
6. Lodi, M., Malchiodi, D., Monga, M., Morpurgo, A., Spieler, B.: Constructionist attempts at supporting the learning of computer programming: a survey. Olympiads Inf. Int. J. Vilnius Univ. Int. Olympiad Inf., 19–121 (2019)
7. Rein, P., Ramson, S., Lincke, J., Hirschfeld, R., Pape, T.: Exploratory and live, programming and coding: a literature study comparing perspectives on liveness. Art Sci. Eng. Program. **3**(1) (2019)
8. Cabrera, L., Maloney, J., Weintrop, D.: Programs in the palm of your hand: how live programming shapes children's interactions with physical computing devices. In: Proceedings of the 18th ACM International Conference on Interaction Design and Children, pp. 227–236 (2019)
9. Moors, L., Luxton-Reilly, A., Denny, P.: Transitioning from block-based to text-based programming languages. In: 2018 International Conference on Learning and Teaching in Computing and Engineering (LaTICE), pp. 57–64 (2018)
10. Powers, K., Ecott, S., Hirshfield, L.: Through the looking glass: teaching CS0 with Alice. ACM SIGCSE Bull. **39**(1), 213–217 (2007)
11. Grupo de Investigación en Robótica Autónoma del CAETI (GIRA), Physical Etoys (2010). https://tecnodacta.com.ar/gira/projects/physical-etoys/, Accessed 15 Junio 2017
12. Kim, S.H., Jeon, J.W.: Programming LEGO mindstorms NXT with visual programming. In: 2007 International Conference on Control, Automation and Systems, pp. 2468–2472 (2007)
13. Citilab, About S4A (2015). https://s4a.cat/, Accessed 15 Junio 2017
14. Pina, A., Iñaki, C.: Primary level young makers programming & making electronics with Snap4Arduino. In: Educational Robotics in the Makers Era, pp. 20–33 (2017)
15. XOD. https://xod.io/, Accessed 24 Jan 2020
16. Ardublock|A Graphical Programming Language for Arduino. https://blog.ardublock.com/, Accessed 15 Junio 2017
17. Microsoft. https://makecode.microbit.org/, https://makecode.microbit.org/, Accessed 24 Jan 2020
18. Arduino, Arduino Playground - Structure. https://playground.arduino.cc/ArduinoNotebookTraduccion/Structure, Accessed 23 Julio 2017
19. Rojas, A.: Reporte Robótica Educativa. Universidad Nacional de La Pampa (UNLPam) (2017)
20. Educabot. https://educabot.org/, Accessed 13 Dec 2019
21. Totem, TotemDUINO|Totemmaker.net, Totemmaker.net. https://totemmaker.net/product/totemduino-arduino/, Accessed 13 Dec 2019
22. Smith, J., Nair, R.: Virtual Machines: Versatile Platforms for Systems and Processes. Morgan Kaufmann Publishers Inc, San Francisco (2005)

23. Ingalls, D.: The evolution of smalltalk: from smalltalk-72 through squeak. In: Proceedings of the ACM on Programming Languages (PACMPL), vol. 4, no. HOPL (2020)
24. Hickey, R.: A history of clojure. In: Proceedings of the ACM on Programming Languages (PACMPL), vol. 4, no. HOPL (2020)
25. Fraser, N.: Ten things we've learned from blockly. In: Proceedings of the 2015 IEEE Blocks and Beyond Workshop (Blocks and Beyond), pp. 49–50 (2015)
26. Resnick, M.: MultiLogo: a study of children and concurrent programming. Interact. Learn. Environ. **1**(3), 153–170 (1990)

A Block–based IDE Extension for the ESP32

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Abstract. Robotics with state-of-the-art microcontrollers leads to plenty of unique opportunities for computer science education at school. This paper introduces an ESP32 extension to Ardublockly specifically designed for educational purposes. It discusses the advantages of block-based programming for school education and presents the new key features within the IDE. To demonstrate the capabilities of the developed extension for computer science education in schools, an exercise in the field of swarm robotics was developed.

Keywords: Physical computing · Swarm robotics at school · Block-based programming

1 Introduction

When computer science teachers want to address new content such as physical computing by building real interactive systems that sense and respond within the real world, they still might use Arduino microcontrollers. Almost all researched sources use or recommend Arduino Uno boards as hardware to implement their (physical computing) projects [5,9–11]. The most recent revision 3 of the Arduino Uno came onto the market in 2010 and was not further developed [4, p. 5]. More modern microcontrollers such as the BBC Micro: Bit started to emerge in 2015 and were spread with huge efforts by BBC and other partners. The Micro: Bit Educational Foundation (established in September 2016) pushed this local educational experiment to a global scale. One of their big contribution was the vision to develop an "inexpensive, powerful and easy-to-use learning tool" [1, p. 1]. Although one of the core design goals of the Micro: Bit is to "open a window into the future" [1, p. 1–2] this failed due to only providing Bluetooth connectivity and no WiFi on the chip, which makes it hard to cover the evolving field of IoT applications [8].

The ESP32 from Espressif Systems entered the market in September 2016 as a powerful, low-cost, low-power microcontroller. A device with 30 times more processor power and 260 times more SRAM compared to an Arduino Uno Revision 3, as well as a small form factor, low weight, embedded WiFi and Bluetooth,

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the ESP32 has been evaluated as an excellent microcontroller for IoT scenarios. The bread board friendly version ESP32-DevKitC is treated as an alternative solution for educational purposes. [6, p. 8–9] [7, p. 143]

As each pupil owns an individual set of previous knowledge and skills in computer science it is our responsibility as teachers to manage these heterogeneous knowledge levels and to support the learning of pupils in all these different (class) levels. This creates the didactic demand to provide a flexible, block-based Visual Programming IDE to effectively teach programming skills within a physical computing environment.

To address those challenges and to introduce the microcontroller ESP32 to computer science education in schools, we developed an extension to Ardublockly. The extension offers ESP32 support and IoT key features, and is developed to boost the use of robotics in schools. A case study at the end of this paper will demonstrate how this block-based IDE can be used to develop swarm-robotics scenarios with learners in schools. This field was chosen to provide a beneficial new direction for robotics in education, as swarm robotics is based on interactive communication between robots and is very rarely discussed in the field of computer science education.

2 Block-based Programming in Education

Typically *programming* is perceived as the act of writing program code in a problem-oriented programming language. Once we set the focus to the entire creation process of a program it turns out that the process of developing an algorithm – as a strategy to solve the problem – is a much more demanding task than merely translating it into a programming language. Fuchs introduced the term *Algorithmic Thinking* as the brain activity which is needed to identify algorithmic structures (like branches, loops and conditions) to solve a specific problem. [3, p. 218]

Block-based programming follows this concept of *Algorithmic Thinking* as learners do not need to have skills in any program language syntax. They rather need to show their problem-solving competence as they recognize and apply control and data structures correctly to develop an executable program solving particular problems. [6, p. 3]

The Cognitive Load Theory of Sweller [2] revealed that the overload of a learner's brain has negative impact on learning results. Block-based programming delivers a positive effect on learning, as it sets a strong focus on creating the algorithm, while at the same time taking the burden from learners to code syntax in a text-based programming language. Wintrop and Wilensky [13] confirmed in their field study that it is much easier for pupils to learn block-based programming than text-based programming. Block-based programming enables lecturers to introduce learners in a step-by-step process to a text-based programming syntax: First they only read the code, then they are asked to comment it and finally they start to write (small) parts of the program in the text-based language. This approach enables teachers to associate one problem with multiple levels of task complexity to teach a heterogeneous group of learners.

3 Block-based Programming Interface for the ESP32

Due to the major benefits that have been evaluated in a detailed comparison between four Block-based Programming IDE's (*Edublocks for ESP32*, *TUNIOT for ESP32*, *Blocklyduino* and *Ardublockly*) [6, p. 12–14], *Ardublockly* has been selected as framework to integrate the ESP32 microcontroller and implement new blocks based on the new possibilities with this more recent microcontroller. After this evaluation on 18 characteristics within six major categories, the major benefit of *Ardublockly* was revealed to be its outstanding didactic qualification, as its view always shows blocks and text-based code simultaneously and it highlights the generated text-based code for each added block in real-time [6, p. 12–14]. As *Ardublockly* was released under the Apache 2.0 license it is open for any modification. Besides the integration of the ESP32 Board into *Ardublockly* **the implementation consists of eleven new modules which were developed with 27 new blocks**. Each implementation was done based on specified requirements. Additionally the advantages for school education were revealed for each implementation. After the integration of the ESP32 with all its interfaces into *Ardublockly*, the primary interest was to develop blocks to use the new features provided by the hardware. *Ardublockly* neither offered a possibility to establish a network communication nor provided implementations of network protocols. Therefore efforts were spent on **one block to connect the microcontroller to an existing WiFi network, and another to switch the microcontroller into access-point mode** and create its own WiFi network.

On top of this basic WiFi connector implementation any network protocol can be implemented. As IoT is a central evolution of the last decade within the field of computer science, the objective was to enable all teachers and lecturers to include real-life IoT scenarios into their classes. Therefore the IoT Network Protocol **MQTT was fully implemented by establishing four new blocks**. This includes the publish feature from the MQTT protocol (e.g. to publish sensor values) as well as the subscribe feature of MQTT to constantly receive new information on a specific topic (Fig. 1).

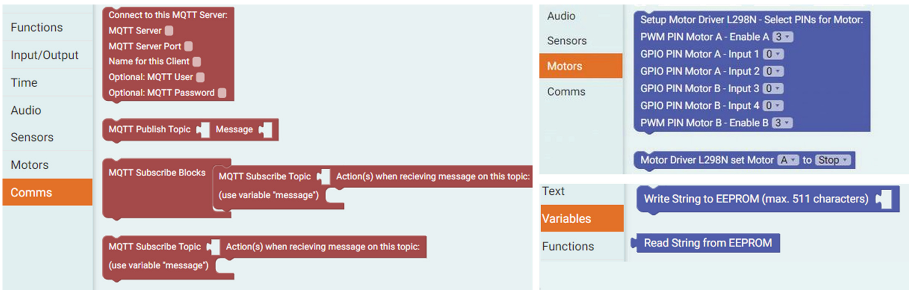

Fig. 1. Part of the introduced blocks. Details to all block implementation can be found in [6, p. 19–31]

To utilize the Block-based IDE with the ESP32 for applications in the field of robotics, features to handle robot movements are key. Admittedly in Ardublockly blocks to handle standard DC motors were missing. Therefore **two new blocks were developed to enable the Motor Driver L298N** to run DC Motors by supporting a two-channel operation. The standard types of movement – forward, backward, stop – have been implemented directly to avoid low-level pin handling. To allow full control of movement a speed regulation for the motors is necessary. This utilizes the technique of pulse width modulation (PWM) to handle the power-flow. Therefore another **3 blocks were developed to implement the generic PWM functionality**.

A robot uses sensors to receive information from its surroundings and to enable orientation. One communication channel to these sensors is the I^2C bus. To facilitate error handling with cabling for sensors that use the I^2C bus, an **I^2C Scanner was implemented using only one block**. It detects the connected I^2C devices and prints their unique device addresses to the serial bus.

Typically the output of microcontroller programs developed in Ardublockly is printed to the serial bus, which is observed by the serial monitor of the Arduino IDE. This turns out to be problematic for robotic scenarios as soon as the robot starts moving. Therefore the **OLED Display Adafruit SSD1306 was included into the IDE by developing three new blocks** as a new option to deliver outputs to the user.

Another characteristic of microcontrollers is that they store all of their variables and actual GPIO Pin statuses within their RAM. This leads to an essential problem when it comes to a (short) power outage at the microcontroller because all data and status will be gone and the program will restart from scratch. The decision to equip learners with the possibility to store information permanently (e.g. GPIO Pin state) and let them recover this information after a reboot led to the **development of two new blocks for EEPROM management**. The blocks allows a string of up to 511 characters to be stored into the EEPROM as the ESP32 emulates the EEPROM with 512 Byte of its flash memory.

All developments together form the new block-based visual programming IDE extension to Ardublocky. The Windows and Linux release together with its documentation can be found at https://github.com/pati5000/Ardublockly-ESP/. In addition to this documentation, two specific manuals for teachers were created, a compact, single-page manual for teachers (*Ardublockly ESP Quick Start Guide*) in German and English and an advanced manual in English that enables teachers to easily develop new blocks.

4 Bringing Swarm Robotics into Schools Using the ESP32

The IDE is developed to be suitable for beginners as well as advanced learners. The following exercise in the field of swarm robotics should demonstrate how powerful the IDE is simply by combining the implemented modules. Swarm robotics was chosen as it is based on interactive communication between robots and provides beneficial new directions for robotics in education. Moreover, swarm robotics is very rarely discussed in the field of computer science education.

The ultimate goal for learners in this example is to build a self-balancing seesaw such that a variable number of robots are distributing their weights to keep the seesaw in balance (Fig. 2).

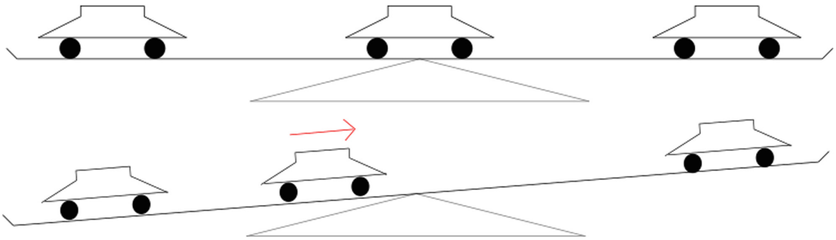

Fig. 2. Seesaw example setup similar to the setup in this video [14]

The seesaw itself is equipped with a ESP32-DevKitC SoC that operates a 3-axis gyroscope and acceleration sensor (model MPU-6050). This microcontroller controls the positioning of the seesaw. It reads the positioning information from the sensor and sends it via a WiFi Network to an MQTT broker using the MQTT protocol. Another PC in the network is supposed to act as an MQTT broker or it is assumed that a MQTT cloud service is used.

The robots subscribe via MQTT to receive this information. Each of them is equipped with a ESP32-DevKitC SoC, a minimum of six infrared sensors, a 3-axis gyroscope and acceleration sensor (model MPU-6050), a L298N motor driver, as well as DC motors and wheels where the quantity depends on the individual design. The infrared sensors are needed to enable the robots to detect the edges of the seesaw. The gyroscope and acceleration sensor is only needed to determine on which side of the seesaw the robot is located. The motor driver and the motors are used to move the robot in specific directions to distribute its own weight. Based on the information of the gyroscope and acceleration sensors the swarm intelligence will calculate and control the move of the robots.

The swarm intelligence is implemented in one program which will be provided to all robots. The robots will communicate on three MQTT topics:

– Subscribe the status of the gyroscope and acceleration sensor in the seesaw (acts as a single source of truth),
– Publish the seesaw and robot status after each cycle of move,
– Negotiate who will take the next action.

The challenge for learners is to develop a protocol for this swarm communication and decision making of the swarm. Only one robot should move at a given time. After a move there should be another cycle of measurement and negotiation before there is a new move.

Most probably it will be required to introduce the learners to the field of swarm intelligence. Therefore lecturers can run the workshop developed by Stovold [12, p. 203–204]. In this workshop the learners try to find a real-life swarm intelligence algorithm based on the example of the behaviour of wild fireflies. The goal is to synchronize their flashing with each other to attract females. The learners should be allowed some time to discuss their ideas in small groups and ideally demonstrate their solutions to the whole class. This will prepare them for the discussion of the algorithm they need to develop for this robot balancing task.

5 Conclusion

The ESP32 and Ardublocky with its ESP extension is an attempt to boost education in computer science, physical computing and especially educational robotics. A modern, powerful and affordable microcontroller and an IDE which is optimized for educational purposes has been developed as a state-of-the-art didactic environment for learners at multiple (class) levels to learn programming at individual depth and speeds by experimenting on physical computing projects.

Learners benefit from block-based programming as algorithmic thinking is developed without the tedious act of learning the syntax from a specific, text-based programming language.

By providing a workshop and an advanced programming example on swarm robotics, this paper picked a field that is rarely discussed in computer science education but is highly visible in nature. This paper also contributes to the development of more holistic, motivating and innovative computer science lectures. Well-designed computer science education is an effective way to support learners to gain relevant competences for their future.

References

1. Austin, J., Baker, H., Ball, T., Devine, J., Finney, J., de Halleux, P., Hodges, S., Moskal, M., Stockdale, G.: The BBC micro: bit – from the UK to the World. Communications of the ACM (2019)
2. Chandler, P., Sweller, J.: Cognitive load theory and the format of instruction. Fac. Educ. - Pap. **8**(4), 293–332 (1991). https://doi.org/10.1207/s1532690xci0804_2
3. Fuchs, K.J., Milicic, G.: Algorithmisches Denken im anwendungsorientierten Unterricht. Didaktik der Naturwissenschaften. Neue Horizonte in Biologie, Geometrie und Informatik (2016)
4. Hughes, J.M.: Arduino: A Technical Reference: A Handbook for Technicians, Engineers, and Makers. O'Reilly Media, Inc., Sebastopol (2016)
5. Kortuem, G., Bandara, A.K., Smith, N., Richards, M., Petre, M.: Educating the internet-of-things generation. Computer **46**(2), 53–61 (2012)
6. Lamprecht, P.: Entwicklung eines Block Programming Interface für den Mikrocontroller ESP32 zum Einsatz im modernen Informatikunterricht (2019). http://dx.doi.org/10.13140/RG.2.2.13935.46249

7. Maier, A., Sharp, A., Vagapov, Y.: Comparative analysis and practical implementation of the ESP32 microcontroller module for the internet of things. In: 2017 Internet Technologies and Applications (ITA), pp. 143–148. IEEE (2017)
8. Micro: bit Educational Foundation: Micro: bit Hardware (2020). https://tech.microbit.org/hardware/
9. Perenc, I., Jaworski, T., Duch, P.: Teaching programming using dedicated arduino educational board. Comput. Appl. Eng. Educ. **27**(4), 943–954 (2019)
10. Przybylla, M., Henning, F., Schreiber, C., Romeike, R.: Teachers' expectations and experience in physical computing. In: International Conference on Informatics in Schools: Situation, Evolution, and Perspectives, pp. 49–61. Springer (2017)
11. Przybylla, M., Romeike, R.: Empowering learners with tools in CS education: physical computing in secondary schools. IT-Inform. Technol. **60**(2), 91–101 (2018)
12. Stovold, J., Powell, S.: Teaching object-oriented programming in secondary schools using swarm robotics. In: Moro, M., Alimisis, D., Iocchi, L. (eds.) Educational Robotics in the Context of the Maker Movement, pp. 201–204. Springer (2020)
13. Wintrop, D., Wilensky, U.: To block or not to block, that is the question: students' perceptions of blocks-based programming. In: Proceedings of the 14th International Conference on Interaction Design and Children, pp. 199–208. Marina Umaschi Bers (2015)
14. Íñiguez, A.: Swarm Technology, Ants, Robots, IoT and Parallel Processing (2016). https://www.youtube.com/watch?v=ElEHN8tHJnc

Automatic Assessment of Programming Solutions for Educational Robots Lego Mindstorms EV3

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Abstract. In this paper we present a method for automatic assessment of the correctness of a solution for a task solved in the visual programming language for Lego Mindstorms EV3. The first step in the proposed method is to translate the solution into its textual representation using image pattern matching and optical character recognition. The second step is to grade a textual representation of the solution. The method is tested on 20 students and all solutions are correctly translated into their textual presentations. Since some of the solutions given by the students were incorrect, deeper analysis about the grading is given.

Keywords: Template matching · Image processing analysis · Visual programming language · Lego mindstorms EV3

1 Introduction

Educational robotics foster computational thinking, creativity and problem solving [1, 2]. Creativity can be seen in different solutions for the same task: a design of the robot is different or a program for the robot is different. Different approaches leading to the same behavior are equally correct. Typically, success of solving tasks with educational robots is tested during class by observing robot movement and tasks execution. Unfortunately, it is unfeasible to follow the continuous progress and solutions of all students if their number in a classroom is relatively big. Automatic assessment would be an invaluable tool for educators in our field. An additional issue is that educational robots usually have a visual programming environment [3, 4]. Assessment for programming tasks for computer science and programming courses is already a developed field [5, 6]. It is used for different programming languages [7, 8, 9], and with different aims [10]. In robotics, programming assignments simulators are usually used, mostly by students who do not have robots at home and who are trying out if their programs work [11, 12]. In this paper we present a method for automatic assessment of the correctness of a solution for the visual programming language for Lego Mindstorms EV3 using image pattern matching, optical character recognition and grading a textual representation of the solution.

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2 Methodology

The data used in this study was collected during several robotics workshops at the University of Zagreb Faculty of Electrical Engineering and Computing (Fig. 1). The participants were 20 students from the Faculty, and this was their first contact with Lego Mindstorms EV3. They had to assemble a mobile robot and solve seven tasks while experimenting with different movements of the robot. The data are screenshots recorded when the students made changes using a mouse or a keyboard. All the screenshots have the same resolution. The last downloaded program, before moving on to the next task, is considered as the final solution of the task. The screenshot of this solution, I, is used for automatic assessment of the correctness of the solution.

Fig. 1. Participants during the workshop.

Lego Mindstorms EV3 has a visual programming environment (Fig. 2) [13]. Commands pool with all possible commands is at the bottom of the screen. Commands can be put anywhere on the screen by dragging and dropping. A program can work only if the commands are connected to the Start block. Commands that are not connected have lighter color and will not be executed when running the program. This paper focuses on blocks that are used most often with beginners in robotics: green blocks (Move Steering and Move Tank) and orange block (Wait). In the same environment students can see the task in the upper right corner. The robot executes the program when the Start block or the Download button in the lower right corner is pressed.

The commands are viewed as separate images and all of the commands have similar layout. Each command has several fixed points with a starting point in the upper left corner $\mathbf{I}_b$ (0,0). Using fixed distances, important parts of the commands can be distinguished. Each part determines a parameter $\mathbf{P}_k(x, y)$ that a student used for their solution and is observed separately. The index k is an ordinal number of the observed parameter. In the example in Fig. 3, we have 5 parameters, $k = 1, \ldots, 5$, rounded with rectangles with different colors. Parameter $\mathbf{P}_1(x, y)$ determines the used command. Parameter $\mathbf{P}_2(x, y)$ determines a feature type, parameter $\mathbf{P}_3(x, y)$ determines a steering direction, $\mathbf{P}_4(x, y)$ power and $\mathbf{P}_5(x, y)$ driving duration. Number of parameters can vary depending on the used command.

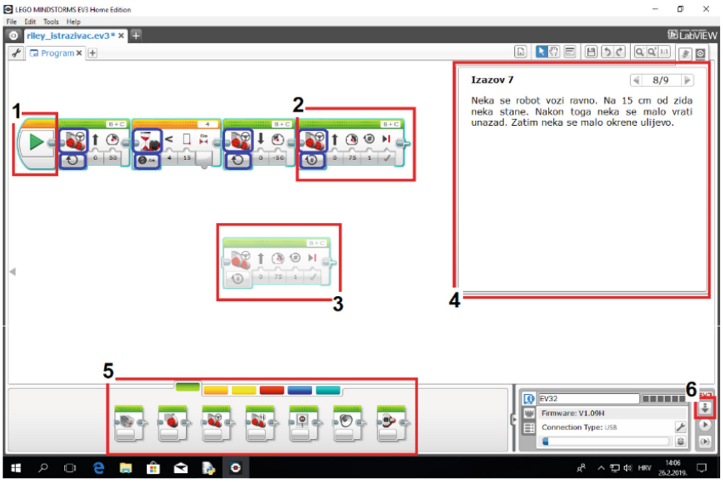

Fig. 2. Screen shot image **I** of Lego Mindstorms EV3 visual programming environment. Red rectangles: 1 – Start Button; 2 – Connected command; 3 – Not connected command; 4 – Task; 5 – Commands pool; 6 – Download button. Blue rectangles: examples of the image patches $\mathbf{I}_p(i, j)$ matched to templates $\mathbf{T}(i, j)$.

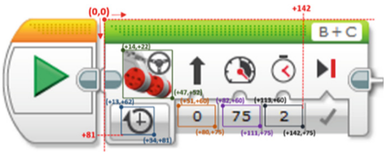

Fig. 3. Coordinates of the fixed points in the *green* command. Colored rectangles represent parameters $\mathbf{P}_k(x, y)$ that students can change and must be graded.

The proposed method is a generalized recognition of the command block i.e. translation of the visual programming commands into English for simpler matching of the progress to the final solutions of the tasks. The separate steps of the method are shown in Fig. 4. The final step of the proposed assessment is to compare the resulting textual program with a ground truth solution of the given assignment.

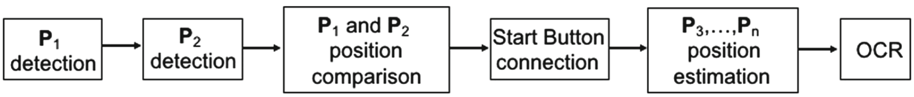

Fig. 4. Flow chart of the method for translating visual program into textual program.

Detection of parameters $\mathbf{P}_1$ and $\mathbf{P}_2$ is done by performing normalized cross correlation between template $\mathbf{T}(i, j)$ and image patch $\mathbf{I}_p(i, j)$ [14, 15]. Templates $\mathbf{T}(i, j)$ are all possible values of $\mathbf{P}_1$ and $\mathbf{P}_2$, image patches $\mathbf{I}_p(i, j)$ are part of screenshot image **I** with the same size as $\mathbf{T}(i, j)$ (Fig. 2, blue rectangles). The correlation coefficient values are assigned to coordinates (x, y) which represent the upper left corner of the image patch $\mathbf{I}_{\boldsymbol{p}}$ in original image $\mathbf{I}$:

$$\boldsymbol{R}(x, y) = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m}\left(\mathbf{T}(i,j) - \overline{\mathbf{T}}\right)\left(\mathbf{I}_{\boldsymbol{p}}(x+i, y+j) - \overline{\mathbf{I}_{\boldsymbol{p}}}\right)}{\sqrt{\sum_{i,j}\overline{\mathbf{T}^2(i,j)}\sum_{i,j}\overline{\mathbf{I}_{\boldsymbol{p}}^2(i,j)}}}, \tag{1}$$

where d_1 and d_2 are the dimension of the template, and $\overline{\mathbf{T}} = \left(\sum_{i=1}^{n}\sum_{j=1}^{m}\mathbf{T}(i,j)\right)/d_1 d_2$, $\overline{\mathbf{I}_{\boldsymbol{p}}} = \left(\sum_{i=1}^{n}\sum_{j=1}^{m}\mathbf{I}_{\boldsymbol{p}}(x+i, y+j)\right)/d_1 d_2$. A match between template and image patch is accepted if the value of the normalized cross correlation exceeds threshold value of 0.95:

$$\mathbf{R}_{cc}(x, y) = \begin{cases} 1, \mathbf{R}(x, y) \geq 0.95, \\ 0, \mathbf{R}(x, y) < 0.95. \end{cases} \tag{2}$$

The value of the threshold is chosen empirically based on possible similarities between commands of the same color.

$\mathbf{P}_1$ and $\mathbf{P}_2$ are observed as part of the same command if their position is no further apart than 5 pixels. If $\mathbf{P}_1$ does not have an associated $\mathbf{P}_2$, the command is still in the commands pool and will not be further observed. Connection to the Start block is observed if the color intensity of the upper band of the command is higher than 170 (Fig. 2). The threshold value of 170 is estimated empirically. $\mathbf{P}_3, \ldots, \mathbf{P}_\mathrm{n}$ position estimation is done based on the coordinates (x, y) of the top left corner of $\mathbf{P}_1$. To account for variations in number of parameters a fixed size rectangle is used to crop out all parameters, the rectangle is divided by using the change in color which is between different parameters.

When all parameters are detected, the optical character (digit) recognition (OCR) is performed (Fig. 5). The first step in OCR is binary thresholding with a threshold value of 110: pixels that contain numbers will be black, and background pixels will be white. We reduce the background by removing rows that have only white pixels. If the number in the parameter has more digits, the digits are separated by finding the white columns between them. All remaining white columns are deleted. Resulting digits are stored in matrices $\mathbf{P}_k^{'}$, where k is the ordinary number of observed digits. Values of elements are

$$\mathbf{P}_k^{'}(i,j) = \begin{cases} 0, \text{for black pixels (digits)}, \\ 1, \text{for white pixels (background)}. \end{cases} \tag{3}$$

The last step is comparison with masks of all possible digits (including the '-'sign) $\mathbf{M}_u$, where u is 0, 1, …, 9 and '-'. The masks have white pixels where the digits are and black pixels where the background is:

$$\mathbf{M}_u(i,j) = \begin{cases} 0, \text{for black pixels (background)}, \\ 1, \text{for white pixels (digits)}. \end{cases} \tag{4}$$

If the comparison coefficient

$$c = \sum_i\sum_j \mathbf{P}_k^{'}(i,j)\mathbf{M}_u(i,j) \tag{5}$$

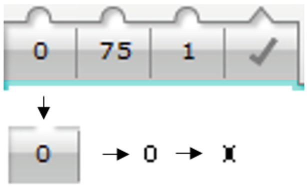

Fig. 5. Optical character recognition. First row: cropped out values of parameters $\mathbf{P}_3$, $\mathbf{P}_4$ and $\mathbf{P}_5$, second row: detected parameter $\mathbf{P}_3$, parameter $\mathbf{P}_3$' after thresholding, and mask $\mathbf{M}_0$ for the number 0. Since the comparison coefficient $c = 0$, the read value of the parameter $\mathbf{P}_3$ is 0. The same algorithm is repeated for all other numbers in the parameters.

is 0, observed digit $\mathbf{P}_k^{'}$ is equal to $\mathbf{M}_u$, and the read number is u. We repeat the comparison until we find mask matrix $\mathbf{M}_u$ that gives comparison coefficient equal to zero for each $\mathbf{P}_k^{'}$.

After all of the steps in the image processing are done, we have a textual representation in the form: Solution = [(P_1, P_2 = *'value'*, P_3 = *'value'*, P_4 = *'value'*)]. The correct ground truth solutions were also prepared in LEGO Mindstorms and translated into the text. Assessment is done by comparing strings of the textual ground truth with the students' translated solution. Final grade is given as a percentage for each correct parameter of the used command. If the text is not matched with the task that the student is working on, it can be graded manually according to the teacher's specifications.

3 Results

We tested the method on 140 collected solutions (20 students and 7 tasks) and all text representations of the solutions were correct. Here we discuss several cases in which the proposed assessment was used. The task that we focus on is Task 2: 'Drive straight ahead for 2 rotations of the wheels with speed of 25'. It has a simple solution but can be solved in multiple ways. The ground truth solution is given in Fig. 6.

Fig. 6. Ground truth solution to task 2.

The first case is when the student solved the task the same way as it is in the ground solution. When the student's solution matches the ground truth, the assessment method gives a textual representation which matches the wording of the task: `Solution = [(Move Steering, Direction = 0, Speed = 25, Rotations = 2)]`. The grade is 100% since the student gets 4/4 parameters correct.

The second case is when the students' solution is correct but does not match the ground truth. A correct solution requires the robot to move forward for exact number of rotations and with an exact speed. The ground truth solution (Fig. 6) uses the Move Steering command, but a solution will be correct even with the Move Tank command or two Large Motor commands (Fig. 7). If the students' solution is only matched to the ground truth, the grade would be 60%. Therefore, we need to define all possible ground truth solutions before automated grading. However, the proposed method gives a correct textual representation of the student's program: `Solution = [(Move Tank, Speed1 = 25, Speed2 = 25, Rotations = 2)]`.

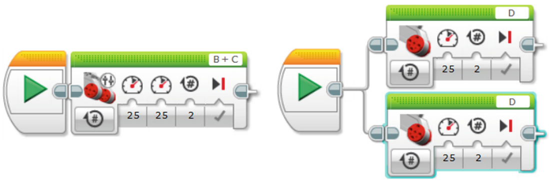

Fig. 7. Correct solutions to task 2 which do not match the ground truth solution. Left: Move Tank command is used, right: two Large Motor commands are used.

Incorrect solutions are the third case. Incorrect solutions can be detected when: (i) a program does not match the ground truth solution at all, i.e. uses different type of block that does not amount to the expected behavior of the robot (Fig. 8, left), and (ii) a solution that in part matches the ground truth but does not follow the requirements of the task (Fig. 8, right). For the first type of incorrect solution the textual representation does not match the task: `Solution = [(Move Steering, Direction = 0, Speed = 50) (Read Distance, 4, 10) (Move Steering, Stop)]`. In this case the grade is 0%. The second type of incorrect solution has grade 80% since the command is correct, and only parameter $\mathbf{P}_2$ is incorrect (seconds are used instead of rotations): `Solution = [(Move Steering, Direction = 0, Speed = 25, Seconds = 2)]`.

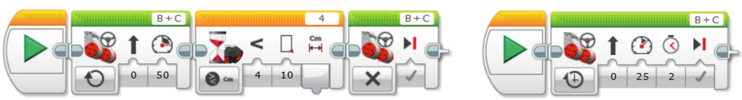

Fig. 8. Left: Incorrect solution to task 2 - nothing in the functionality of the program match the task, right: partial correct solution - wrong type of parameter $\mathbf{P}_2$ is used.

4 Conclusion

Automatic assessment of Lego Mindstorms EV3 programs gives teachers opportunity for deeper understanding of their students' progress. This paper presents a method that reads the solution by translating visual programming to textual representation. Comparing the textual representation with the expected solution, the automatic assessment of students' programming solutions can be made. The method works without error on the collected data from the 20 students included in the study. This method can be used for further analysis of students' progress, if screenshots are taken and analyzed often throughout a lesson. Automatic assessment allows teachers to be able to work with bigger loads of students, without compromising the quality of work and care they provide them with. In that case, the teachers do not need to save all screenshots but only the textual representations which reduces resource cost.

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References

1. Benitti, F.B.V.: Exploring the educational potential of robotics in schools: a systematic review. Comput. Educ. **58**(3), 978–988 (2012)
2. Jagust, T., Cvetkovic-Lay, J., Sovic Krzic, A., Sersic, D.: Using robotics to foster creativity in early gifted education. In: International Conference on Robotics and Education RiE. Springer, Cham (2017)
3. Shin, J., Siegwart, R., Magnenat, S.: Visual programming language for Thymio II robot. In: Conference on Interaction Design and Children (IDC'14). ETH Zürich (2014)
4. Trower, J., Gray, J.: Blockly language creation and applications: visual programming for media computation and bluetooth robotics control. In: Proceedings of the 46th ACM Technical Symposium on Computer Science Education. ACM (2015)
5. Douce, C., Livingstone, D., Orwell, J.: Automatic test-based assessment of programming: a review. J. Educ. Res. Comput. (JERIC) **5**(3):4, 1–13 (2005)
6. Ihantola, P.: Review of recent systems for automatic assessment of programming assignments. In: Proceedings of the 10th Koli Calling International Conference on Computing Education Research. ACM (2010)
7. Ala-Mutka, K., Uimonen, T., Jarvinen, H.: Supporting students in C++ programming courses with automatic program style assessment. J. Inform. Technol. Educ. Res. **3**(1), 245–262 (2004)
8. Ahoniemi, T., Reinikainen, T.: ALOHA-a grading tool for semi-automatic assessment of mass programming courses. In: Proceedings of the 6th Baltic Sea Conference on Computing Education Research: Koli Calling. ACM (2006)
9. Helminen, J., Malmi, L.: Jype-a program visualization and programming exercise tool for Python. In: Proceedings of the 5th International Symposium on Software Visualization. ACM (2010)
10. Leal, J.P., Moreira, N.: Using matching for automatic assessment in computer science learning environments. In: Proceedings of Web-Based Learning Environments Conference (2000)
11. CoSpace Robot. http://cospacerobot.org/. Accessed 13 Jan 2020
12. Koenig, N., Howard, A.: Design and use paradigms for gazebo, an open-source multi-robot simulator. In: Proceeding of IEEE International Conference on Intelligent Robots and Systems, Japan (2004)
13. The Lego group. https://www.lego.com/en-us/mindstorms/. Accessed 13 Jan 2020
14. Marengoni, M., Stringhini, D.: High level computer vision using OpenCV. In: 24th SIBGRAPI Conference on Graphics, Patterns, and Images Tutorials. IEEE (2011)
15. Briechle, K., Hanebeck, U.D.: Template matching using fast normalized cross correlation. In: Proceedings of the SPIE 4387 Optical Pattern Recognition XII (2001)

The Concept of Using AR and VR Technologies in the Vocational Training System in Robotics and Automation

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Abstract. Development of automation and robotics causes a need for implementing an innovative approach towards teaching. It is especially important for vocational education, as for this an expensive equipment is needed to train within real-life setups. Thus, AR and VR technologies give an opportunity to decrease costs, while keeping a high level of course-taught skills and knowledge. The paper consists of an overview of possible applications of virtual and mixed realities for education purposes and a presentation of MILAN project. This involves a description of key ideas for skill-transfer based on e-learning platform using various ICT solutions; VR and AR among others. Also, already implemented VR methods in two robotics-training cases are presented.

Keywords: Automation and robotics · Augmented reality · Vocational education and training · Virtual reality

1 Introduction

Automation and robotics (A&R) are fields still gaining in their meaning for the global economy. As a number of factories implementing A&R solutions, following Industry 4.0 trends, is continuously increasing, also a need for employees qualified towards professions from this area rises [10]. Their education does not necessarily have to be realised at the universities. Basic skills, even for robot programmers or automation technicians, might be taught in secondary vocational schools as well as in different kinds of vocational training. However, institutions realising Vocational Education and Training (VET) often suffer from lack of money; especially for the expenses of buying professional tools and machines typically used in the factories. This brings a need for creating a new approach towards teaching practical technical skills and competencies effectively with fewer devices required.

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Today, one of the most promising solutions for this challenge is replacing or supplementing conventional exercises with exercises using advanced ICT solutions such as Augmented Reality (AR) and Virtual Reality (VR).

2 AR and VR in VET

Nowadays Augmented reality (AR) and Virtual Reality (VR) are used by many educational institutions [1]. Primarily, this is caused by new possibilities they implement to teaching in various educational environments. Moreover, their application no longer requires expensive hardware nor software.

2.1 AR in VET

In an extended study, Yilmaz (2018) reviews the literature regarding using augmented reality (AR) in education, including 38 articles published between 2016 and 2017 [12]. This includes a comparison of levels and fields of education, types of used AR material as well as educational advantages of this approach.

By embedding digital content in a real environment, AR is a promising tool to develop a new methodology of workspace-related learning [5]. The positive effects of AR in this context has been proven in various aspects, e.g. on the efficiency of instructions regarding increased attention, participation and motivation of users [6]. Furthermore, an experimental and exploratory character of AR-activities can be combined well with situated and constructivist learning theories [3].

Education on operation and maintenance of machines (from motor vehicles up to whole industrial plants) is often paramount in the training process of industrial-technical vocational training [4]. These machines are not only getting more complex, but full accessibility of their every part (spatial as well as content-related) cannot be guaranteed for every case due to increasing automation. By overcoming the media gap between real and digital training content, AR not only visualizes machines' elements that are practically hidden but may also present the related processes and cause-effect relationships in a systematic context. As AR involves also a real environment and just display additional layers, it is rather used with the real setups. Its typical application may involve details recognition and labelling them, so a student can learn simultaneously while looking at the real machines. Moreover, AR may be used to expose elements which are hidden from outside or to present simulations of the real processes such as flows or heat transfers.

AR can also support technicians in maintenance and technical assistance services by technicians, while they are not experienced enough to deal with the increasing complexity of modern products [11].

One of the main problems encountered in manual assembly workstations is human error in performing operations. Dalle Mura, Dini and Failli propose an innovative system based on the interaction between a force sensor and an augmented reality (AR) equipment used to give the necessary information about the correct assembly sequence to the worker and to alert them in case of errors occurring [2]. Michalos et al. present an Augmented Reality (AR) tool for supporting operators where humans and robots cooperate in a shared industrial workplace [9]. The system provides AR visualization of an assembly process, video and text-based instructions, and production status updates.

2.2 VR in VET

Application of VR in education gives an opportunity of creating complex laboratories and setups without the need of spending high amounts of money nor big areas. This is particularly useful for industrial-technical vocational training as equipment required for effective learning is relatively expensive. Students using such frameworks may either observe 3D parts or assemblies from different views or take part in interactive exercises. This is beneficial in comparison to traditional learning as an application of VR connects practical approach with theoretical knowledge [7]. Furthermore, a student may freely experiment within a framework with no risk of damaging setup, which engages their creativity and own initiative.

The results state that using VR can foster motivation of students to learn and develop skills, which makes studying significantly more efficient and effective. VR can also encourage students to get good teaching practices and implement innovative learning models into technology.

2.3 Limitations and Problems of Using AR/VR Technologies in VET

Despite all advantages and technological potential in educational institutions, AR/VR technology is not commonly used in vocational or workplace-related training [4]. Although AR technology significantly contributes to education, there are still several problems that need to be solved [12]. The main problems occurring while applying the mentioned methods are difficulty in using simulated reality, more time needed to complete a course and poor performance of equipment to fully benefit from the framework [1].

On the one hand, creating content and its maintenance is often time-and-cost-consuming. Therefore, many teachers and learners are reluctant to use AR/VR, especially due to the amount of technical knowledge of 3D object development required [12]. On the other hand, the application of AR/VR technologies may require more than one device. Moreover, students need to have a good level of spatial orientation, collaborative skills, problem-solving skills, and base technological knowledge [12]. Although younger people are surrounded by new technologies since they were born, they may still not be competent enough to implement these for educational purposes [8].

Clearly, there is a problem of a lack of appropriate methodology and learning infrastructure, systems and tools. Their development could enable effective implementation of AR/VR technologies into VET. The use of more innovative techniques does not necessarily require pedagogical innovations; it is significantly more beneficial to design Virtual Learning Environments, beginning with a pedagogical approach to maximize learning outcomes [8]. This requires the active involvement of academic staff in designing the virtual learning environment, to obtain maximum learning benefits.

3 MILAN Project

MILAN project (Ref. No. 2018-1-PL01-KA202-050812) [13] is directly addressed towards the Erasmus+ call 2018 Horizontal priority "Open and innovative practices in a digital era". The project is run to elaborate high-quality, open-access and innovative training materials and tools in the field of Robotics and Automation, involving VR and AR technologies. All MILAN training materials are going to be uploaded to an interactive e-learning platform. This web-based platform will enable a new quality of training, oriented towards the personal needs of the users. It is targeted to the students tending to develop in the field of Advanced Manufacturing. The MILAN training system is supposed to contain online e-learning courses, lessons for mobile devices, interactive exercises and films available either from PCs, tablets or smart-phones. MILAN's outcomes are also going to involve modern ICT solutions, including Virtual and Augmented Reality.

The main target groups of the project are:

- People employed at SMEs: operators of advanced machines (robots, automats, assembling cells/machines) and middle-level technical staff
- Teachers/trainers/consultants in the field of Robotics and Automation
- Students of vocational schools

The expected outcomes of the project are the following:

- *Case Studies* - Information about best practices and technologies which may be used for the development and exploitation of the project outputs.
- *MILAN Curricula* - Structure and specification of network modules supporting vocational education and training in the field of advanced manufacturing.
- *MILAN Training Content* - Training course content in the scope of Advanced Manufacturing with the utilization of ICT solutions including VR and AR technologies, for education.
- *Multifunctional Educational-Training Network Platform* - Training Network Platform that will contain:
  - eLearning system
  - lessons for mobile devices
  - interactive exercises with AR and VR technologies implemented
  - films for PCs, tablets and smartphones
- *MILAN Training Methodology* - Methodology dedicated to supporting project implementation. It supposed to combine innovative learning approaches such as e-learning, ICT solutions, especially AR, VR, Gamification, Interactive Services, and new means of technology such as mobile ICT devices. The MILAN Methodology will outline all training course milestones and help in achieving them.

MILAN training system will be accessible for users as a multifunctional educational-training network platform via a graphical user interface (see Fig. 1). This means a student will be able to log in to the platform and learn from the resources uploaded to it, but also get an advantage of using additional resources such as MILAN project's website and YouTube channel or a remote connection with laboratories of ŁUKASIEWICZ – Industrial Research Institute for Automation and Measurements PIAP (access to the camera in KUKA robot's cell) and Technical University of Košice (modelling and virtual laboratory).

The lessons offered in the MILAN Training System would not only be based on text content. They would also include multimedia materials such as graphics, films and simulations, as well as access to the virtual library of books, journals, conference proceedings and papers. As mentioned above, the system will also use AR/VR methods to gain a practical approach to learned topics (see Fig. 1).

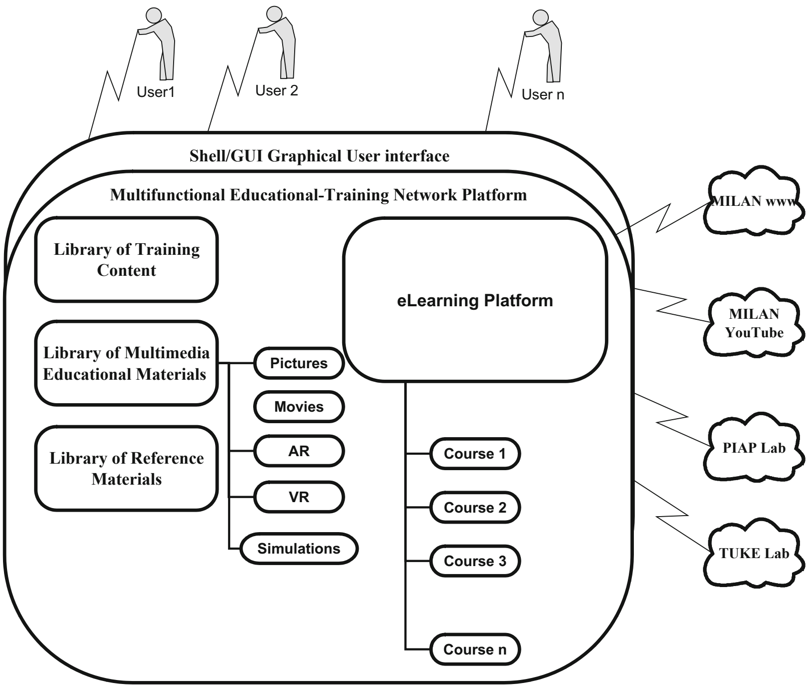

Fig. 1. A general concept of the structure of the MILAN Training System

However, it is also considered whether not to connect the MILAN training system with other existing and available collections of materials and information on robotics such as repositories or open digital libraries.

All training content of the MILAN project will be divided into four blocks:

- Basics of Advanced Manufacturing
- Automation and Robotics in Advanced Manufacturing
- ICT in Advanced Manufacturing
- Occupational safety and health

These are going to contain modules matching them directly. Furthermore, the modules are going to consist of lessons and additional materials such as videos or interactive exercises. However, it is not obligatory to complete all assigned lessons. A student will be able to create a course composed of materials of their own choice. Thus, this approach responds to the need of learner-tailored training.

4 Use of VR/AR in Automation and Robotics Training

4.1 General Concept

The expertise of MILAN project's participants in an application of simulated reality into Automation and Robotics training is mainly based on preparing VR interactive environment and 3D instructions for real setups. However, these two should be easily transferable into AR with some modifications. The exercises could be then integrated with real objects such as trails or QR codes marked on the tables and transform a real environment into a workstation. This could give a use especially in robotic welding or sealing training. Interactive instructions, on the other hand, could be projected partially-transparent onto the real setup and help in verifying if a given task is performed properly.

4.2 Robotics Training Lab in the Centre for Research and Development of Modern Technologies

The Centre for Research and Development of Modern Technologies CBiRNT [14] is a Polish institution specialised in training for the automotive sector. It has a diversity of robotic cells prepared for different applications and performance - among others, a setup with four workstations and two industrial manipulators, one on a dockable manual trolley and another on a dockable mobile robot. This setup enables students to practice their programming skills in terms of combining mobile robotics for factories with simple assembling and palletizing processes.

Moreover, the whole modelled setup (see Fig. 2) has been programmed in a Robot-Studio software and implemented in VR for HTC VIVE goggles afterwards. This lets a student observe simulated possible applications of robots; thus, it may be practically applied as a multimedia instruction for learners.

4.3 Use Case of E-learning Course with ABB YuMi Robot

Tallinn University of Technology prepared a course involving VR in robot programming. Its main goal is to provide basic robotics theory and to teach skills of real ABB YuMi robot use, to students. The course combines theoretical knowledge with its practical application. This is realized within tasks complicated enough to enable a deep understanding of how to manipulate the robot and to keep it attractive for students. Thus, one of such tasks is programming ABB YuMi to play the xylophone

For most of the robotic virtual simulation software packages, it is possible to convert the virtual model to usable VR model (see Fig. 2), which can be run over the internet or downloaded into a computer. For the current training, the students were asked to test the VR model of the YuMi robot using Oculus Rift VR glasses to get an even deeper understanding and virtual feeling and perception how the whole system works.

The course finishes with testing the real robot behaviour to full fill the given task and verifying the robot program developed on the stage of virtual simulation. The developed program is uploaded into the YuMi robot available over the internet and running as a live YouTube channel.

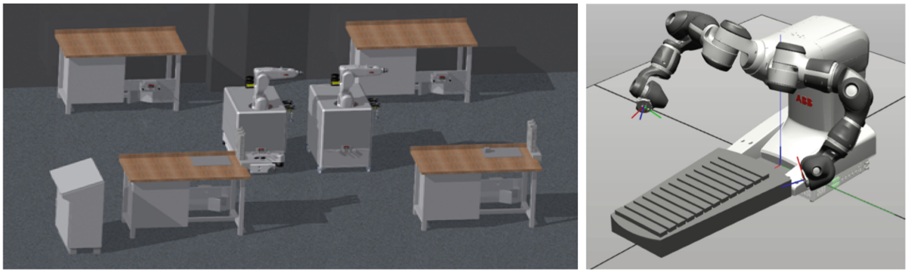

Fig. 2. Presented applications of VR – a visualisation of the setup used in the CBiRNT Centre (left) and a running VR model of the ABB YuMi robot (right)

5 Conclusions

The technical capabilities of modern ICT tools allow the implementation of advanced systems of supporting vocational education both onsite and remotely. These solutions are very effective for education in the field of modern manufacturing technologies, especially related to automatic control and robotics. It is worth noticing that the range of expertise and skills expected from an employee of an automated/robotised plant is continuously changing. The tasks of such an employee are not limited to supplying resources, removing the final products and operating the machine with basic control buttons, e.g. START, STOP. This person is usually supervising the whole setup on spot and should be able to assess its condition, so as to act if necessary (change a program or a configuration). Therefore, they should be aware of using the tools for remote monitoring, modelling and simulations, among others. Regular training and raising qualifications are the best ways to keep up with these new challenges. Thus, modern VET support systems with the ICT technologies (VR/AR) applied, such as those developed in the MILAN project, will play an important role in these.

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References

1. Akçayır, M., Akçayır, G.: Advantages and challenges associated with augmented reality for education: a systematic review of the literature. Educ. Res. Rev. **20**, 1–11 (2017)

2. Dalle, M.M., Dini, G., Failli, F.: An integrated environment based on augmented reality and sensing device for manual assembly workstations. Procedia CIRP **41**, 340–345 (2016)
3. Dunleavy, M., Dede, C., Mitchell, R.: Affordances and limitations of immersive participatory augmented reality simulations for teaching and learning. J. Sci. Educ. Technol. **18**(1), 7–22 (2009)
4. Fehling, C.D., Müller, A., Aehnelt, M.: Enhancing vocational training with augmented reality. In: Proceedings of the 16th International Conference on Knowledge Technologies and Data-driven Business, October 2016
5. Henrysson, A., Ollila, M., Billinghurst, M.: Mobile phone based augmented reality. In: Emerging Technologies of Augmented Reality: Interfaces and Design, pp. 90–109. IGI Global (2007)
6. Kamarainen, A.M., Metcalf, S., Grotzer, T., Browne, A., Mazzuca, D., Tutwiler, M.S., Dede, C.: EcoMOBILE: integrating augmented reality and probeware with environmental education field trips. Comput. Educ. **68**, 545–556 (2013)
7. Kustandi, C., Fadhillah, D.N., Situmorang, R., Prawiladilaga, D.S., Hartati, S.: VR use in online learning for higher education in indonesia. Int. J. Interact. Mobile Technol. (iJIM) **14**(01), 31–47 (2020)
8. Martín-Gutiérrez, J., Mora, C.E., Añorbe-Díaz, B., González-Marrero, A.: Virtual technologies trends in education. EURASIA J. Math. Sci. Technol. Educ. **13**(2), 469–486 (2017)
9. Michalos, G., Karagiannis, P., Makris, S., Tokçalar, Ö., Chryssolouris, G.: Augmented reality (AR) applications for supporting human-robot interactive cooperation. Procedia CIRP **41**, 370–375 (2016)
10. Pilat, Z., Goszczyński, T., Klimasara, W., Słowikowski, M., Zieliński, J.: Use of the ICT in vocational training in the area of industrial robotics and automation. In: 7th International Conference Mechatronic Systems and Materials (MSM 2011), pp. 7–9 (2011)
11. Porcelli, I., Rapaccini, M., Espíndola, D.B., Pereira, C.E.: Technical and organizational issues about the introduction of augmented reality in maintenance and technical assistance services. IFAC Proc. Vol. **46**(7), 257–262 (2013)
12. Yilmaz, R.M.: Augmented reality trends in education between 2016 and 2017 years. In: State of the Art Virtual Reality and Augmented Reality Knowhow, vol. 81, p. 97 (2018)
13. MILAN project. http://milan-project.eu/. Accessed 21 Jan 2020
14. Centre for Research and Development of Modern Technologies CBiRNT, Wrzesnia, Poland. http://cbirnt.wrzesnia.powiat.pl/

Cross Topics

The Effectiveness of a Robot Animal as a Virtual Instructor

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Abstract. The use of virtual robot animals (VRAs) can have a potential impact on applications with affective and aesthetic interfaces. In particular, VRAs can be used in instructional videos in order to develop new ways to engage young learners and to foster personalization of educational instruction. In this paper, we explore the perception of the virtual instructor appearance and its effect on knowledge recall outcomes for young learners. We conducted an experiment with three different virtual instructor appearances: (1) robot animal, (2) animal, and (3) human. The content of the video instruction had two themes: (A) A topic related to robotics (e.g., introductory concepts about robotics), and (B) a topic unrelated to robotics (e.g., Dutch culture). A total of 131 students participated in this study. They originated from two secondary public schools in Bogota, Colombia. Our results showed that the robot animal as a virtual instructor was perceived as the least familiar, common, attractive, interesting, and natural compared with the virtual instructors with the animal and human appearance. Moreover, learners in the condition with the virtual robot animal scored significantly lower on knowledge recall for both topics. A follow-up study can focus on ways to increase positive reactions toward robotic animals as virtual instructors. Video about this research: https://youtu.be/PY1CN0DoKF4.

Keywords: Virtual robot animals · Virtual animals · Virtual humans · Virtual instructor · Virtual teacher · Instructional video content · Robotic appearance · Knowledge recall · Perception · Uncanny valley of virtual animals

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1 Introduction

New trends, challenges, and developments in robotics have led to the question whether a robot could become an effective teacher. In past studies, social robots have been used, for example, to foster language acquisition, and in support of science education, and technology education [4]. In this pedagogical process, the robots were used as a tool, a peer, a tutor or teacher [2, 4]. While actual robots can be employed in direct physical interactions with students, there is also a possibility of developing virtual agents with robotic appearance to be used in simulated environments. For instance, Li et al. (2016) showed that it is possible to use an embodied pedagogical character with a robotic appearance as a virtual instructor. Li et al. suggest that the use of a virtual robot could have almost the same effect on students' recall compared to a human teacher in instructional video content. To test this claim, we examined whether a virtual robot with non-human traits could replace a human instructor in pre-recorded instructional video's. The result of our investigation significantly contributes to research on pedagogical agents that can be used in the area of educational robotics.

Robot Instructors

One of the important goals in the field of social robotics is to design robots to be used as education companions and tutors [2]. The decision on whether a robot design is useful for educational purposes is highly dependent on its impact on learning outcomes. For example, Belpaeme et al. (2018) showed than the Nao (human appearance with arms and legs) and Keepon (yellow snowman appearance without arms and legs) robots had a medium-sized effect on cognitive learning gains in students. A virtual prototype of the Nao robot was used in an instructional video by Li et al. (2016), who found that a Nao as a virtual robot agent can have a positive effect on students' knowledge recall compared to a non-virtual robot, and a similar effect to a non-virtual human teacher. This study offers some important insights into the effect of robotic appearances as a virtual instructor and their wide possibilities in the pedagogical context.

Robotic Appearance and the Uncanny Valley Effect

Research in robotics on the effect of robot appearances has primarily been based on the "uncanny valley theory" [5]. This theory explores the effect of human-like appearance on the affinity and/or familiarity of the users towards the character. An interesting aspect of the theory is that when the robot comes closer to having human traits, it may be perceived with an increasing revulsion. This effect is called the "uncanny valley" and it is found when the robot is close to but fails to attain a realistic appearance [5]. While anthropomorphic features have been the subject of many classic studies in robotic appearance, recently, the focus has begun to shift toward animal appearances. For example, Schneider, Wang and Yang (2007) suggested that a safe strategy preventing the uncanny valley effect is to design virtual animals with non-anthropomorphized appearance, in such a way that they could emote and communicate as a human. However, Schwind et al. (2018) note that, similarly to virtual/robotic humans, the level of realism of the virtual animal-like characters could generate negative reactions.

Summary

To sum up, the literature shows that the theory of the uncanny valley can be applied to robots both with a human and non-human appearance, such as animals. However, currently very little is known on whether the familiarity's perception described in uncanny valley theory can also affect a robot with animal appearance when it acts as a virtual instructor. In our experiment, we tested different appearances of a virtual animal instructor, compared to a human instructor, on students' perception of the character and its possible effect on cognitive learning outcomes.

2 Method

In our previous research on the uncanny valley effect toward virtual animals [8], we designed virtual pandas both with a robotic and a natural appearance. This study used the same virtual character appearances in order to explore if the robotized and natural version of the panda, when used as a virtual instructor have (1) a different effect on users' perception of the appearance of these characters, and (2) if the appearance of the virtual character has an effect on the cognitive learning outcomes, particularly, knowledge recall.

2.1 Design and Material

We conducted an experiment with three different renditions of the instructor appearance, (1) virtual robot animal, (2) virtual animal, and (3) (video recorded) human, each presented in an instructional video. The content of each video instruction focused on one two themes: (A) A topic related to robotics (e.g., introduction concepts about robotics), and (B) a topic unrelated to robotics (e.g., the Netherlands and Dutch culture). This resulted in a 3 × 2 design with six experimental conditions (three virtual instructors and two topics), see Fig. 1. As the native language of the participants was Spanish, all experimental material was in Spanish.

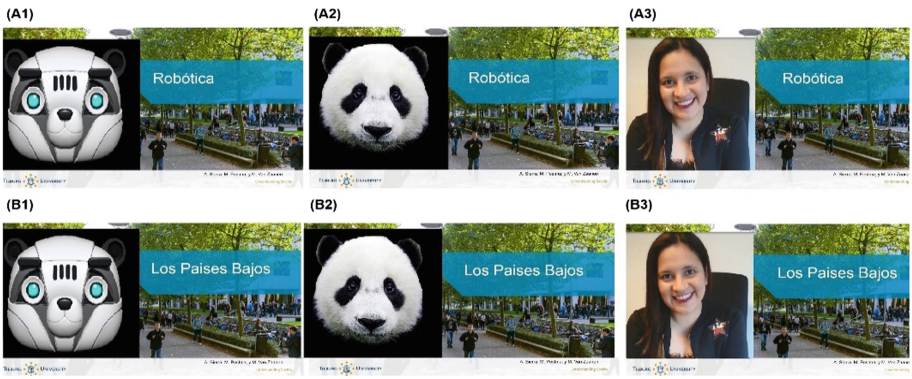

Fig. 1. Participants viewed a video featuring (A1) Robotics with robot panda instructor, (A2) Robotics with panda instructor, (A3) Robotics with human instructor, (B1) The Netherlands with robot panda instructor, (B2) The Netherlands with panda instructor, and (B3) The Netherlands with human. Video about this research: https://youtu.be/PY1CN0DoKF4

2.2 Procedure

Prior to the experimental sessions, participants were asked to fill out a pre-test called "domain knowledge". The pre-test contained questions related to robotics and Dutch culture, to ensure that participants were not already knowledgeable on the content of the instructional videos. At the start of the experimental session, participants were asked about their age, gender, and nationality. Each participant watched one of the six (different) video instructions for 10 min. After the video, participants answered questions about: (1) knowledge recall of the presentation, (2) social presence, (3) interpersonal attraction, (4) presentation skills, (5) enthusiasm, (6) overall experience, (7) concentration, and (8) a questionnaire on the perception of virtual instructors. This questionnaire was administrated online and its completion took approximately 10 min. In total, the experiment took less than 30 min to complete by each participant.

2.3 Participants

Ethics approval was obtained from the Research Ethics and Data Management Committee of the Tilburg School of Humanities and Digital Sciences with the reference REC#2019/89. The experiment was conducted in two secondary public schools in Bogota, Colombia (see Fig. 2). A total of 131 students participated in this study. All students have either given their written consent or received consent by their legal representatives for participants younger than 18 years. The directors of the schools I.E.D Almirante Padilla and I.E.D Prado Veraniego gave permission to the teacher and researcher to conduct the study on the school premises. We recruited a total of 68 students from the Almirante Padilla School, and a total of 63 students from the School Prado Veraniego. Participants ranged in age from 11–17 years (M = 13.6). The sample included 56 females (42.7%) and 75 male (57.3%) participants. The participants' courses were distributed between the seventh (59.5%) and eighth (40.5%) grade. The participants were more or less evenly distributed between the six experimental conditions.

Fig. 2. Student participants (a. Prado Veraniego School and b. Almirante Padilla School).

2.4 Instrumentation

Domain Knowledge and Knowledge Recall. To measure domain knowledge and knowledge recall, we designed a pre-test and post-test for this study (see Table 1). The pre-test 'domain knowledge' consisted of 10 items with four multiple-choice answers on topics related to the Netherlands and to robotics. In order to test if the pre-tests questions are not easy or intuitive to answer by participants, we analyzed the pre-test results before to do the experiment. We found that the majority of participants had a low percentage of assertiveness in their answers on the pretest for all questions except question 3 *"Which of these words are associated with robotics*?" on the topic of robotics. For this reason, question 3 was modified in the post-test to have a higher level of difficulty in this question compared to the pre-test to ensure that the post-test depended on the video instruction stimulus and not for other reasons. The post-test, which we referred to as 'knowledge recall', consisted of the pre-test questions apart from question on the topic of robotics (which was replaced by another question). *Domain knowledge* and *knowledge recall* of the same topic were measured as the number of correct responses where the maximum possible score was 5 (see Table 1 below).

Liking. Li, Kizilcec, Bailenson and Ju (2016) developed a set of questions that measure participants' affinity towards the virtual instructor. The questionnaire consisted of three sub-components: *social presence*, *interpersonal attraction*, and *presentation skills*. Social presence was measured using five items. The reliability for social presence was good (standardized Cronbach's alpha = .707). Interpersonal attraction was measured using four items with good reliability (standardized Cronbach's alpha = .787). Presentation skills were measured using three questions, with good reliability (standardized Cronbach's alpha = .748). Finally, a question about concentration of the participant was assessed using a single-item question with a scale from 1 to 5 (with 1: Not at all, and 5: Absolutely).

Table 1. Pre-test and post-test questionnaires.

Robotics	The Netherlands
1. DATA: How many robots are there in the world? **a. 1.2 million (Correct answer)** b. 1.8 million c. 5 million d. 5.8 million	1. DATA: How many people live in the Netherlands? **a. 17 million (Correct answer)** b. 10 million c. 40 million d. 47 million
2. CURIOUS DATA: The first robot was: a. Vacuum cleaner b. A toothbrush **c. A pigeon (Correct answer)** d. A mouse	2. CURIOUS DATA: The Netherlands is famous for having many: a. Houses b. Buildings **c. Bikes (Correct answer)** d. Cars

(*continued*)

Table 1. (*continued*)

Robotics	The Netherlands
3. CURIOUS WORDS: Which of these words are associated with robotics? (**Pre-test**) a. Zoomorphic robot, Artificial intelligence, Sensory feedback, likely **b. Zoomorphic robot, Artificial intelligence, Sensory feedback, android (Correct answer)** c. Metrics, streams, advantage, braventure, factfulness d. Metrics, streams, advantage, braventure, polls 3. CURIOUS WORDS: Which of these words are associated with robotics and these are correctly written? (**Post-test**) a. Nanotenologic, zomorphic, mecatronic **b. Nanotechnology, zoomorphic, mechatronics (Correct answer)** c. Nanotecnology, zoomorphic, mechatronics d. Nanotechnology, zomorphic, mecathronics	3. CURIOUS WORDS: Which of these words are associated with the Dutch language? a. Bedankt, alsjeblieft, lekker, random **b. Bedankt, alsjeblieft, lekker, hallo (Correct answer)** c. Der abend, das all, ansichten, der arbeitsplatz d. Der abend, das all, ansichten, der bahnhöfe
4. LIST: What robot names do you remember? a. Nao, Asimo, Mariana, Aibo, Walker **b. Nao, Asimo, Paro, Aibo, Walker (Correct answer)** c. John, Victor, Caxi, Porto, Mili d. John, Fox, Caxi, Porto, Mili	4. LIST: What names of the Netherlands do you remember? a. Tilburg, Rotterdam, Barcelona, Haya **b. Tilburg, Rotterdam, Amsterdam, Haya (Correct answer)** c. Berlin, Hamburg, Munich, Cologne d. Berlin, Bremen, Munich, Cologne
5. INTERESTING PEOPLE: What is the name of the engineer who created a robot equal to himself? a. Tanmay Bakshi b. Tanmay Baksshyn c. Hiroshi Hoshiguros **d. Hiroshi Ishiguro (Correct answer)**	5. INTERESTING PEOPLE: What are the names of the King and Queen of the Netherlands? a. Harry and Meghan b. Harry II and Meghan c. William II and Maxima **d. Willem-Alexander and Maxima (Correct answer)**

Appearance Perception Questionnaire. We used a questionnaire from our previous study with virtual animals [8]. It contains semantic differential questions that are designed to measure participant perception of the familiarity, commonality, naturalness, attractiveness, interestingness, and animateness of the virtual instructor. All measures were assessed using five-point Likert scales. This scale corresponds with the evaluation used in the scholar system of Colombia (see Table 2 below). The appearance perception was measured using six items with good reliability (standardized Cronbach's alpha = .771).

Table 2. The appearance perception toward virtual instructor questionnaire.

1. What do you think of the virtual instructor's appearance?			
Familiarity	Very strange	1 2 3 4 5	Very familiar
Commonality	Very unusual	1 2 3 4 5	Very common
Attractiveness	Very ugly	1 2 3 4 5	Very attractive
Interestingness	Very boring	1 2 3 4 5	Very interesting
Naturalness	Very artificial	1 2 3 4 5	Very natural
Animateness	Very inanimate	1 2 3 4 5	Very animate

3 Results

Data preprocessing and analysis was performed using SPSS 25.0. In the first set of analyses, we examined the impact of the virtual instructor appearance on the participant's perception. Since the variables obtained in the data collection phase all showed non-normal distributions, we made use of non-parametric tests. A Kruskal-Wallis H test showed that there was a statistically significant effect of the virtual instructor appearance on participants' perception of *familiarity*: $\chi 2(2) = 9.109, p = 0.011$, *attractiveness*: $\chi 2(2) = 8.576$, $p = 0.014$, *interestingness*: $\chi 2(2) = 6.322$, $p = 0.042$, *naturalness*: $\chi 2(2) = 20.478$, $p < 0.001$, and *animateness*: $\chi 2(2) = 6.942$, $p = 0.031$ (see Fig. 3). The mean

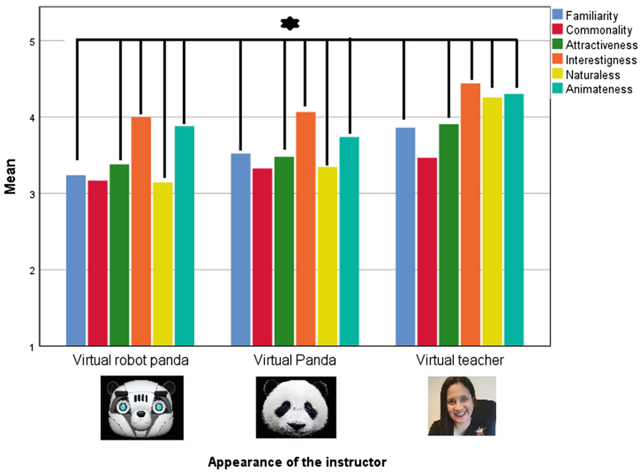

Fig. 3. Mean scores of participants' perception of familiarity, commonality, attractiveness, interestingness, naturalness, and animateness in relation to the appearance of the instructors.

rank of the familiarity score was 53.70 for the virtual robot panda, 66.59 for the virtual panda and 77.38 for the human instructor. The mean rank of the attractiveness score was 57.58 for the virtual robot panda, 61.57 for the virtual panda and 78.97 for the human instructor. The mean rank of the interestingness score was 58.96 for the virtual robot panda, 62.23 for the virtual panda and 76.91 for the human instructor. The mean rank of the naturalness score was 51.44 for the virtual robot panda, 60.52 for the virtual panda and 86.08 for the human instructor. The mean rank of the animateness score was 62.89 for the virtual robot panda, 58.11 for the virtual panda and 77.48 for the human instructor. There was no significant effect of appearance on commonality $\chi 2(2) = 2.190$, $p = 0.335$.

The second set of analyses examined the impact of the appearance knowledge recall and concentration. There was no significant difference in domain knowledge (pre-test) between the experimental conditions with different virtual instructors: $\chi 2(2) = 0.006$, $p = 0.997$. A Kruskal-Wallis H test was conducted to measure the potential effect of on domain knowledge (pre-test), knowledge recall (post-test), and concentration (see Fig. 4). There was a statistically significant effect of appearance on knowledge recall (post-test): $\chi 2(2) = 6.533$, $p = 0.038$, with a mean rank of the knowledge recall score of 55.39 for the virtual robot panda, 67.83 for the virtual panda and 72.81 for the human instructor. Finally, there was no effect of appearance on concentration: $\chi 2(2) = 0.382$, $p = 0.826$.

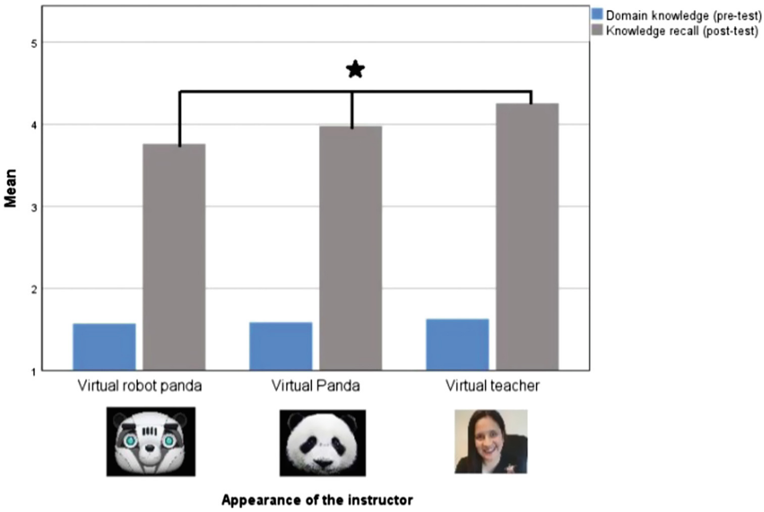

Fig. 4. Participants' domain knowledge (pre-test) and knowledge recall (post-test) in relation to the appearance of the instructors.

4 Discussion

The first goal of the current study was to explore the relationship between the appearance of the virtual instructor and participants' perception. The results showed a significant effect of the appearance on familiarity, attractiveness, interestingness, naturalness, and animateness, with no significant effect on commonality. Contrary to expectations, the virtual robot animal instructor was considered to be the least familiar, attractive, interesting, and natural virtual character, compared to the natural version of the animal instructor and the human instructor. These results corroborate the findings of much of the previous work on the uncanny valley of virtual animals, where the robot animal led to a less pronounced 'uncanny' feeling compared with the natural version [8]. This finding, however, is contrary to previous studies which have suggested that using a virtual animal that has more animal-likeness but emotes and communicates like a human is a good strategy [6]. In our study, the virtual character retained its animal appearance, while it had the human role of being an instructor. However, students considered a human teacher more familiar, interesting and natural. This result may be explained by the fact that the learners who participated in the study are not in contact with robots during a normal school day. Another possible explanation for this is that humans tend to feel more attracted to objects with anthropomorphic properties in their appearance, such as androids or humanoid robots that have more typically been explored in the theory of the uncanny valley [5].

The second goal of this study was to determine if the appearance of the virtual instructor influences knowledge recall and another learning outcomes. The results indicate that the appearance of the virtual instructor indeed had a significant effect on knowledge recall, also when taking into account their previous knowledge about the topics. We found no effect of the appearance of the virtual instructor on concentration. On the one hand, these results are consistent with the outcomes of Li et al. (2016), who showed that the appearance of a virtual character had a recall effect on participants. On the other hand, the results showed that the virtual robot had less effect on knowledge recall compared to the animal and human instructors. In the results of Li et al. (2016), the virtual robot had a similar effect on knowledge recall compared to the human instructor, although the android appearance of their instructor could have affected the results. This study supports evidence from previous observations (e.g., Belpaeme et al. 2018) that robotic appearances can affect learning outcomes, also in a virtual environment. One of the issues that emerge from these findings is that a virtual robot animal does not appear to be a suitable virtual instructor (yet) in instructional video content.

This study was performed in Colombia, we do not if the type of the animal (e.g. panda) would it have made a difference with an animal that the pupils have more familiarity in this country, however, the panda animal was used because we wanted to make continuity with the study of "uncanny valley of the virtual animals" where the panda animal was the main character in this previous study [8]. Current findings are consistent with the previous study where the panda robot had a low score in familiarity (which fell into the uncanny valley) compared with real panda. Likewise, these findings are consistent when it comes to an instructional video.

In future investigations, we may want to focus on virtual robotic animals or humans with different designs of virtual instructors in order to increase positive reactions by the users.

5 Conclusions

The purpose of the current study was to determine if a virtual robot animal can be used effectively as a virtual instructor. Our results show that a virtual robot animal does not elicit particularly positive reactions in terms of familiarity, interestingness, and naturalness compared with virtual animal and human instructors. These findings confirms our previous findings on the uncanny valley of the virtual animals, where the users had a more positive reaction toward the animal with natural traits compared to the robotic version. One of the more significant findings to emerge from this study is that the appearance of the virtual instructor had a significant effect on knowledge recall. This finding offers some insight into the design of other agents to be used as virtual instructors. To further investigate these relationships, the study should be repeated using other designs of virtual robot instructors (e.g., using other animals or humans, improving the realisticness of the animation, adding the full body, manipulating emotional facial expressions, etc.) to establish whether it will have the same effects as in this study.

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References

1. Belpaeme, T., Kennedy, J., Ramachandran, A., Scassellati, B., Tanaka, F.: Social robots for education: a review. Sci. Robot. **3**(21), eaat5954 (2018)
2. Causo, A., Vo, G.T., Chen, I.M., Yeo, S.H.: Design of robots used as education companion and tutor. In: Robotics and Mechatronics, pp. 75–84. Springer, Cham (2016)
3. Li, J., Kizilcec, R., Bailenson, J., Ju, W.: Social robots and virtual agents as lecturers for video instruction. Comput. Hum. Behav. **55**, 1222–1230 (2016)
4. Mubin, O., Stevens, C.J., Shahid, S., Al Mahmud, A., Dong, J.J.: A review of the applicability of robots in education. J. Technol. Educ. Learn. **1**(209–0015), 13 (2013)
5. Mori, M., MacDorman, K.F., Kageki, N.: The uncanny valley: the original essay by Masahiro Mori. IEEE Spectrum, 98–100 (2012)
6. Schneider, E., Wang, Y., Yang, S.: Exploring the uncanny valley with japanese video game characters. In: DiGRA Conference, September 2007
7. Schwind, V., Leicht, K., Jäger, S., Wolf, K., Henze, N.: Is there an uncanny valley of virtual animals? A quantitative and qualitative investigation. Int. J. Hum Comput Stud. **111**, 49–61 (2018)
8. Sierra Rativa, A.S., Postma, M., van Zaanen, M.: The uncanny valley of the virtual (animal) robot. In: International Conference on Robotics and Education RiE 2019, pp. 419–427. Springer, Cham, April 2019

From Diagram to Breadboard: Limiting the Gap and Strengthening the Understanding

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Abstract. In fall 2018, the national Danish Broadcasting Corporation (DR) launched a large scale investment into Educational Robotics, providing 65.000 fourth grade students, with micro:bits. With years of experience teaching STEM related afterschool activities, it is the authors experience, that working with the breadboard and the popular Fritzing diagrams, in combination with the micro:bit, comes with its own set of problems. Materials aimed at solving these were developed and a study with four experimental conditions in a between-subject design, in which participants (N = 172) engaged in a short teaching session on electronics, as well as taking a pre- and post-test, were carried out. Results show that the provided solutions both strengthened the understanding of the breadboard and limited the gap between diagram and breadboard.

Keywords: Electronics · Breadboard · Diagram · Circuit · Micro:bit · Ultra:bit · Robot · Education · Educational Robotics · Experimental · Computational Thinking · CT · STEM · K-12 · Primary education

1 Introduction

Educational Robotics (ER) [1–3] is a popular way of supporting and exemplifying Computational Thinking (CT) [4] and teaching of STEM (Science, Technology, Engineering and Mathematics). And in the fall of 2018, the national Danish Broadcasting Corporation (DR), launched project ultra:bit, in order to give Danish primary school pupils access to learning STEM through ER technology. The project provided 65.000 fourth grade pupils[1] with micro:bits [5, 6]. With 25 external connections, the micro:bit affords pupils with ways of working creatively with designing and developing prototypes for new technologies, while not limiting them to the build-in sensors and actuators. A popular way to implement these prototypes is with the use of a breadboard and for this purpose several tools have already been developed, e.g. the Adafruit Dragon Tail[2]. While at the same time, Fritzing diagrams have proven a popular choice for illustrating how to build electrical circuits. Since the non-profit organization Teknologiskolen (School

[1] In the Danish primary school system, fourth grade student are usually between 9–11 years old.
[2] Adafruit, Dragon Tail: https://www.adafruit.com/product/3695. [Accessed 31 Jan. 2020].

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of Technology) [7] opened its doors in fall 2015, the authors of this article have taught pupils aged 10–16, STEM related afterschool activities on a weekly basis, through the use of ER and with an emphasis on learning-by-doing and constructionism [8]. Today Teknologiskolen have roughly one hundred pupils, spanning six different teams, which once a week receives afterschools classes.

From the past years of teaching at Teknologiskolen, it is our experience that when working with the breadboard and Fritzing diagrams, the pupils are prone to make a lot of connections errors (see Fig. 1), as well as focusing on using the exact rows/holes (letters/numbers) as on the diagrams. This could indicate that the breadboard is difficult to understand, and that the pupils therefore have a hard time grasping how the holes are connected internally. Likewise, the pupils have a hard time reading and understanding standard electrical diagrams, even after having worked with Fritzing diagrams for a longer period of time. This could indicate that Fritzing diagrams are too far removed from the design of standard diagrams, in order for working with these too lead to a better understanding of standard diagrams. From previous conversations with primary school teachers, it is clear that these problems are also present in their classrooms. With our own problems, those of regular primary school teachers and the national investment in the micro:bit in mind, we are therefore interesting in providing concrete solutions to these problems. We aim for the solutions to be implementable by the individual teacher, here and now, instead of having to wait years for a possibly product being produced and made available. This have led us to formulate the following research questions:

- RQ1: Can we enhance upon the design of the standard breadboard, in order to strengthen the understanding of how its holes are connected internally?
- RQ2: Can we design a new type of electrical diagram, which limits the gap between standard diagrams and the breadboard, while staying true to the design of these?

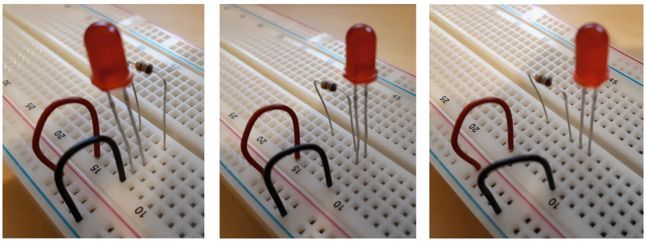

Fig. 1. Examples of what we refer to with “connection errors”.

1.1 Preliminary Study

The materials used in the experiments comprising the study described in this article, were developed through a smaller preliminary study.

The preliminary study used an iterative and incremental development process as described by Larman [9] integrated into a user-centered process as described by Rogers, Sharp and Pears [10]. The study spanned three iterations, with each iteration consisting of four phases (requirements, design, prototyping, evaluation).

In each iteration, four-five pupils from Teknologiskolen participated, the pupils were 4^{th}–6^{th} graders (10–12 years old) and were selected based on their varying experience/inexperience with breadboards, electronics and robot technology. Throughout the iterations, the pupils were actively involved in the different stages of the iterations and acted in the role of informants, as defined by Druin [11].

Furthermore, the theoretical foundation for the design of the developed materials was based upon the Gestalt theories and the principles of proximity and similarity [12].

Results
To accommodate for RQ1, a 3D printed plastic cover, designed as an overlay to fit on top of a standard breadboard in order to visualize the internal connections between the holes, were developed. Before the cover would be glued on top of the breadboard, the supply lines would first be colored red/black using a permanent marker, with the red line being the outward facing line on both sides to ensure symmetricity. The symmetry serves two purposes, the first is to avoid unnecessary confusion due to the order of the supply lines changing along with the orientation of the board, with the second being that the boards likewise affords having Adafruit's Dragon Tail for the micro:bit and the likes thereof, plugged in regardless of its orientation. A total of 30 models of the final prototype were produced for use in this experiment.

Likewise, to accommodate for RQ2, a new type of diagram was developed, which were designed to further explain the components connections in comparison with a standard electrical diagram, while at the same time staying true to the original design of these. Furthermore, the new type of diagram was designed to complement the new type of breadboard, why the design is built upon visual references to these, namely the white 1×5 hole long squares, as well as a color representation of the supply lines.

In addition, three different tasks (T1–T3) were designed, tested and refined, for use in the pre- and post-tests in the study described in this article, along with the time set aside for these.

The developed breadboards can be seen in Fig. 2, while the design of the new type of diagrams along with T1–T3, can be seen in Figs. 3, 4 and 5.

In the tests, each of the tasks were printed on their own sheet of paper, along with a visual explanation of the symbols used in the diagram, this explanation can be seen in Fig. 6.

1.2 Related Work

Available products like littleBits[3], have already been developed with the aim of making working with electronics more available for a younger audience. Yet these are far removed from standard materials and are not compatible with ER technologies like the micro:bit. We have not been able to find any research into expanding upon the breadboard or diagrams, in order to solve the research questions stated in this study.

[3] littleBits: https://littlebits.com/. [Accessed 31 Jan. 2020].

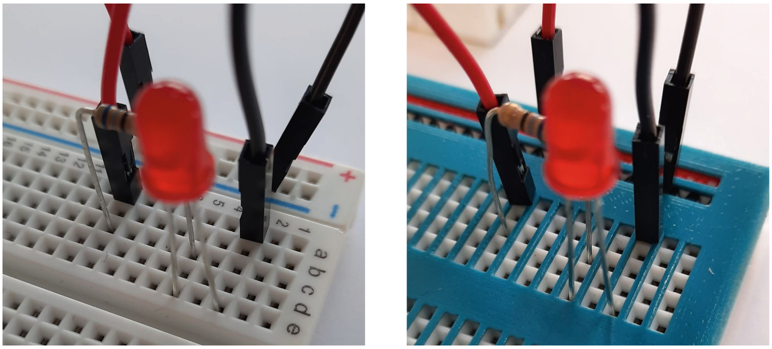

Fig. 2. T1 on a standard breadboard (left) and T1 on the new type of breadboard (right).

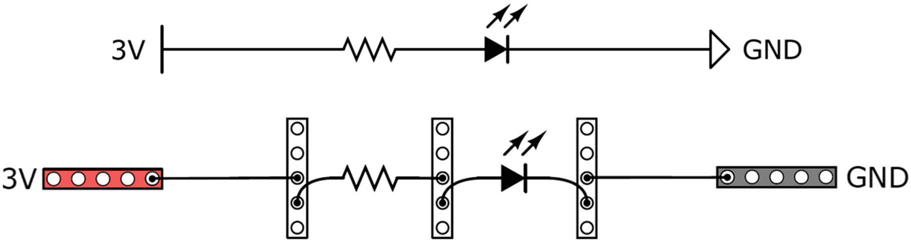

Fig. 3. T1: The standard diagram used in C1–C2 (top) and the new type of diagram used in C3–C4 (bottom).

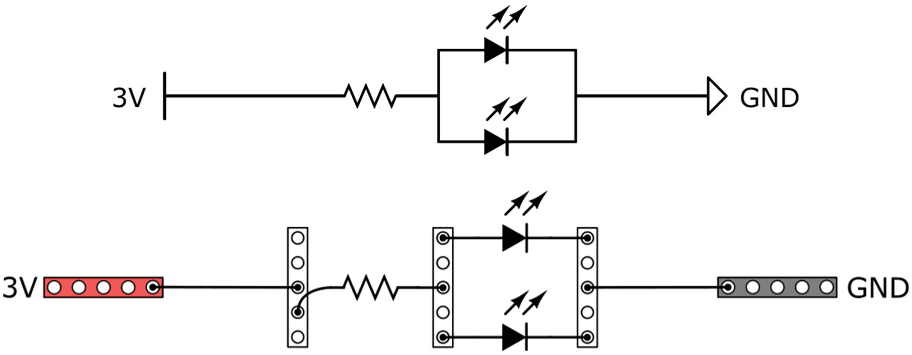

Fig. 4. T2: The standard diagram used in C1–C2 (top) and the new type of diagram used in C3–C4 (bottom).

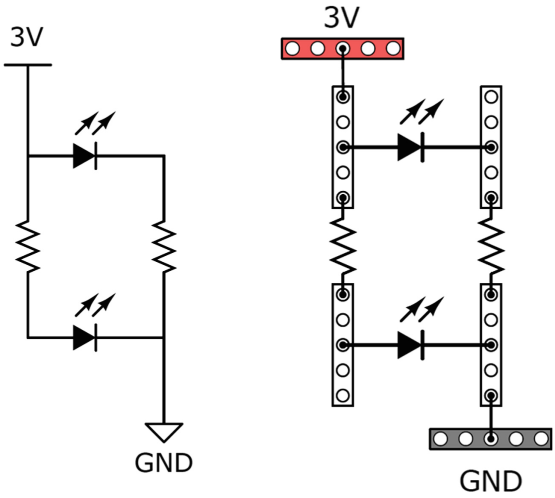

Fig. 5. T3: The standard diagram used in C1–C2 (left) and the new type of diagram used in C3–C4 (right).

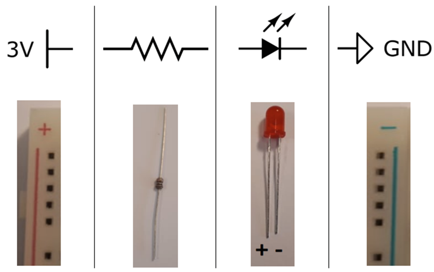

Fig. 6. The symbol explanation which were included with all tasks, regardless of the condition.

2 Method

The study was carried out with four experimental conditions (C1–C4) in a between-subject design in which participants (N = 172) filled out a short demographic questionnaire, as well as took both a pre- and post-test, with a short teaching session in between.

Participants were 4th grade pupils from three different public primary schools in Denmark, of which 88.4% were 10 years old, with 48.8% being female and 50% being male. In an effort to get as accurate results from the comparisons as possible, parallel classes were used whenever possible, in order to avoid comparing classes from schools which focus on technology differed greatly. For an overview of the schools and classes involved as well as when the experiments took place, see Table 1.

Table 1. The participating school classes

School	Class	Date	Condition
Tingløkkeskolen (TLS):	4.C (n = 26)	2nd of Dec., 2019	C1
Tingløkkeskolen (TLS):	4.A (n = 24)	3rd of Dec., 2019	C4
Holluf Pile Skole (HPS):	4.C (n = 16)	5th of Dec., 2019	C2
Holluf Pile Skole (HPS):	4.B (n = 19)	5th of Dec., 2019	C3
Antvorskov Skole (AVS):	4.C (n = 23)	12th of Dec., 2019	C1
Antvorskov Skole (AVS):	4.B (n = 20)	12th of Dec., 2019	C2
Antvorskov Skole (AVS):	4.A (n = 21)	12th of Dec., 2019	C3
Antvorskov Skole (AVS):	4.D (n = 23)	12th of Dec., 2019	C4

2.1 Conditions

The four experimental conditions (C1–C4) all shared the same questionnaire and pre-test, while the involved equipment and post-test differed according to the condition in question. The teaching taking place between the questionnaire/pre-test and the post-test, were in overall kept the same for all four conditions. However, during the teaching session, when the researcher was drawing the breadboard or the diagram of T1 on the whiteboard, the drawing was drawn in a fashion similar to the equipment used in the respective condition. The four conditions can be seen in Table 2.

Table 2. Experimental conditions C1–C4

	Standard breadboard	New breadboard
Standard diagrams	C1 (n = 49)	C2 (n = 36)
New diagrams	C3 (n = 40)	C4 (n = 47)

2.2 Procedure

The procedure for the experiment were the same for all four experimental conditions and was planned as a one-module (45 min) teaching session.

Before each session, the following components were handed out to each of the participants: 1x standard breadboard, 1x red wire (5 cm long), 1x black wire (5 cm long), 2x 47 Ω resistors and 2x 5 mm Red LEDs. In the case of condition C2 and C4, the breadboard would be swapped out with the new type of breadboard directly after the pre-test. The sessions consisted of the following steps:

- **Introduction:** The participants were given a short introduction to us researchers, who we were and what we would be doing, as well as being assured that it is perfectly okay to find the involved tasks too difficult to solve.

- **Questionnaire/Pre-test:** The participants were asked to fill out the questionnaire. After everyone had done so, they were given five minutes to individually try and solve the pre-test (T1, standard diagram, standard breadboard).
- **Teaching:** One of the researchers – the same for all the experiments – gave the participants a short lecture on the flow of electricity, by comparing it to that of water. Followed by a short introduction to the handed-out components, comparing the wires and resistors to regular and half blocked water pipes, and the LEDs to that of a water pipe with an internal watermill inside it. Afterwards the participants were given a short introduction on how to read an electrical diagram (T1, conditional specific), after which the task would be solved in plenum. To ensure that every participant had a working circuit, the researchers would check them one by one, by supplying their circuit with electricity. When all the participants had had their LED light up, they were told to disassemble the circuit and put the components back on the table.
- **Post-test:** The participants were given ten minutes to try and solve the post-test (T1–T3, conditional specific). Furthermore, they were informed that when they thought they had solved a task, they should raise their hand and a researcher would come and check it. However, they were also told that the researchers would only be allowed to say, "there are several mistakes, try again", "there is one mistake, try again" or "it is correct – give it a checkmark and note down the time".
- **Debriefing:** The participants were informed about the purpose of the experiment, the existence of different conditions, as well as being reassured that it is perfectly okay not having been able to solve the involved tasks and complimented for their participation. The latter in order not to risk leaving them with a sense of failure, and thus scare them away from the topic in the future.

2.3 Data Collection

Quantitative data was collected through the combined questionnaire, pre-test and post-test, while qualitative data was collected through short semi-structured follow-up interviews, with selected participants (two-three from each condition) and conversations with the teachers, in addition to the researchers' observations throughout the sessions. The interviewed participants were interviewed individually in order to limit their influence on one another's answers.

To ensure participant anonymity, the participants filled out the following code for later identification and comparison between the questionnaire, pre-test and the post-test: The first letters of their mother's name, the first letter in their own name, the first letter of the street they live on and the first number of their house number.

2.4 Analysis

During the experiment, five participants from AVS, class 4.D did not wish to partake in the post-test, bringing the total number of participants in C4, down to $n = 42$.

Throughout the experiments, it was noted a few times that a participant had skipped T1 and moved on to T2 right away, due to finding it boring to repeat T1. Therefore, in these very rare instances the data have been adjusted to reflect these participants ability to solve T1, since it must be assumed that they would have been able to, see Table 3 for an overview of these instances.

Pearson's Chi-Squared test was used in order to find the level of significance between the conditions.

Table 3. The number of participants being noted down as having completed T1, due to their completion of T2.

School	Class	Number of participants	Condition
Tingløkkeskolen (TLS)	4.C (n = 26)	1	C1
Tingløkkeskolen (TLS)	4.A (n = 24)	2	C4
Antvorskov Skole (AVS)	4.C (n = 23)	1	C1
Antvorskov Skole (AVS)	4.B (n = 20)	1	C2
Antvorskov Skole (AVS)	4.D (n = 23)	1	C4

3 Results

In the following section we will present the quantitative and qualitative data, which were obtained during and from the experiments.

3.1 Questionnaire

The demographic showed that genderwise the participants were 48.8% female, 50% male, 0% neither, with 1.2% not reporting their gender. It also showed that 88.4% of the participants were 10 years old, with 4.8% being 9 and 6.8% being 11. Furthermore, 46.7% reported themselves as having often worked with programming, 50.3% reported having some experience and 3% having zero experience. For robotics the percentages where (16.2%, 76.6% and 6%) and for electronics (31.7%, 52.7% and 15.6%).

3.2 Pre-test

None of the participants in C1–C4 solved T1 (standard diagram), likewise none of the participants were observed displaying any understanding of how to read the diagram and or how to implement it on the breadboard (standard breadboard).

3.3 Post-test

In comparison with the pre-test, quite a lot of participants – after having received the short lecture – managed to solve one or more of T1–T3 in the post-test. The specific percentages of participants who solved T1, T2 or T3, for each condition and class, can be seen in Table 4, 5, 6 and 7.

Table 4. The percentage of participants in C1, who solved T1–T3

	Task 1	Task 2	Task 3
C1: AVS, 4.C (n = 23)	69.6%	47.8%	13.0%
C1: TLS, 4.C (n = 26)	53.8%	34.6%	7.7%
C1: Total (n = 47)	61.2%	40.8%	10.2%

Table 5. The percentage of participants in C2, who solved T1–T3

	Task 1	Task 2	Task 3
C2: AVS, 4.B (n = 20)	75.0%	35.0%	10.0%
C2: HPS, 4.C (n = 16)	87.5%	31.3%	6.3%
C2: Total (n = 36)	80.6%	33.3%	8.3%

Table 6. The percentage of participants in C3, who solved T1–T3

	Task 1	Task 2	Task 3
C3: AVS, 4.A (n = 21)	71.4%	42.9%	20.8%
C3: HPS, 4.B (n = 19	57.9%	31.6%	10.5%
C3: Total (n = 40	65.0%	37.5%	17.5%

Table 7. The percentage of participants in C4, who solved T1–T3

	Task 1	Task 2	Task 3
C4: AVS, 4.D (n = 18	66.7%	50.0%	38.9%
C4: TLS, 4.A (n = 24)	91.7%	62.5%	37.5%
C4: Total (n = 42)	81.0%	57.1%	38.1%

When looking closer at the percentages of participants correctly solving T1 (C1: 61.2%, C2: 80.6%, C3: 65.0% and C4: 81.0%), we can see that it differed significantly between C1 and C4 ($p = .040$), in addition there were also a marginally significant difference between C1 and C2 ($p = .056$), see Fig. 7 and Table 8.

Regarding the percentage of participants who solved T2 (C1: 40.8%, C2: 33.3%, C3: 37.5% and C4: 57.1%), there were a significant difference between C2 and C4 ($p = .035$) and a marginally significant difference between C3 and C4 ($p = .075$). There were, however, no notable difference in percentage between C1, C2 and C3 (see Fig. 8 and Table 8).

Furthermore, when looking at the percentage of participants who solved T3 (C1: 10.2%, C2: 8.3%, C3: 17.5% and C4: 38.1%), it differed significantly between C1–C3 and C4 ($p = .002$, $p = .002$ and $p = .038$), as well as there being a notable difference in percentage between C1 and C3, as well as between C2 and C3 (see Fig. 9 and Table 8).

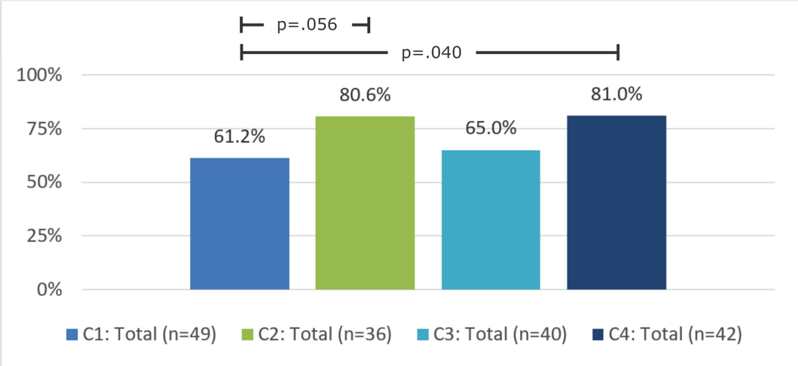

Fig. 7. The percentage of participants in C1–C4 who solved T1 in the post-test.

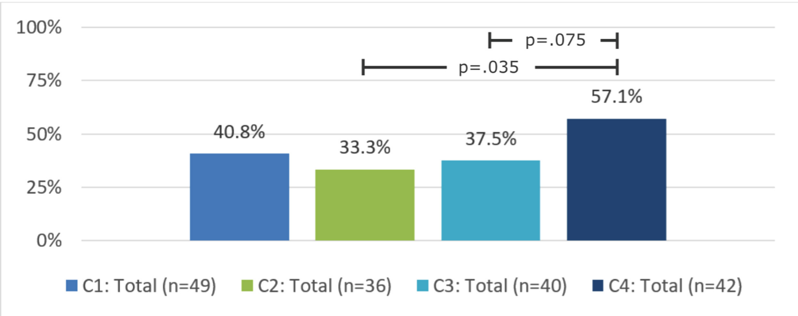

Fig. 8. The percentage of participants in C1–C4 who solved T2 in the post-test.

There were not found to be any significant relation between the participants gender, self-reported previous experience with robotics, programming and or electronics, and their ability to correctly solve T1, T2 or T3 in the post-test.

3.4 Semi-structure Interviews

When the participants were afterwards asked what had been the most difficult, the most common answer was “the last task”. When asked about what had been the easiest, the most common answer would be “when we made the first tasks together (during the short lecture)”.

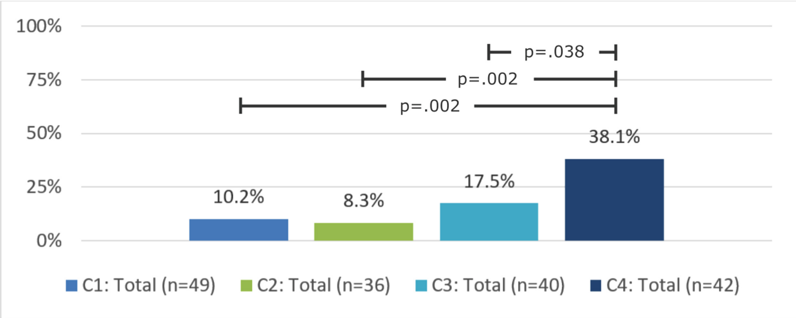

Fig. 9. The percentage of participants in C1–C4 who solved T3 in the post-test.

Table 8. The level of significance in percentages of participants solving T1–T3, between selected conditions.

Condition	Task	Result
C1 (n = 49) and C2 (n = 36)	T1	x^2 (1) = 3.653, p = .056
C1 (n = 49) and C4 (n = 42)	T1	x^2 (1) = 4.218, p = .040
C2 (n = 36) and C4 (n = 42)	T2	x^2 (1) = 4.422, p = .035
C3 (n = 40) and C4 (n = 42)	T2	x^2 (1) = 3.170, p = .075
C1 (n = 49) and C4 (n = 42)	T3	x^2 (1) = 9.911, p = .002
C2 (n = 36) and C4 (n = 42)	T3	x^2 (1) = 9.319, p = .002
C3 (n = 40) and C4 (n = 42)	T3	x^2 (1) = 4.306, p = .038

When asked if working with the tasks and material were funny or boring, all participants answered that they had found it funny. When asked why this was, two types of replies came up again and again "because it is something new" and "because we were building something".

The participants were also asked which type of board – the standard or the new – they found the easiest to understand (for this purpose, both boards were laid out in front of them, and they were told that they were essentially the same). Very few of the participants would hastily pick the standard breadboard. When asked why, they would often reply "I just think so", when faced with follow up questions on which holes are connected to one another, they became more unsure. When followed up with the same question regarding the new board, they had no trouble pointing out which holes are connected. When asked once again about which board they found the easiest to understand, they would most often grinningly reply "ah, then this one".

The participants were likewise asked which type of diagram – the standard or the new – they found the easiest to understand. For this purpose, both diagrams for T2 were likewise laid out in front of them, together with a board of the type they had been working with. Here however, most participants would quickly point to the standard diagram. Yet when asked about where to begin, most had a hard time answering this. When asked regarding the new type, they for the most part could follow it quite well. When halfway through explaining the implementation (the resistor had been implemented), they would be asked to continue with the standard diagram (the next step was to implement the LED's in parallel). Here they became very vague and most faltered and did not know how to. Once again, they were then asked to switch back to using the new type, and for the most part, were able to continue explaining it step by step. In the end, they were once again asked which type, they found the easiest, and like with the previous question, they would most often grinningly reply "this one" and point to the new type.

3.5 Observations

While conducting the experiments, several observations made by the researchers were noted down and the most relevant of these will be reported in this section.

During the short lecture between the questionnaire/pre-test and the post-test, the participants in C1 and C3 had a high focus on which rows/holes (numbers/letters) the researcher used, when solving T1 together with the participants. This continued even though it was stressed several times throughout the lecture, that it was purely the connections formed by the components which mattered, and not which rows or holes were used for this, since these were all essentially alike. With there being no numbers/letters on the new breadboards, this was not the case with the participants in C2 and C4, who displayed no greater interest in using the same rows or holes as the researcher.

While solving T2 in the post-test, it became apparent that the participants in C2, had made nearly no connection errors when trying to implement the diagram. However, they had often ended up either implementing the two LED's in serial instead of in parallel, using two resistors along with two LED's or switched around the LED's and the resistor. Yet, due to the restricted response system set in place for feedback from the researchers, the participants as a result, very often ended up searching for connection errors, where there in fact were none, instead of looking for errors in relation to the diagram.

It is also worth mentioning that the participants in C4 from AVS 4.D, were generally very unmotivated and reluctant to commit to the post-test. A follow up conversation with the teacher attached to the class, also revealed that there were some clear differences between the classes when faced with new and challenging tasks. In addition, it is also worth mentioning that this test took place in the afternoon as they were the last class to be tested – which could likewise have been and influence.

4 Discussion

In this section we will first discuss the findings from the experiments and in light of the gathered data, we will discuss to which degree the developed solutions fulfill the requirements of the research questions. We will then share some thoughts on how to transition from the developed materials to standard materials, as well as comment on the limitations of the study and future directions.

4.1 The Developed Solutions

The results show that participants working with the new type of breadboard (C2, C4), were less prone to making connection errors than those working with the standard breadboard (C1, C3). In contrast to participants in C1 and C3, the participants in C2 and C4, paid no greater attention to which rows/holes, the researcher used when solving T1 together with the participants during the short lecture. These observations indicate that the new breadboard facilitate a better understanding of how the breadboards holes are internally connected. When looking at T1 in the post-test, the participants in C2 and C4 alike, also had a higher percentage of participants who correctly solved the task, when compared to participants in C1 and C3. However, for the participants in C2, this was not the case for T2 and T3. This can be explained by the observations made during the experiment, in which the participants in C2 were observed being focused on finding connection errors, where there often were none. Yet, due to the restricted feedback system set in place for the researchers, the participants could not be informed that the errors instead lied with how to diagram had been interpreted. Should the new type of breadboard therefore be used during regular teachings, this should not prove a problem. When asked, most participants (C1–C4) likewise found the new type of breadboard to be the easiest to understand. Based on these results, we therefore conclude that the new type of breadboard, strengthens the understanding of how a breadboards holes are internally connected, when compared to standard breadboards.

The results also show that there was no apparent difference in the percentage of participants who solved T1–T2, between the participants who worked with standard breadboards and standard diagrams (C1), and those working with standard breadboards and the new type of diagram (C3). However, a higher percentage of participants working with the new type of diagram (C3–C4), were able to correctly interpret and implement the more complex circuit of T3 in the post-test, as compared to those working with standard diagrams (C1–C2). This indicates that the new type of diagram, is better at facilitating how to implement the presented circuit, on a breadboard. When asked, most participants regardless of condition, were quick to point out the standard diagram as the easiest to understand. This stood in stark contrast to their ability to explain how to implement the diagram on a breadboard, in which they all fared better with the new type of diagram. A possible explanation for this, is that the standard diagram has fewer lines, why it might at first glance, seem easier to understand, while not proving to be so at a deeper look. Based on these results, we therefore conclude that the new type of diagram, limits the gap between interpreting a diagram and implementing the circuit on a breadboard, when compared to standard diagrams, while at the same time staying true to the original design of these.

Furthermore, the results also show that participants working with a combination of the new breadboard and the new type of diagram (C4), had the highest rate of success, in all of the tasks in the post-test (T1–T3). Based on this result, we therefore conclude that the optimal result from using the developed materials, happens when they are implemented alongside one another.

By building our solutions on adding upon existing and readily available materials, we have allowed schools to autonomously and cost efficiently, implement the solutions themselves, with the only requirement being access to a 3D printer.

Having provided concrete solutions, which both strengthens the understanding and limits the gap from diagram to breadboard, we consider the requirement of RQ1–RQ2, to be fulfilled.

4.2 Thoughts on How to Transition to Standardized Materials

We acknowledge that the pupils will at some point in time, have to transition from the developed materials, to standard materials, due to these also being the industry standard. In regard to this, we recommend that educators begin this transition, by teaching the pupils how to identify the connection-junctions on standard diagrams and draw a box around these in order to imitate the boxes used in the new type of diagram. When the pupils have become comfortable with standard diagrams, we then recommend the removal of the cover.

4.3 Limitations and Future Directions

A longer running experiment, in which the developed materials are implemented into the context of regular teachings, should provide a deeper insight into the effect of these. Comparing the transition from the new type of diagrams, to standard diagrams, with that from Fritzing diagrams to standard diagrams, would likewise prove interesting. Furthermore, we are looking into the possibility of developing a free application for designing diagrams of the new type, in order to give teachers and researchers around the world easier access to working with these themselves. In addition to this, we are also considering developing vinyl sheets, as a possible alternative to the 3D printed covers.

5 Conclusion

With this study we have presented concrete solutions on how to strengthen fourth grade pupils understanding of how the breadboards holes are internally connected, as well as how to limit the gap between diagram and breadboard, while staying true to the original design of these. We have fulfilled this by developing a 3D printable cover for standard breadboards, as well as designing a new type of electrical diagram to work alongside it. Having carried out a study with four experimental conditions in a between-subject design, in which participants (N = 172) engaged in a short teaching session on electronics, as well as taking a pre- and post-test, we have concluded that the offered solutions fulfill the requirements of our research questions. The concrete solutions presented in this study, furthermore, allows teachers around the world, to implement these solutions here and now, with the only requirement being access to a 3D printer. The developed materials will be made available here: https://tiny.cc/r3bnsz.

References

1. Atmatzidou, S., Demetriadis, S.: Advancing students' computational thinking skills through educational robotics: a study on age and gender relevant differences. Rob. Auton. Syst. **75**, 661–670 (2016)

2. Blanchard, S., Freiman, V., Lirrete-Pitre, N.: Strategies used by elementary schoolchildren solving robotics-based complex tasks: innovative potential of technology. Procedia Soc. Behav. Sci. **2**(2), 2851–2857 (2010)
3. Bers, M.U., et al.: Computational thinking and tinkering: exploration of an early childhood robotics curriculum. Comput. Educ. **72**, 145–157 (2014)
4. Wing, J.M.: Computational thinking and thinking about computing. Philos. Trans. A. Math. Phys. Eng. Sci. **366**(1881), 3717–3725 (2008)
5. AU - Ultrabit. https://cctd.au.dk/currently/news/show/artikel/danish-broadcasting-corporation-dr-launches-ultrabit/. Accessed 31 Jan 2020
6. DR – Ultrabit. https://www.dr.dk/om-dr/ultrabit. Accessed 31 Jan 2020
7. Teknologiskolen. https://www.teknologiskolen.dk/. Accessed 31 Jan 2020
8. Harel, I., Papert, S.: Constructionism. Ablex Publishing, Norwood (1991)
9. Larman, C.: Agile and Iterative Development: A Manager's Guide. Addison-Wesley Professional, Boston (2004)
10. Preece, J., Rogers, Y., Sharp, H.: Interaction Design: Beyond Human-Computer Interaction, 4th edn. Wiley, Hoboken (2015)
11. Druin, A.: The role of children in the design of new technology. Behav. Inf. Technol. **21**(1), 1–25 (2002)
12. Palmer, S.E., Brooks, J.L., Nelson, R.: When does grouping happen? Acta Physiol. (Oxf.) **114**(3), 311–330 (2003)

A Robotic Teacher Community to Foster the Integration of Educational Robotics in School

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Abstract. The digital society requires the acquisition of skills related to computer sciences like computational thinking or competences in coding. Also transversal competences like communication, collaboration and creativity are increasingly important. Educational robotics is perceived as a valuable tool to increase such competences and is more and more present in the new school curricula. However only few teachers carry out educational robotics activities in their classes. The Roteco project aims to train school teachers in the field of educational robotics and computer science and to develop a community where teachers can find support and exchange experiences and educational activities in order to increase the presence of robotics in school classes. In the project a teacher training and a collaborative platform have been developed. The platform allows teachers to contact other teachers or experts. Teachers can easily publish, select and download didactic activities of other pairs with the related materials. In this paper the project and first results are presented.

Keywords: Educational robotics · Community · Teacher training

1 Introduction

Nowadays the classic skills labeled with the triad “reading, writing and arithmetic” are no longer sufficient. The digitalization of the society increasingly requires citizens to acquire skills in the computer science domains like computational thinking or competences in coding as well as “soft skills” like creativity, communication or cooperation [1]. Those skills are considered essential and required for many professions in the digital societies and for being an autonomous digital citizen [2].

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To foster the acquisition of such competences in schools, educational robots are increasingly used. Robots activities indeed may promote the creativity, foster the development of coding and problem-solving skills, enhance the collaboration and the communication through collaborative work on the robotic tasks and promote the development of computational thinking (e.g. [3–5]).

Computer science (and thus also robotics and computational thinking) have therefore been introduced in several school curricula (e.g. England (UK), France, Finland, Italy as well as Germany and Switzerland on regional level) [6, 7]. In Switzerland, educational robotics is present in the new curricula in Italian- and in German-speaking Cantons [8, 9]. The teacher training universities have therefore started to offer training courses in these areas [10]. In some cantons of the German-speaking part of Switzerland for example, teachers have to attend obligatory further training courses in the field of "Media and Computer Science". However, it is questionable whether an obligatory training is enough to successfully implement robotics and programming in the school classes. Often happens that only pioneers and teachers that are more affine with computer sciences implement robotic activities in their classes. The survey by Chevalier, Riedo and Mondada [11] on the perception of educational robotics by teachers, distinguished two categories among teachers: pioneers and followers. "Pioneers" voluntarily introduce robots into the classroom. They however often act alone and their developed materials are only exchanged in individual cases. It does not facilitate the diffusion of robotics. "Followers" however need support to carry out educational robotics activities: they need for example to have access to tested and validated didactic activities that they can use in their classes and to receive a support of other colleagues.

This result tell us that teacher training is important but is not enough. To be sustainable and effective, the training must allow also a long-term support. This can be reached for example through a Professional Learning Community (PLC) [12–16]. A PLC is a community where the participants share their knowledge and foster their metacognitive skills (learning to learn) following the learning model of the cognitive apprenticeship [17]. In this case the apprentice observes the master or imitates him (modelling) then the master assists and facilitates the work (coaching) provides support in terms of hints and feedbacks (scaffolding) and finally gradually decreases the support provided to leave more autonomy to the learner (fading). In this paper, PLC is intended as a community of teachers that share the common value of wanting to bring educational robotics in classes in order to prepare children to the digital society. Sharing and critically reflecting on their practices in a collaborative manner is another common value. A PLC can therefore be the space where "pioneers" and "followers" exchange their practices and co-construct didactic activities.

Several international studies have shown that PLC can have a positive impact on teacher practice and student learning [18, 19]. For example, in the review of Vescio et al., [18] it is pointed out that a PLC can positively change school culture in the sense of greater collaboration among teachers, a shift in focus on student learning and increased professional development of teachers. Dionne, Lemyre & Savoie-Zajc [20], highlighted that a PLC can have positive impacts on the cognitive, emotional and ideological dimension. On the cognitive dimension, a PLC can for example foster the knowledge and skills of teachers that can learn from other teachers. On the affective dimension teachers are supported from other colleagues and can collaborate with them in finding solutions for their needs and on the ideological dimension a PLC can encourage the collective commitment of teachers to a common goal. In the last years different online teachers community have been created worldwide as for example: https://www.teachersconnect.com/, http://www.scientix.eu/, https://www.teacherspayteachers.com/ or https://www.digitaltechnologieshub.edu.au/. On these platforms, teachers can find materials of different disciplines mostly in English. Community specifically dedicated for robotics and computational thinking activities based on the Swiss curricula are however inexistent.

2 Roteco Project

The project "Robotic Teacher Community (Roteco)" aims at creating a community that enable teachers to independently carry out activities in the field of educational robotics, computer science and computational thinking in class in order to prepare children for the digital society. In this community, teachers find, develop and exchange educational activities related to educational robotics and, more generally, to computer sciences. Furthermore, they are informed with the latest news, events and courses in these fields. Beside the development of the community another aim of the project is to develop trainings for teachers in the field of educational robotics. The project covers all three major language regions of Switzerland. It is supervised by the University of Applied Sciences and Arts of Southern Switzerland (SUPSI), the Swiss Federal Institute of Technology Zurich (ETH Zurich) and the Swiss Federal Institute of Technology Lausanne (EPFL Lausanne) and is founded by the Swiss Academies of Arts and Sciences. The project started in may 2018 and has a duration of two years.

2.1 The Roteco Community

In the first phase of the project a collaboration platform has been developed. The platform serve as the principal tool to create a community. A first version of the platform www.roteco.ch went online in February 2019. This platform allows teachers to register, create their own profile, easily publish didactic activities, select activities of other teachers and download the related materials. The platform also allows to search and contact other teachers or experts. Teachers are informed about news, events and training courses in the field of educational robotics and computer science education. In order to build a community and simplify contacts between teachers, there are social functions implemented like the possibility to "like" an activity uploaded by another teacher or comment it. The platform is available in three languages (Italian, German and French) and will be further developed in the next month adding new features like for example a search function to search for activities more efficiently.

After few months of existence of the platform, there are already around 700 members that shared more than 450 activities (May 2020). These activities cover all school levels (from kindergarten to high school). The activities are based on different type of robots or are unplugged. Most activities are interdisciplinary and connect robotics with mathematics, natural sciences, arts, languages, geography, music and other disciplines. Teachers can download the activities where the objectives are indicated and step-by-step instructions are given on how to implement them in the classroom. Teachers can then comment the activity and give advice on how to improve it as well as upload their own activities. In addition to the description of the activity teachers can also download the materials needed (e.g. exercise sheets etc.) and in some cases videos and pictures of the different steps are presented.

On the platform, in addition, teachers can find around 70 courses, 100 news and 80 events as well as articles and reports about the implementation of computational thinking in schools. From the beginning of the school year in September 2019 until the end of May 2020 there have been around 50’000 page visualizations.

2.2 Training

In addition to the platform, a 3-day training course in robotics and computational thinking was also developed. In this training the robot “Thymio II” is used. Thymio II has a wide range of sensors (nine IR proximity sensors, a three-axis accelerometer, a microphone, a temperature sensor, a remote control receiver, an SD-card slot, and five capacitive buttons) as well as two motors, a loudspeaker, and 39 LEDs spread all over its body [11]. It allows to introduce a reflection on the sensor-actuator loop and on the event-driven programming. Thymio II can be programmed through visual or text programming languages. Besides the functioning of the robot “Thymio II”, which is for example already successfully used in some schools in Switzerland, France and Italy, during the training are also presented some didactic activities. The activities combine robotics with other disciplines and above all with transversal competences such as cooperation, communication and creativity. At the end of the training, a national event for teachers is organized, thus facilitating contacts between teachers and creating a nationwide community. Teachers from different regions have to connect via video conferencing and steer the Thymio robots, which are located at the EPFL in Lausanne and remotely connected, in order to carry out a mission “on Mars” (R2T2-Mission). In order to carry out the different phases of the mission which involve, for example, following a wall, moving an obstacle, placing the robots on markers, etc., the teachers must not only program correctly, but also collaborate with the teachers of the other language regions. Only through mutual agreement between the different language regions it is possible to complete the mission successfully. In the R2T2 mission, different aspects of computational thinking according to Shute et al., [21] occur, such as the analysis of the available information, the division of the problem into smaller manageable problems, the formulation of hypotheses as to how the problem can be solved, the examination of these hypotheses, etc.

This training can also be seen as a kind of team-building measure. The activities are further focused on social content and transversal competences and not only on the technical elements. Consequently a “non-technical” teacher brings robotics and computational thinking to schools and more children are reached.

3 Conclusion and Next Steps

Educational robotics can foster the development of the necessary skills requested in a digital society. Teachers need however to be able to bring educational robotics in school.

For the moment pioneers are the ones that bring robotics in school [11] while the majority of teachers would need more support to feel comfortable in doing such activities with their classes. One possible support could be found in a PLC where experts, pioneers and followers can share their experiences, knowledge, skills and materials. The pairs can emotionally support teachers that are starting to explore the educational robotics world. The Project Roteco has created a platform that aims in creating a community. The first results are promising since there are already more than 450 activities that have been shared among around 700 teachers. However, it cannot be excluded that users on the platform are solely the pioneers that share materials among each other. The aim of a community like Roteco is however to engage also the beginners in order to expand the presence of robotics in schools. The training courses can help achieving this aim since through the courses is possible to reach also teachers that have never used robots before. These teachers need then to be supported and followed in the community.

The project is still ongoing and it will be interesting to analyze such questions. For next year, when the Roteco members will have used the platform for a longer period, a survey is planned in order to analyze who are the teachers that are most active in a community, how much they share, how many contacts they build online and what they need in order to foster those elements.

The next steps of the project also foresee an extension to at least four other swiss cantons in order to find more members and offer more courses.

References

1. World Economic Forum.: New Vision for Education: Fostering Social and Emotional Learning through Technology. WEF, Geneva (2016)
2. Herzog, E., Wehrli, R., Hassler, M., Schärer, S.: Il futuro della svizzera digitale. Economiesuisse (2017)
3. Park, I.-W., Han, J.: Teachers' views on the use of robots and cloud services in education for sustainable development. Cluster Computing **19**(2), 987–999 (2016). https://doi.org/10.1007/s10586-016-0558-9
4. Nugent, G., Barker, B., Grandgenett, N., Adamchuk, V.: The use of digital manipulatives in k-12: robotics, GPS/GIS and programming. In: IEEE Frontiers in Education Conference, San Antonio, Texas, USA (2010). https://doi.org/10.1109/fie.2009.5350828
5. Atmatzidou, S., Demetriadis, S.: Advancing students' computational thinking skills through educational robotics: a study on age and gender relevant differences. Rob. Auton. Syst. **75** (Part B), 661–670 (2016). https://doi.org/10.1016/j.robot.2015.10.008
6. Bocconi, S., Chioccariello, A., Dettori, G., Ferrari, A., Engelhardt, K.: Developing computational thinking in compulsory education – implications for policy and practice. Publications Office of the European Union, Luxembourg (2016). https://doi.org/10.2791/792158
7. Bocconi, S., Chioccariello, A., Earp, J.: The Nordic approach to introducing computational thinking and programming in compulsory education. Report prepared for the Nordic@BETT2018 Steering Group (2018). https://doi.org/10.17471/54007
8. Dipartimento Educazione Cultura e Sport.: Piano di studio della scuola dell'obbligo ti-cinese. Dipartimento Educazione Cultura e Sport, Repubblica e Cantone Ticino, Bellinzona (2015)
9. Deutschschweizer Erziehungsdirektoren-Konferenz (D-EDK). Lehrplan 21. D-EDK, Bern (2014)

10. Negrini, L.: Teacher training in educational robotics. an experience in Southern Switzerland: the PReSO project. In: Lepuschitz, W., Merdan, M., Koppensteiner, G., Balogh R., Obdrzalek, D. (eds.). Robotics in Education: Methods and Applications for Teaching and Learning, pp. 92–97. Springer, Heidelberg (2019). https://doi.org/10.1007/978-3-319-97085-1_10
11. Chevalier, M., Riedo, F., Mondada, F.: Uses of Thymio II: how do teachers perceive educational robots in formal education? IEEE Rob. Autom. Mag. **23**(2), 16–23 (2016). https://doi.org/10.1109/MRA.2016.2535080
12. DuFour, R., Eaker, R.: Professional Learning Communities at Work. Solution Tree, Bloomington (1998)
13. Grossman, P., Wineburg, S., Woolworth, S.: Toward a theory of teacher community. Teacher Coll. Rec. **103**(6), 942–1012 (2001). https://doi.org/10.1111/0161-4681.00140
14. Lieberman, A.: Professional learning communities: a reflection. In: Stoll, L., Seashore Louis, K. (eds.) Professional Learning Communities: Divergence, Depth and Dilemmas, pp. 199–205. Open University Press, New York (2007)
15. Stoll, L., Bolam, R., McMahon, A., Wallace, M., Thomas, S.: Professional learning communities: a review of the literature. J. Educ. Change **7**, 221–258 (2006). https://doi.org/10.1007/s10833-006-0001-8
16. Wenger, E.: Communities of Practice: Learning, Meaning and Identity. Cambridge University Press, New York (1998)
17. Collins, A., Brown, J.S., Newman, S.E.: Cognitive apprenticeship: teaching the craft of reading, writing and Mathematics! In: Resnick, L.B. (ed.). Knowing, learning, and instruction: Essays in honor of Robert Glaser, pp. 453–494. Lawrence Erlbaum Associates, Hillsdale, NJ (1989). https://doi.org/10.4324/9781315044408-14
18. Vescio, V., Ross, D., Adams, A.: A review of research on the impact of professional learning communities on teaching practice and student learning. Teach. Teach. Educ. **24**, 80–91 (2008). https://doi.org/10.1016/j.tate.2007.01.004
19. Hedges, H.: Blurring the boundaries: Connecting research, practice and professional learning. Camb. J. Educ. **40**(3), 299–314 (2010). https://doi.org/10.1080/0305764X.2010.502884
20. Dionne, L., Lemyre, F., Savoie-Zajc, L.: Vers une definition englobante de la communauté d'apprentissage (CA) comme dispositive de development professionnel. Revue des sciences de l'éducation **36**(1), 25–43 (2010). https://doi.org/10.7202/043985ar
21. Shute, V.J., Sun, C., Asbell-Clarke, J.: Demystifying computational thinking. Educ. Res. Rev. **22**, 142–158 (2017). https://doi.org/10.1016/j.edurev.2017.09.003

MAKER DAYS for Kids: Learnings from a Pop-up Makerspace

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Abstract. Makerspaces exist in different forms with different target groups and goals. Dedicated makerspaces are often organized as communities of practise. They provide space, devices, tools and materials for (digital) (re)production to support (social) innovation and to democratize STEAM education. The potential of makerspaces as authentic learning environments to teach 21st century skills is one reason why pop-up makerspaces are especially designed for children and teenagers, with a great focus on the tools and activities offered. The MAKER DAYS for kids are one example of a temporary makerspace for more than 100 participants with an open approach to encourage (especially female) participants to pursue a career in STEAM domains. Based on the gathered data of the last MAKER DAYS in 2018 and 2019 at Graz University of Technology, this publication focuses on the challenges in the design of maker activities in pop-up makerspaces and comments on the changes and improvements that were/are applied to the last/upcoming event.

Keywords: Maker movement · Maker education · Maker space · Pop-up maker space · STEAM education · Computer science education · Design education

1 Introduction

In the face of current ecological, economic and social challenges, there is a "need to encourage (young) learners to develop skills for collaboration, creativity, problem solving, creative computational thinking and critical thinking", described with the terms 21st century skills/competencies [1, 2]. Makerspaces are thought to meet these requirements, as the maker movement took roots in various learning contexts that are linked to more authentic learning experiences including the use of new technologies. Makerspaces exist in different forms. The MAKER DAYS implement a temporary makerspace. With 110 participants (206 daily visits) in 2018 and 132 participants (239 daily visits) in 2019, there is a solid data basis for investigations in the role of pop-up makerspaces to help children and teenagers, especially girls, "become more fluent and expressive with new innovative technologies as well as traditional tools" [3]. The contribution of this work is to summarize the most important organizational and didactical issues in the context of a pop-up makerspace with an open approach.

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2 About the Event

As described in the publication *Setup of a Temporary Makerspace for Children at University* [3], the MAKER DAYS for kids took place in August 2018 and 2019 at Graz University of Technology. The pop-up makerspace was open for four days. Children and teenagers between the ages of 10 and 14 had to register for the event. In 2019, the pop-up-makerspace was made up of four rooms (about 400 m^2) with different workshop areas focusing mainly on coding, physical computing, robotics, electrical engineering, digital fabrication, crafts and arts.

3 Research Approach and Data Collection

An action-based research approach is used for the evaluation and adaption of the MAKER DAYS, with pre and post questionnaires (including quantitative and qualitative questions), observations, field notes and qualitative interviews. The data is collected and analysed in a systematic way to allow a critical reflection based on the initial research problem. The results are considered in the planning and implementation of the subsequent event, which marks the start of a new research cycle [4].

For the MAKER DAYS in 2018 and 2019 an innovative evaluation concept was applied to document the activities of a single participant in the makerspace. In 2019, each participant got an empty sticker card with their name and an ID on it. The ID was consequently used to match the questionnaires, (digital) results, photos and videos of the results, field notes and post-event reflections. In 2019, extensive interviews with the tutors were conducted after the event. The interviews were analysed and contributed much to the findings that are presented in this publication.

4 Lessons Learned from the MAKER DAYS Events

4.1 How to Achieve a Balanced Gender Ratio

One goal of the MAKER DAYS is to achieve a gender balance on each day. In 2018, more than twice as many boys than girls visited the MAKER DAYS on the first two days. One reason for this was, that we only had limited time to promote the MAKER DAYS. Consequently, registrations were handled according to the first come – first served principle. As addressed in [5], (maker) events, where registration is required, may face the problem of a lower girls' participation, as "the participation of boys in technology-related offers is rather supported by (grand)parents".

In 2019, the promotion of the event already started in February. All registrations were collected until May. At this time, there were more male than female registrants. Therefore, only some of the registrations were confirmed in May and registration was left open until a balanced gender ratio was finally achieved.

4.2 Breaking the Ice

After visiting the registration desk in the morning, the new participants were guided through the makerspace by a (peer) tutor. After the tour, participants were asked to fill out a questionnaire and to choose an activity to start with. Some of the participants, especially those who came alone, without a friend or sibling, felt intimidated or were not familiar with that kind of self-directed learning. Therefore it is good to have a simple and attractive activity that can be offered. In 2019, we prepared a folded invitation card (for (grand)parents, friends) for the closing event that took place on Saturday. The participants were supposed to add an LED, a coin cell and copper band to the card. The LED should light up as soon as the card is closed. The card also provided some hints on where to place the components.

4.3 Announcement of Activities/Workshops

All activities during the MAKER DAYS were announced in form of printed workshop cards that were filled out by the tutors and put on a board. The workshop card included the title, the name of the tutor, the time, the workshop starts, the name of the workshop area, a short description of the content and the maximum number of participants. But the workshop cards did not seem to help them decide.

For some workshops or, more general, activities it was hard to define a starting time, as they were "ongoing". For other workshops, it was necessary to schedule personal "time slots", so that everyone interested had the chance to take part. On the other hand, some tutors were searching for more participants and had to cancel some of the workshops after repeated efforts. Given the diversity and dynamic of situations, it is difficult to announce activities with a "static" card. As well as that, the handwriting on the workshop card was quite unreadable in some cases. Moreover, with one sentence or a few words, children may not understand what the workshop is about.

4.4 Sticker Card

For the MAKER DAYS 2019, a sticker card was introduced. The idea was to hand out the corresponding sticker after a participant had spent a certain amount of time on a specific activity or created a (valuable) product. The main goal of the sticker card was to investigate, whether the collection of stickers has a positive and/or negative influence on the participants' motivation and attitude towards learning. Many tutors were sceptical about the sticker card at first, but the interviews revealed that the sticker card had more positive than negative effects. The younger the participant, the more important was the collection of stickers. Younger participants were more likely to ask the tutor for a sticker and talked about their sticker card with their peers. For older participants, the sticker card did not play an important role.

4.5 The Importance of a Structured Experience

In their publication, Davidson and Price [1] describe the characteristics of "experiential learning activities" that contribute to the acquisition of 21st century competencies.

Accordingly, "progress happens over bumpy roads, not on super highways". This means, that (young) learners need to get involved in ill-defined problem solving with multiple iterations. In the context of the MAKER DAYS, we must pave the way for this kind self-directed learning, creating a learning environment, where children use new technologies and/or traditional tools to create a (digital) product and where (peer) tutors facilitate the process of making. Davidson and Price [1] run a series of maker events and workshops with more than 100 participants of different ages and educational backgrounds. They found out, "that not all novice makers needed structured design, but without some structured experience to start with, some participants might never engage in maker activities". This is also true for activities in the course of the MAKER DAYS. It is important to find a simple introductory example or activity from which young learners can imply whether they want to proceed with a more purposeful activity/social innovation in this area or not [6].

4.6 Social Innovation and (Peer) Feedback

"Feedback is one of the most powerful influences on learning and achievement" and to help young learners to engage in iterative, creative and collaborative activities, there is a need to provide them with appropriate (peer) feedback [7]. Talking about maker activity design, it is important that the activity does not only address a specific knowledge or skill set from the STEAM domain or the usage of key technologies or popular maker tools. No less important is to ask for its social relevance and how the activity or project can possibly contribute to common good. For the MAKER DAYS, participants had the chance to contribute to the development and creation of the so-called *make.city* – an idea of a place, where people like to live (in the future). With tape, a square of 9 m^2 was marked on the floor. At the beginning of each day, participants discussed with a tutor, which buildings and facilities the city needs. As well as that, the discussion was based on a *daily theme*: The participants were asked, how they wanted to *live*, *learn*, *play* and *move*. The tutor wrote the participant's ideas on single notepads and put them on a poster. Then the participants, which were involved in the discussion, were asked to rate each idea by putting a sticky dot on the corresponding notepad. This way, the participants agreed on certain ideas to be put into action. Lego® bricks in various designs were used as main construction material, but the participants could use the materials and tools of all the other workshop areas too. But there was a problem with this approach. The participants, who came to the Lego® construction area, were asked to look at the approved ideas on the poster. In some cases, the idea was accepted, but in other cases, they wanted to work on their very own ideas. In both cases, they started building immediately. For the age group (10–14 years), Lego® is still an attractive toy and it was nearly impossible for the tutor to interfere in the process of making to help the participants reflect on what they were doing or planning to do. This often led to arbitrary buildings with no meaningful story behind it. In 2019, a "new" feedback process was introduced to better support critical thinking and collaboration. As part of the Horizon 2020 project *DOIT (Entrepreneurial skills for young social innovators in an open digital world)* a feedback cube was developed [8]. The cube has five questions on it: "What do you like?", "What can be improved?", "What would you do differently?", "How does the idea contribute to the solution of the problem?" and "Is there something, you don't understand?" The cube can be used in a setting, where young learners are supposed to comment on the ideas or prototypes of their colleagues. For the purpose of the make.city, the questions were adapted and referred to the *daily theme* of the MAKER DAYS. The feedback cube was only applied in the context of the make.city, but also other tutors of different workshop areas stated, that they would like to have an instrument to make an idea more valuable – for the participant, for society and for content understanding.

4.7 The "Keychain Syndrome"

Due to a cooperation with the local FabLab, it was possible to set up a small digital fabrication lab, called the *modeling corner*, with one 3D printer and one vinyl cutter. The tutor, who was responsible for 3D printing in the first year, came up with the idea of creating personalized keychains to introduce the participants to the 3D modeling software Tinkercad. The participants felt excited about their simple but attractive product and wanted to create even more of that kind. But in fact, the *modeling corner* became a keychain factory and participants would not engage in creating more complex constructions with multiple iterations. Blikstein [9] used the term "keychain syndrome" to describe a vicious circle: *"First, the equipment is capable of easily generating aesthetically attractive objects and products. Second, this generates an incentive system in which there is a disproportionate payoff in staying a 'local minimum' where the projects are very simple but at the same time very admired by external observers.* In 2019, there were clearly defined rules for 3D printing. It was only possible to create 3D objects to be included in the make.city, taking account of the *daily theme*. For the MAKER DAYS 2020, we would also like to apply the feedback process, described in 4.6, to the 3D modeling/printing workshops.

4.8 Coding and Robotics in Different Contexts

Five different workshop areas focused on programming activities: *Textile Studio* (creating an embroidery design), *hAPPy-Lab* (creating an app/game directly on the smartphone), *Smart Lab* (combining micro-controllers with handicraft), *Robo World* (solving tasks with Ozobot, Thymio and mBot), *Codegarden* (selected coding tutorials and free programming). The numbers of female and male participants show that it is important to provide various approaches to coding and robotics and to consider the presence of female tutors in this context. Activities in the *Codegarden* were less attractive to girls (18 girls:42 boys). But more girls than boys created an embroidery pattern with the app *Pocket Code (18:6)*, developed an app on the smartphone (42:35) and created a handicraft project with a built-in microcontroller (17:13).

The goal of the hAPPy-lab was to introduce participants to the basic concepts of coding by using the app Pocket Code. All in all, the participants were supported by four female tutors in the hAPPy-lab, which might have contributed to the high participation of girls in this activity [5].

5 Conclusion

To sum up, the idea of a pop-up-makerspace for more than 60 participants per day that contributes to a positive attitude towards STEAM and triggers a self-directed development of 21st century competencies, sound easier than it is – starting with some organisational details, such as the registration process to ensure a gender balance or the use of an ID to keep track of the participants' activities within the makerspace.

The following recommendations can be made: (1) Prepare a simple and attractive activity to start with. (2) Think of a dynamic system to announce activities in an open learning and teaching setting. (3) Think of actions to motivate participants to visit various workshop areas and try out new things. (4) Prepare a basic task for each workshop areas from which young learners can imply whether they want to proceed or not. (5) Think of an (feedback) instrument to make an idea more valuable. (6) Be aware of the "keychain syndrome". (7) Think of different approaches to coding and robotics to ensure that girls engage in coding activities.

References

1. Davidson, A.-L., Price, D.W.: Does your school have the maker fever? An experiential learning approach to developing maker competencies. In: LEARNing Landscapes. Teaching With Technology: Pedagogical Possibilities and Practicalities, vol. 11, pp. 103–120 (2017)
2. Ingold, S., Maurer, B., Trüby, D.: Chance MakerSpace. Making trifft auf Schule (2019)
3. Grandl, M., Ebner, M., Strasser, A.: Setup of a temporary makerspace for children at university: MAKER DAYS for kids 2018. In: Merdan, M. et al. (ed.) Robotics in Education. Current Research and Innovations. Advances in Intelligent Systems and Computing Ser, vol. 1023, pp. 406–418. Springer, Cham (2020). https://doi.org/10.1007/978-3-030-26945-6_37
4. Rose, S., Spinks, N., Canhoto, A.: Management Research: Applying the Principles. Routledge, Abingdon (2015)
5. Schön, S., Rosenova, M., Ebner, M., Grandl, M.: How to support girls' participation at projects in makerspace settings. overview on current recommendations. In: Moro, M., Alimisis, D., Iocchi, L. (eds.) Edurobotics 2018. AISC, vol. 946, pp. 193–196. Springer, Cham (2020). https://doi.org/10.1007/978-3-030-18141-3_15
6. Strasser, A., Grandl, M., Ebner, M.: Introducing electrical engineering to children with an open workshop station at a maker days for kids event. In: Bastiaens, pp. 980–989 (2019)
7. Hattie, J., Timperley, H.: The power of feedback. Rev. Educ. Res. (2007). https://doi.org/10.3102/003465430298487
8. Schön, S., Voigt, C., Jagrikova, R.: Social innovations within makerspace settings for early entrepreneurial education - the DOIT project. In: Bastiaens, T., et al. (ed.) Proceedings of EdMedia+Innovate Learning 2018, pp. 1716–1725. Association for the Advancement of Computing in Education (AACE), Amsterdam, Netherlands (2018)
9. Blikstein, P.: Digital fabrication and 'making' in education: the democratization of invention. In: Walter-Herrmann, J., Büching, C. (Hg.) (ed.) – FabLabs: of Machines

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