Working With Robots: Design and Evaluation of an Introductory Computer Science Teaching Unit With Educational Robots

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Abstract
As our world continues to digitalize more and more, Computer Science concepts have started to interweave with our daily life. Accordingly, teaching these concepts in schools is becoming increasingly relevant. An illustrative and practical way to do this is by using haptic examples of these very same concepts in form of educational robots. This offers the benefit of motivating and playful access to the field for young students. However, to integrate the robots productively into Computer Science lessons, engaging teaching units are essential. To support the design of those teaching units, we surveyed students and teachers to evaluate their preferences regarding the use of robots in Computer Science lessons. The survey had 95 participants, 6 teachers, and 86 students, from 6 different classes of 4 different schools. Using the results of this survey, we further designed, conducted, and evaluated a teaching sequence for a German 6th-grade Computer Science course. As a robot, we used the educational kit LEGO MINDSTORMS (Model 51515) alongside Apple iPads. The course consisted of 30 students, 15 of them male and 15 female, aged between 11 and 13. During the sequence, we observed the students' motivation and their progress in learning computer programming concepts. We also examined the results of their exercises. We found that the robots positively impacted the students' motivation and learning process. In this paper, we present both the survey and the teaching unit, as well as their respective results.

Keywords: Educational Robotic, Computer Programming Education, New Technologies in Education

Introduction

The subject of Computer Science gains more and more importance in our ever-growing digital world. Schools have the task to prepare young people for a self-determined life in our society and a successful start into their professional lives. Without knowledge of the digital world and basic Computer Science concepts, this is not possible anymore nowadays.

Therefore, in the German federal state of North Rhine-Westphalia, Computer Science became a mandatory subject for the first time this year in 5^{th} and/or 6^{th} grade, with students of age 11 to 13 [1].

However, the mathematical and Computer Science concepts are often abstract and hard to comprehend for students at this age. Educational robots represent a tangible representation of these concepts and therefore a possible solution to approach this problem.

This brings us to the core of this paper: how can teaching units with educational robots for this age group be designed and how do they influence the performance and motivation of the students. To examine this, we have carried out the following steps, to design and evaluate a teaching unit with the educational robot LEGO MINDSTORMS:

1. A survey to determine the preferences of students as well as teachers for the use of robots in teaching units
2. The design of a teaching unit considering these results and the core curriculum for Computer Science in North Rhine-Westphalia
3. Carrying out this teaching unit in a German 6^{th} grade class in North Rhine-Westphalia
4. An evaluation of the teaching unit using the students' results for their assignments during class and a survey conducted with the students of this class to determine their motivation during class

Related Work

Activities with educational robots can serve learning objectives from a wide range of disciplines from technology and design to mathematics and science [4]. Barker et. al. suggest the use of robots in a variety of disciplines [5].

Zhong et. al. found in a recent survey based on 20 studies over the last 18 years that robots, in general, improve the learning progress of students in mathematics, more specifically regarding "graphics and geometry", "number and algebra", and "practice and synthesis application". In the survey, they used robots, mainly LEGO robots, for "learning by interacting", "learning by programming" and learning by "building and programming" [6].

Educational robots are also used to demonstrate principles of Computer Science. As shown by Magnenat et al. robots can be used in this field with great effect to teach the otherwise often abstract concept of event handling [7]. Therefore this effect of robots in computer programming classes is commonly tested. However, the results vary greatly considering the students' performances [8, 9]. In our previous work as well as studies by Çankaya et al. an increase in the students' motivation was detected [10, 11].

The students' motivation is strongly linked to their perception of the robot. The results of a survey performed by Serholt et al. show a generally positive response towards the robots as long as the robot is not able to grade the assignments [12]. Lakatos et al. on the other hand found that the children's perception of the robot is influenced by the activities the children experience with the robot. They also found differences in the children's perceptions considering their gender [13].

One example of educational robots is the LEGO MINDSTORMS. As early as the late 1960s, the inventor of logo, Seymour Papert, was busy with how students can be interestingly taught programming [14]. In the mid-90s he developed software that made it possible to move Lego bricks [15]. In cooperation with the Danish Toymaker LEGO, he first introduced a programmable robot in 1998. This was called LEGO MINDSTORMS Version RCX. In 2006, the MINDSTORMS NXT was presented, and replaced in 2013 by the EV3. Finally, in 2020, LEGO Mindstorms Robot Inventor (model 51515) became the new model. At the time of this work, this is the latest model published, which is also used for our teaching unit [16].

Preferences toward the design of Computer Science lessons from students and teachers

To determine the preferences of students and teachers for a teaching unit with robots we carried out an online survey with Qualtrics [17].

We used two separate surveys: one for teachers and one for students. In both surveys, we started with questions about the participants. For the students, we asked about their school, age, grade, and gender. For the teachers, we asked about their age, gender, and for how many years they have been teaching.

Afterward, the students had four blocks with questions for different topics. We asked the students first how much they are interested in the subject. The answers were given on a five-scaled Likert scale (very much, much, neural, little, very little). This question was followed by a couple of free text questions. First, we asked what the students were thinking about when hearing the term Computer Science. Afterward, we asked what they were most interested in regarding the subject, followed by the question of what the students thought about when thinking about robots. Next, we asked if they had ever worked with robots in class before.

Following this first block of questions, we asked questions about the students' self-assession for their performance in class. We started with the question of how difficult the subject was for the student. We again used a five-scaled Likert scale (very easy, easy, neither easy nor hard, hard, very hard). A similar Likert scale was used to have the students assess their performances and how often they participated actively in the lessons. Afterward, we wanted the students to assess how the other students and the teacher assessed their performances and how the student thinks their performance might change in the future. For all these questions we used five-scaled Likert scales.

For the next block, the questions varied depending on if the participant has worked with robots in class before. For the students who had worked with robots we asked as a free text question with which robot they had experience. This question was followed by three Likert scales questions about the learning process with the robot. First, if they liked working with the robot, followed by if working with the robot helped them to understand the topics of the lessons, and finally if they wanted to work with a robot more often in lessons. For the students who had not worked with a robot before we just asked one question: how much they would like to work with a robot during lessons. We again used a five-scaled Likert scale.

In the last question block, we wanted the students to give feedback on their current Computer Science lessons. First, the students rated their lessons on a five-scaled Likert scale from very good, to very bad. Afterward, they were given four free text questions, starting with what they liked and disliked about their lessons, followed by their wishes for future lessons, and finally which topics they had covered in the subject so far.

The survey for the teachers was slightly different. Here we had three blocks of questions, starting with their self-assessment for their lessons. First were two Likert scales, where we wanted to know how the teachers assess the difficulty during their lessons and rate the student's motivation during the lessons. These questions were followed by two free text questions, first asking about the differences between different topics in teaching Computer Science and if they noticed a difference between the students' genders. In both cases, we asked them to explain their answers. As the last question in this block, we asked if they used robots or simulations of robots in their lessons before.

The next block of questions diffracted again depending on if they used robots or simulations. If they had used robots or simulations before, we asked which ones they had used. Afterward, we used the Likert scales and asked them to rate the use of the robot or simulation first for understanding the topic and second for the students' motivation.

For the teachers who had not worked with robots or simulations before, we asked why they hadn't used them and if they want to try in the future.

In the last question block, we asked the teachers what advantages and disadvantages they saw by using robots in class and which special factor of their current teaching was particularly positive or negative. All of these questions had free-text answers.

86 students, from 6 different classes of 4 different schools participated in this survey. The student's age was between 14 and 18 years. 67% of our participants were male and 26% were female. The remaining students choose not to specify their gender. Most of our participants (43%) were interested in the subject of Computer Science. Another 20% were very interested and 24% had neutral feelings towards the subject. 6% stated to be less interested in the subject or not interested at all.

A clear majority (~60%) of the students first thought about programming when thinking about Computer Science, some other noteworthy answers were logic, IT, and hardware components. Programming was also with ~38% the topic that was most interesting for our participants, followed by logic with ~21%.

The students answered that they liked the topics (namely programming, theories behind computer programming, and logical problems) with ~36% and the lesson designs (e.g. working in group, high topic variety) with ~30% most about their class. The answers regarding what the students did not like about their lessons diffracted a lot more. While ~15% stated that the lessons were too hard ~8% stated they were too easy. Considering their performances most students stated in all assessment questions to be either good or very good in the subject. Surprisingly, a lot more students stated to be very good in the self-assessment than in the other assessment questions.

Some students wanted to program more, others less. There was no clear majority in the answers to that question. In the future, most students (~22%) wanted to work more freely and practically. 46% answered that they would really like to work with robots.

When thinking about robots most students (~57%) named technical components, while ~18% named the tasks robots were used for. Other answers to this question were examples of robots both real and from science fiction. 26% of our participants had worked with robots in their class before. For the robots the students worked with, they named the following: Calliope, LEGO MINDSTORMS, Magic Jinn, and Cozmo.

Regarding the influence of the robot on their performances the students were indecisive. Most students (52%) answered that the robot would help to understand the topics ‘a little’ better. However, a clear majority (81%) of the students thought that the robot helped their motivation.

In the teacher’s survey, we had 6 participants. Three participants were male, two female, and one decided not to answer the question about their gender. The teacher’s age varied between 34 and 60 years. The least experienced teacher was teaching for half a year and the most experienced taught the subject for 15 years. Most of the teachers (50%) assessed their lessons to be ‘easy’, the others thought their lessons were either ‘hard’ or ‘neither easy nor hard’. All teachers thought their students to be either ‘motivated’ or ‘very motivated’ in the lesson. All teachers named a couple of differences in the students’ motivation depending on the topic of the lesson but there were no clear trends in their answers. All teachers agreed that motivation does not differ between the students’ genders.

66% of the teachers had used robots or simulations of them in their lessons. They named Calibot and Robot Karol and stated to mainly use them in grades 5 to 9. All of them saw a positive impact from using these devices in both the performance and motivation of the students. The teachers who have not used robots or robot simulations in their classes did not teach the grades to do so or had not enough devices at their school. All of them would use robots if they had the opportunity. As positive aspects of using robots, the participants named the visibility of the programs, higher motivation from the students, and the haptic aspect. As negative aspects, the teachers named the lack of ideas to use robots for older students and the high time and organization costs.

Constraints of the teaching unit

The teaching sequence was carried out in a 6^{th} grade at a German secondary school in North Rhine-Westphalia. The course started with the subject of Computer Science about half a year before this teaching unit started. The students had little to no experience with computer programming. There are 30 students in the class, 15 of them male and 15 female. The age varies between 11 and 13.

The lessons were held from 14:20 till 15:50 and were mandatory for all students. For the lessons, the students got Apple iPads for usage in class. These tablets had neither a pen nor a keyboard. The students were not allowed to take these devices home or use them for anything but the lessons. All results were saved in the school’s cloud. The robot model was the LEGO MINDSTORMS model 51515 “Tricky” (Fig. 3). As the programming tool, we used the corresponding LEGO MINDSTORMS EV3 HOME app. This app works with programming blocks similar to Scratch (Fig. 4).

The students used the robots in small groups of two or three. The usage of the robot was also limited to the lessons and the students could not take the robot home.

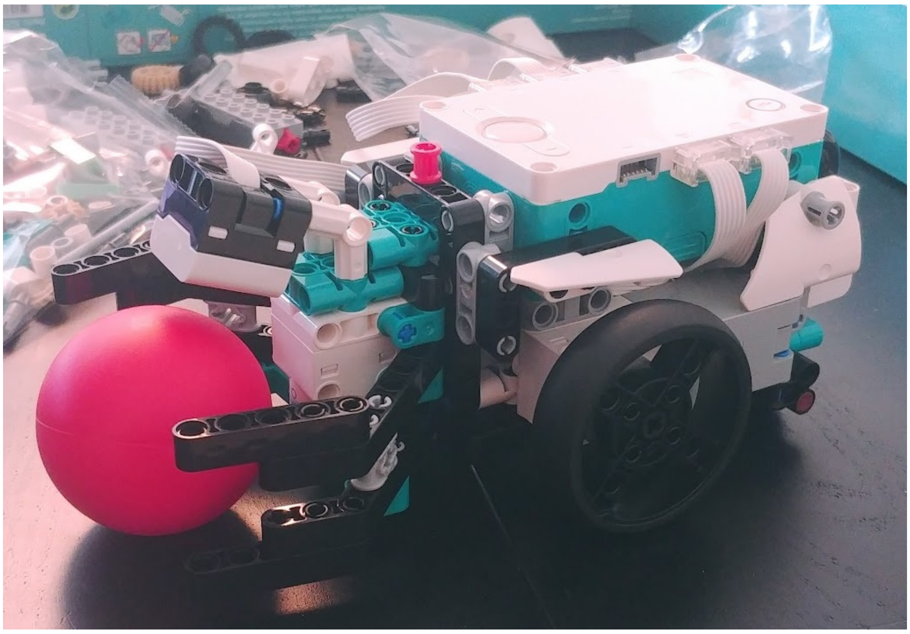


Figure 1: LEGO MINDSTORMS 51515 "Tricky".

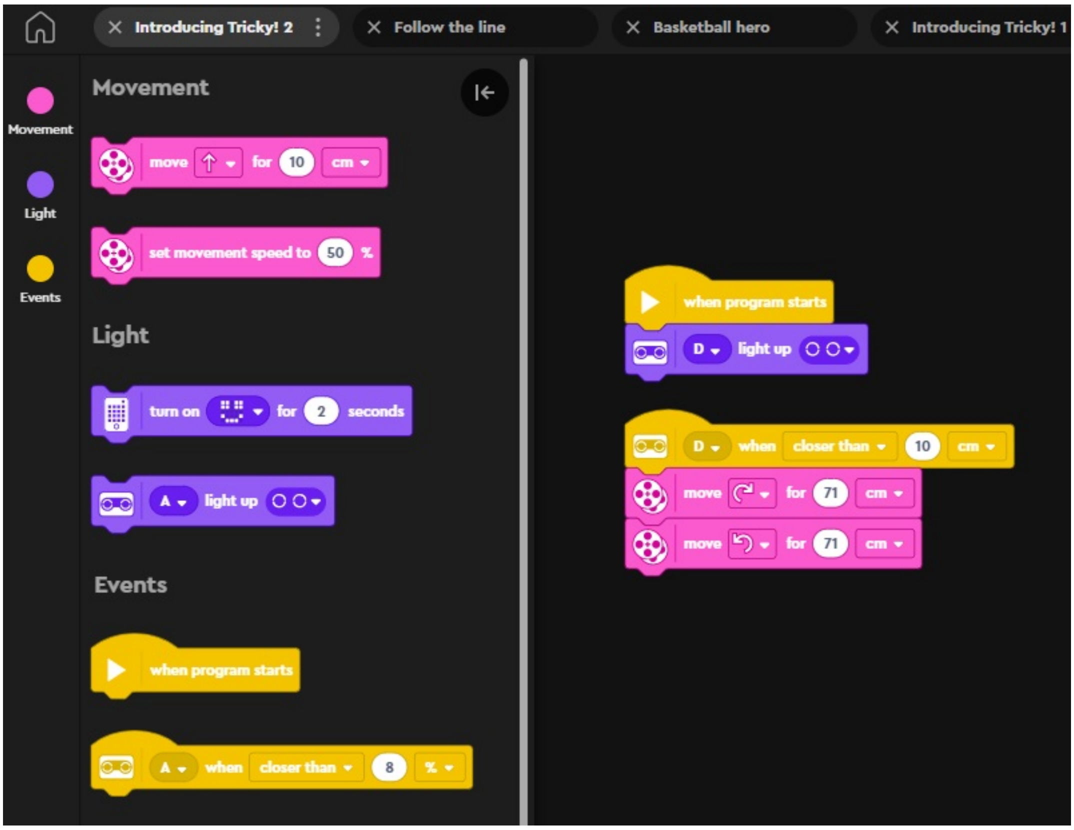


Figure 2: LEGO MINDSTORMS EV3 HOME App.

The teaching unit: design considerations and execution plan

We designed the teaching unit according to the core curriculum from the German federal state of North Rhine-Westphalia for 5th and 6th Grade and the results of our online survey considering the preferred teaching methods of the students. According to the curriculum, we choose the competency-based goals for each lesson. The complete plan for the teaching unit, each row representing one 90-minute lesson, is shown in the following table:

Lesson topic	**Competency-based lesson goals** The students …
The robot as a programming tool: getting started with LEGO MINDSTORMS	… recognize the robot as a use case for executing an algorithm and recognize its benefit and limits
First implementation with LEGO MINDSTORMS: movements, sound effects, and light	… design rules of acting for the wanted robot behavior and display them in a program schedule plan
LEGO MINDSTORMS movements in different shapes using counter loops	… identify the counter loop within given rules of acting, display them in a program schedule plan, and transfer them into code
Using branches to control supersonic and touch sensors	… identify the counter loop within given rules of acting, display them in a program schedule plan, and transfer them into code … name use cases for sensors in their everyday life
Autonomous vehicles: first steps to program a parking assistant for the LEGO MINDSTORMS	… describe the everyday use case of a parking assistant and transfer it to rules of acting for the LEGO MINDSTORMS
Programming a parking assistant using loops with conditions	… program a parking assistant for the LEGO MINDSTORMS using a loop with conditions
Update the parking assistant by using linked conditions and measurements for the supersonic sensor	… interpret the supersonic sensors' return values in context and use them within their program
Comparing the LEGO MINDSTORMS parking assistant with the real-life example of autonomous vehicles	… describe the technical ideas behind an autonomous vehicle
Evaluating the consequences of autonomous vehicles	… describe and discuss the consequences of using autonomous vehicles in our everyday lives.

Table 1: Planned lessons.

The teaching unit includes the subject areas 'algorithms', 'automaton', and 'artificial intelligence', as well as 'Computer Science, humans, and society'.

It starts with an introduction to the LEGO MINDSTORMS and corresponding programs. Gradually, more and more program blocks are introduced and used by the students. Additionally, the students learn about motors and sensors both for the LEGO robot and in their everyday lives. The unit concludes with a project to program a parking assistant for the robot inspired by a real parking assistant.

Challenges during the teaching unit

During the teaching unit, some challenges emerged. The first challenge we had to face was dealing with technical problems and updates. In our first lesson, all robots needed a software update, even though we updated the robots a day before this lesson. Therefore, a lot of time was lost, as we had to update the robots one by one, given that the robots can only update while connected to a power source and the iPads don't have a USBport. After this, we invested in a mobile charging station for the robots. This solved the problem of updating the robots one by one, but the updates still appeared regularly during lessons.

Other technical inconveniences were the motors and sensors of the robots. In the chosen construction the robot uses 3 motors, two for the wheels and one for the clutch, and 2 sensors, a supersonic sensor, and a color sensor, all of which were used during the teaching unit. From time to time some of these did not work which led to high frustration with the students and a lot of additional work for the teachers. All these technical problems could only be solved by teaching with multiple teachers, so one of them could focus on the technical problems, while the other focused on the actual teaching. However, most German schools don't have the resources to do this.

Another major issue was classroom management. We figured out quickly that an average classroom was not big enough for our teaching unit. From previous experiences, we learned that robots fall and break a lot. Therefore a lot of time during the lessons was needed to rebuild and repair the robots. We hence decided to use the floor for every programming exercise for this teaching unit. But at the same time, we still needed tables for the students to make notes and pay attention to the blackboard during instructions. Therefore we choose a bigger room (in our case a chemistry room but an auditorium or a gym would work fine, too) where we could use little table groups paired with a 1 m^2 mat to work on the floor. We also used acoustic signals to change from the tables to the mat and the other way around. With this classroom management, we were able to keep an overview of the students and their work while also maintaining a comfortable noise level.

Another issue that is partly related to technical problems was the usability of the LEGO MINDSTORMS app. Although the app is designed for children, it was overwhelming for the students at first, providing a lot of different use cases and functions. Most of these problems were solved as the students got accustomed to the app. However, there were still a lot of programming blocks to choose from and the students had difficulties deciding on the best ones, as well as distinguishing them from each other. Hence we decided to limit the programming block by handing out a selection of blocks that were used for the tasks. New programming blocks were added to that handout when introduced during class. The students were not necessarily limited to that selection, but the programming blocks given on the handout were enough to solve the given tasks. This limitation especially helped the less performing students.

Lastly, it was not simple for the students to see the connection between theory and programming tasks. Some students who performed very well during theory did not perform as well in the programming exercises and vice versa. During both conversations in the small groups and the whole class, it became clear that the students often did not make the connection between the theoretical terms like loop and branch and the used programming blocks, even though they were specifically used while introducing each new programming block. After detecting this issue a task was given to the students where they had to sort the programming blocks into the basic programming constructs. Although that task helped a lot of the students, some of them still had problems detecting the differences later on.

Survey at the end of the teaching unit

During the last lesson of the teaching sequence, the students evaluated the unit in a paper survey. 25 of 30 students participated in this survey (13 male and 12 female). The survey was divided into four sections.

The first section focused on the students' interest in the teaching unit. First, we asked the participating students to rank the teaching unit by how interesting the lessons were. The answers were given on a five-scaled Likert scale ('very interesting', 'interesting', 'neutral', 'boring', and 'very boring'). Afterward, the same scale was used to determine how interesting the robots, the programming exercises, and the exercises with the program schedule plan were.

The second section focused on the difficulty of the teaching unit. For this section, we used a similar five-scaled Likert scale with the options 'very easy',' easy', 'neither easy nor hard',' hard', and 'very hard'. We asked about the difficulty in working with the robot in general, during the programming exercises and the exercises with the program schedule plan.

Afterward, the students were asked to state if they would like to work with the robot more often and if they liked the teaching unit. For these questions, they could choose from a three-scaled Likert scale with the options 'yes', 'no opinion', and 'no'.

All three first sections were chosen to get a general overview of the students' thoughts and feelings towards the robots and the teaching unit in general.

The third section contained four questions, starting with the children's opinion if they would like to program as much without a robot as with a robot. We also wanted them to substantiate their answers. Afterward, we asked two questions about reading the teaching lesson they just participated in and asked them what they particularly liked and disliked about that lesson. During this specific lesson, the students used most of the robot's functions. Therefore the students had a better access point to think about the particularities of the lessons, the robots and their preferences about them. In the last question, we asked the students to give advice and ideas for further improvements to the teaching sequence.

For the first questions considering the students' interests we found that most students had neutral feelings considering the teaching unit itself, both the exercises in programming and the program schedule plan, but were at least interested in working with the robot. The answers in the second section were all similar. Most students choose either 'easy' or 'neither easy nor hard' in all three questions.

In the third section, for the question if the students liked to work with the robots more often, 91% of the students' answers were split between 'yes' and 'no opinion'. Only 9% answered that they did not want to work with the robots again.

Correspondingly, most students choose 'no opinion' to answer the question if they liked the teaching unit. A lot more students choose 'yes' for this question than 'no'.

The majority of the students (58%) answered that they would not have as much fun during programming exercises without the robot, 9 students (36%) answered to at least have as much fun programming without the robot and 2 students (8%) were undecided. The most popular reason for preferring the robot was that the robot is more fun than programming without it. 4 students (16%) also explained that they preferred the robot because they could see the program executed right away using the robot. The reasons for programming without the robot were more varied. Some students stated that the robot was annoying, others just liked or were interested in computer programming in general and liked to explore working without the robot as well. 7 students (28%) did not give a reason for their answer at all.

Regarding the last robot lesson (Tab. 1), most students liked to work freely with the robot. For this exercise, the students were told to create a program of their choice using at least one of the robot's sensors. Using the sensors was another popular part of the lesson for a lot of students. The students also liked that they were allowed to work in their preferred groups. Individual students also stated that they liked the given tasks and their results. For the less popular parts of the lesson, 7 students (28%) named the update that had to be installed on the robot during that lesson. 3 students (12%) also complained about the waiting time and other technical problems as well. Only 3 students (12%) did not like the exercises. They explained that there were not enough exercises and 1 student (4%) did not understand the task at first. 9 students (36%) disliked nothing about the lesson, 2 (8%) disliked everything, and 2 students (8%) did not answer that question.

Regarding further improvements to the teaching unit a third of the students stated that it was either already good and did not need further improvements or that they did not know how to improve the lessons. 3 students (12%) suggested not learning at all and just playing games and 2 students (8%) did not answer this question. The other students had various ideas to further create variety during lessons. Some students wanted harder exercises and more time to freely explore the robot's functions during programming tasks. Others wanted to have more time off the display and plan lessons on their own. They also suggested integrating little challenges with the class for more motivation.

The students' performance during the programming exercises

We also considered the students' handed-in results from their programming tasks. When the students worked in their dedicated groups during the lessons, they uploaded their results.

Overall the results were good. Most groups handed in correct solutions for most of the given tasks. More than half the groups also handed in some voluntary additional tasks.

Within the solutions, the students used the concepts of infinite loops, counter loops, loops with conditions, branches, and partly even parallel branches with conditions that were not discussed in class. They also used the supersonic and color sensors properly within their conditions.

However, the students usually did not explain their solutions but just handed in screenshots from their programs. Therefore, it is hard to determine from the solutions only if the students did understand their program code or the theoretical structures used in the algorithms. It is also unclear if the students worked as a team in their group or if some students just profited from the other's work. From observations in class, we know that some groups worked less communicative than others. When identified we spoke to the students and in one case changed their group constellation. Also by examining the students' Computer Science folders we could confirm the tasks there to be complete and correct.

Due to organizational difficulties (there are no exams planned in the curriculum for Computer Science for the 6th graders) we couldn't test the students in a written or oral exam.

Conclusion

In summary, we conducted a survey to determine students' and teachers' preferences for the use of robots during Computer Science lessons. Afterward, we designed and executed a teaching unit with robots for a 6th grade course in Germany. In the end, we evaluated this teaching unit and the benefits of using the robots by evaluating the students' performance during class and a survey about the students' thoughts.

During both surveys, we observed that robots increase the students' motivation in learning computer programming concepts. The results of the teachers' survey and the students' results during the teaching unit show indicators that the use of robots also increases the students' performance but considering the small number of participants there is further research necessary before jumping to conclusions.

The execution as well as the results of the survey at the end of the teaching unit, also show that the increased motivation fast decreases again when technical errors occur. Therefore, strategies to handle these errors are needed. An additional person in the classroom focusing on technical problems seemed to be a big advantage.

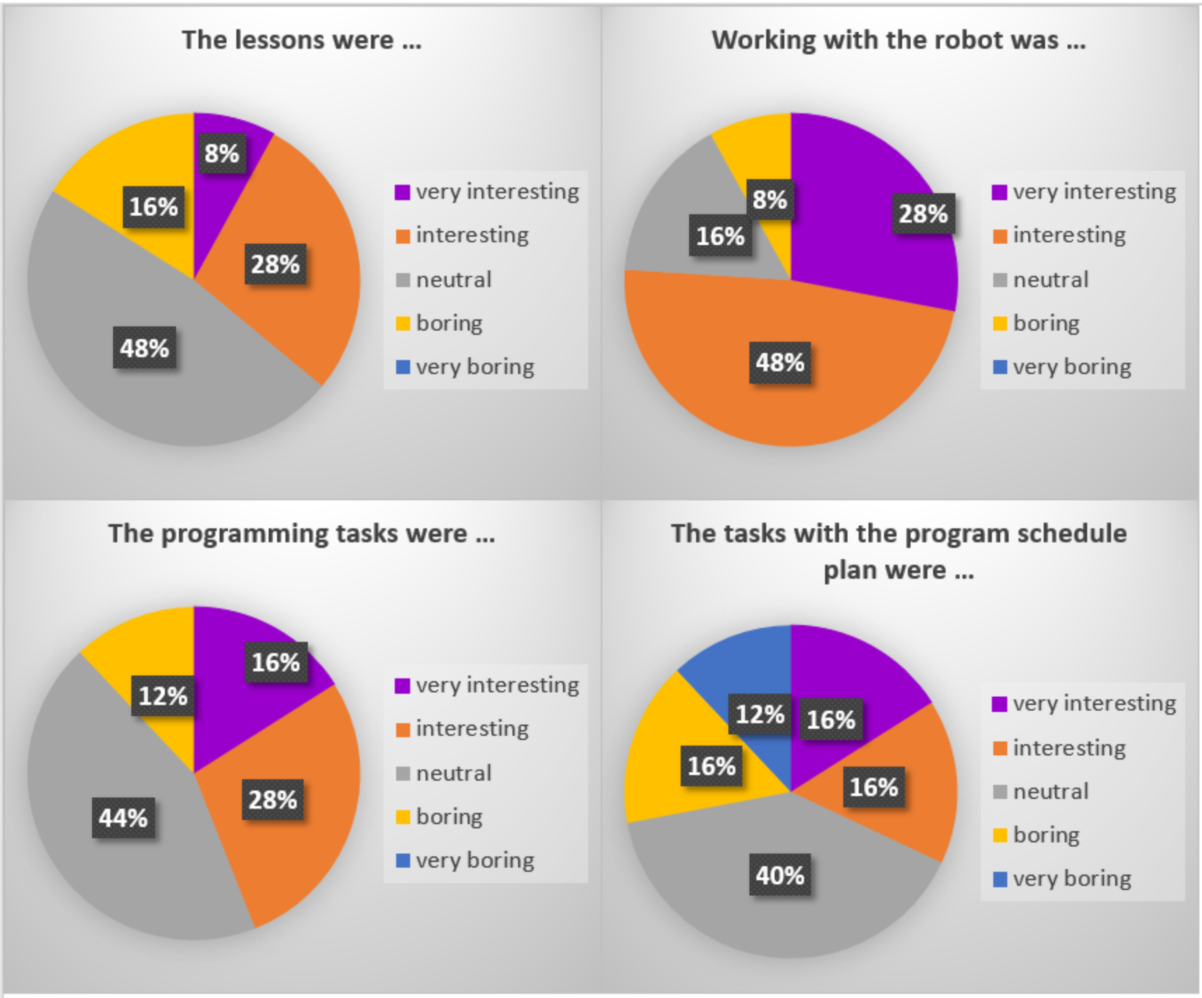
Working in small groups, especially in exercises where the students could explore their own ideas during computer programming was preferred by the students. Still, lesson phases where the students can connect theory and practical programming exercises are necessary to fully comprehend the computer programming ideas. For this phase, some students needed more time than originally planned for the teaching unit. In summary, the students need both periods where they can explore freely with the robot and phases to learn the ideas and connect these with their computer programming. More discussions with the whole class about specific program codes seemed very beneficial for the students to advance their codes.

In conclusion, robots do provide the hands-on approach to computer programming for younger students we hoped for. Even when considering the extra expenditure of time needed for the technical support and maintenance, the benefits for the learning process are worth keeping on and enhance teaching units with robots.

Appendix

1. Results of student survey at the end of the teaching unit

Block I:



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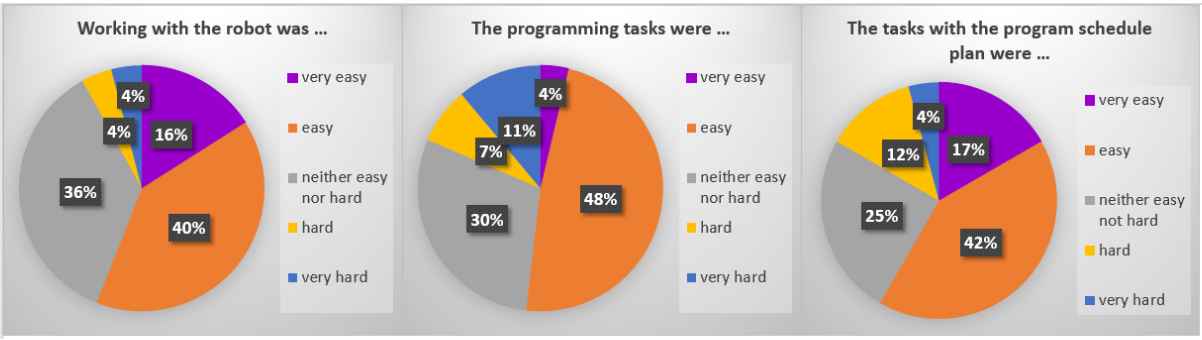

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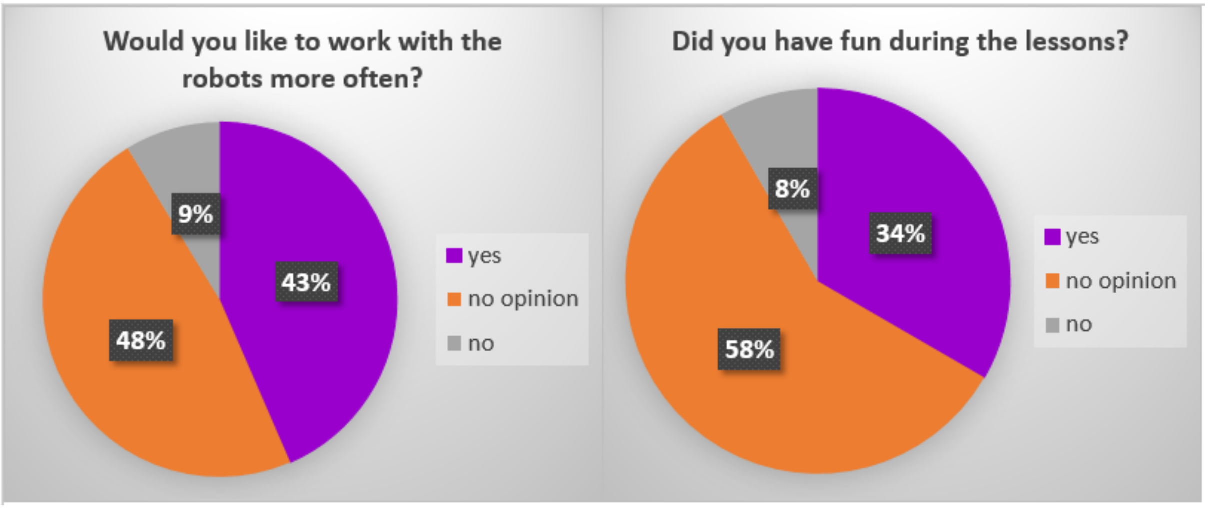
Would you like to work with the robots more often?
9%
43%
48%
yes
no opinion
no
Did you have fun during the lessons?
8%
34%
58%
yes
no opinion
no

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