Robots in Education: Influence on Learning Experience and Design Considerations

Kira Bungert, University of Bonn, Germany
Lilli Bruckschen, University of Bonn, Germany
Kathrin Müller, University of Paderborn, Germany
Maren Bennewitz, University of Bonn, Germany

The European Conference on Education 2020
Official Conference Proceedings

Abstract

The influence of computer science is increasingly present in today's life. To prepare students adequately for the challenges of an increasingly digital world an early education on this topic is necessary. Robots are a playful access for students, as they are an illustrative and practical example of many important computer science concepts.
In this paper we present the results of multiple studies on the design and functions of robots for the education of students between the ages of 11 and 13. We both accompanied and designed teaching units with mobile and humanoid robots over multiple weeks. In these units we observed how students were able to learn concepts of computer science if they were explained with the help of a robot and how their perceptions of the robot changed over time. We further conducted an interview survey with the students as well as uninvolved adults (ages 18 to 35) to determine possible differences in design and functionality choices for robots. We found that contact to robots helps students to gain a sense of familiarity towards digital concepts, that students were able to transfer knowledge from the known robot to a new task and that there is a clear difference between the perception of robots in adults and young students.

Keywords: educational robotic, computer programming education, new technologies in education

Introduction

Since the invention of the Internet and the rise of home computers 50 years ago, the world has been undergoing a digital revolution, which has greatly influenced our daily lives. This revolution is still ongoing and judging from its past it seems likely that even today's exotic new technology may be a common part of our lives in the near future [1]. One new technology that is slowly emerging today are robots. Like computers before them, they have first been mostly used inside the industry but have slowly become more accessible for consumers [2]. Also, similar to computers they show a lot of potential use cases, e.g. by providing services [3], helping in construction work [4] or retail [5] and supporting education programs [6].
This brings us to a point at which we can reasonably predict that robots will likely be an important part of our near future and at which we can already see that they may provide benefits for education. Furthermore, robots also represent a tangible representation of otherwise oftentimes abstract mathematical and computer science concepts. Therefore, an integration of robots in existing educational programs is a logical conclusion helping students to prepare for the challenges of our digital world. This brings us to the core of this paper: how we should design robots for education and what influence they have on the learning experience of students. To examine this, we conducted 3 studies:

1. A survey to determine children's general ideas about behavior and designs of robots.
2. A 6-week observation about the effects of robots on a 6th grade computer science course.
3. An implementation and evaluation of a 10-week robot supported programming courses for girls between the ages of 11 and 13.

From those studies, we derived the following three theses: First, contact with robots helps students to gain a sense of familiarity towards digital concepts. Second, students are able to transfer knowledge from the known robot to a new programming task. Third, there is a clear difference between the perception of robots in adults and young students. In the following, we first give a summary of relevant related work, discuss each of the 3 studies in detail and give a conclusion about the general results of the studies.

Related Work

As computers before them, robots now present a new tangible representation of computer science, mathematics and physic principles, as well as a possible teaching support. Therefore, their influence on education has been increasingly studied over the last years.
In a recent survey based on 20 studies over the last 16 years, Zhong et al. have found that robots in general improve the learning progress of students in mathematics, more specific regarding "graphics and geometry", "number and algebra", and "practice and synthesis application". Robots were used for "learning by interacting", "learning by programming" and learning by "building and programming". Most of the studies were performed with a LEGO robot [7]. Another classification of possible robot application in education is given by Mubin et al., who list three classes for robots: tutors, peers and tools. They further list language, science and technology as promising fields for the use of educational robots [8]. Using language as an example, a robot could function as a tutor and help the students remember vocabulary [9], as a peer detect whether a student pronounces a word correctly and encourage them [10], or as a tool play a game with the student in which it incorporates phrases from a

nonnative language [11]. One of the advantages of robots comes in their various forms and abilities, which makes it possible to tailor robots for their specific use case. As demonstrated by Mukai et al., an electronic robot kit, in their case the Boebot multi-function kit, can be used to teach students principles of electronics [12]. Similarly, Riedo et al. show how the accelerometer of a mechanical Thymio robot can be used to demonstrate effects of gravity [13], while Carpin et al. use the kicking motion of a humanoid to teach students about physics [14].

Another possible use case for robots is 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 [15]. The effect of robots as a general tool to teach programming is also commonly tested and while the results are mixed [16,17] the robots were able to increase the motivation of the students [18].

It is also important to keep in mind how robots are perceived by students and teachers. A survey performed by Serholt et al. found that students generally respond positively towards robots in education as long as the robots are not able to grade their assignments [19]. Kim et al. looked at the effect of educational robots on the teachers. They found that after using robots in the classroom most teachers viewed them significantly more positive than before [20]. Different attitudes of students towards robots than towards humans can also be beneficial in some scenarios, e.g. in the case of special education of students on the autism spectrum. In such scenarios robots are often more easily accepted by students than other humans [21] and can serve as mediator between teacher and student [22].

Robot perception can also vary based on the design used. Fong et al. propose the use of four classes for robot design, depicted in Figure 1: anthropomorphic, zoomorphic, caricatured and functional [23]. Thereby, anthropomorphic robots have human-like designs, often accompanied by a humanoid form with a head, two legs and two arms. According to Duffy, this design is suited for scenarios with a social context, so that robots can use their similarity with humans to use non-verbal communication [24]. Zoomorphic robots, on the other hand, are designed to mimic non-human animals, both in optic and behavior. Caricatured robot designs are inspired either by human or non-human animals and exaggerate selected features of their appearance to focus on them, commonly mouths or eyes [3]. Lastly, functional robot design places more emphasis on the task that the robot needs to fulfill than their appearance. This often results in very technical designs, however, such design typically allows to look into the inner workings of a robot, as internal parts are often visible.

All in all, the literature shows a variety of use cases for robots in education, not unlike as it was with computers 50 years ago [25].

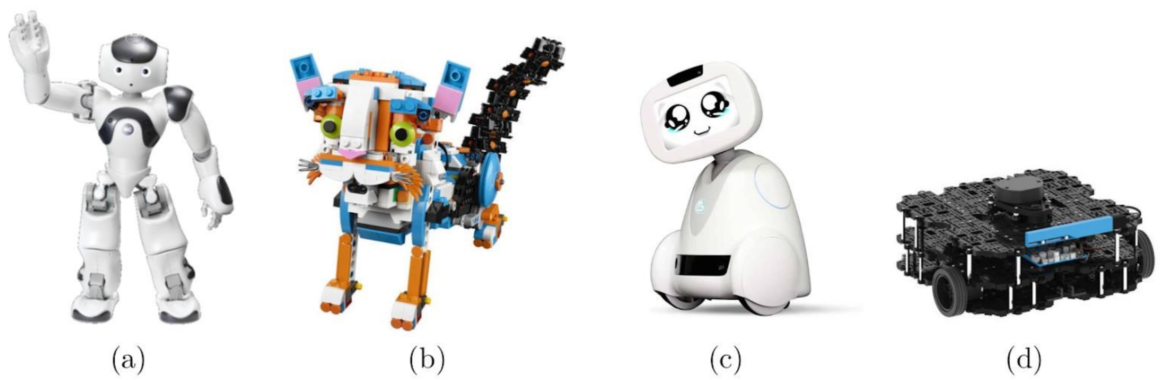

Figure 1: Examples of different robot design classes: (a) an anthropomorphic NAO robot [26], (b) a zoomorphic LEGO BOOST robot [27], (c) a caricatured Buddy robot [28], (d) a functional Turtlebot Waffle robot [29].

Robot conceptions of primary school children

The aim of the first empirical study was to get a first insight into children's conceptions of robots. We conceived a questionnaire which was filled out by students in a laboratory of the university of Paderborn in the run-up to a robot workshop.

The questionnaire had the following structure:

- Which robots do you know?
- How old are you?
- Are you male or female?
- Imagine that you meet someone who does not know any robots. Please, explain to this person what a robot is, based on the following themes:
  - What can a robot do?
  - What are robots for?
  - Can robots be controlled? If so, how? If not, why not?
  - Can you teach a robot anything? If so, how? If not, why not?
  - What does a robot look like? (drawings)

The evaluation was carried out using methods of qualitative content analysis and the Software MaxQda [30]. In the beginning, each question formed a category. During the analysis, we built up an inductive category system for each question.
In total 79 questionnaires (43 girls and 36 boys) of children between ages 7 and 10 with free-text responses were analyzed. The complete results of this part of the questionnaire and a complete interpretation can be found in [31].
The most frequently known robots are robotic lawn mower (32.9%), robotic vacuum cleaner (26.6%) and droids from Star Wars (17.7%). Regarding the question of what a robot can do, the most common answers of the children were movements (39.74%), housework (32.05%), helping (26.92%), and speaking (21.79%). They also thought that robots are there to help (46.15%), to work (32.05%), or to make something easier (23.08%).
In the second part of the questionnaire we wanted to get an insight into the technical understanding or technical perception of children regarding robots. The first question here was: Can robots be controlled? Most of the children in our study thought that robots can be controlled (92.41%). The results regarding the question how robots can be controlled are particularly interesting. Here, most of the children mentioned remote control (60.8%). In addition, programming (27.8%) and by computer (19.0%) were mentioned in not inconsiderable numbers. Additionally, many children hold the opinion that we can teach a robot at least somethings (see Table 1), e.g. by programming.

Code	Percent
yes	77.22
No answer	6.33
Don’t know	6.33
No	5.06
Unclear answer	3.8
Yes, but not everything	1.27

Table 1: Results for the question: Can you teach a robot anything?

The images of the study (see Figure 2) did not produce any unexpected results. Many pictures show robots with angular heads and bodies as often found in children's films, books, or with household robots. Some children also painted robots that resemble animals (zoological designs), humans (anthropomorphic designs) or specialized machines (functional designs). Most of the robots are a mixture of technology and living beings.

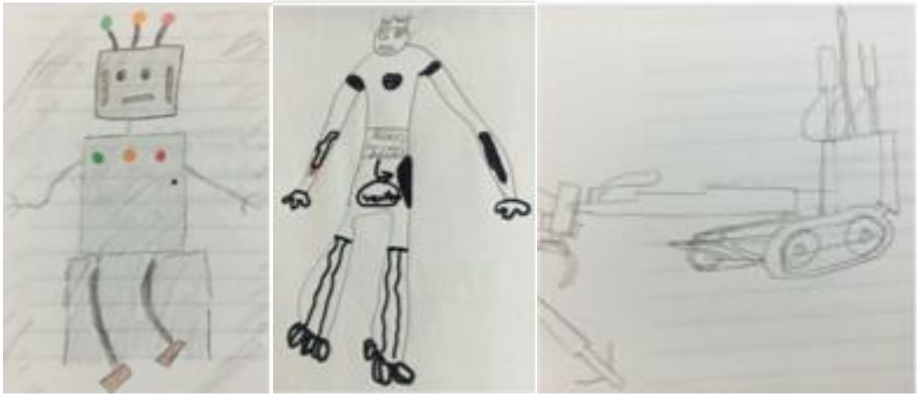

Figure 2: Example pictures, from left to right made by: girl, age 9, boy, age 10, boy, age 10.

The results were interpreted as children seeing robots more as helpers in our everyday life than something that replaces humans.
Many children of primary school age also realized that robots are controllable and adaptable. However, they could not explain much about the last aspect. The painted pictures of the children seemed to be very much influenced by general robot representations in movies, books etc. They allowed only very vague conclusions to be drawn about tangible ideas about robots. The complete results of the study can be found in [31].

In order to be able to compare the student’s conceptions of robots with those of adults we performed a follow-up interview with members of the University of Bonn as well as an online survey. The interviews were set up within the framework of Grounded Theory [32]. The questions were based on a self-created interview guide and each took 6 to 12 minutes. During the execution, the interviews were recorded as audio recordings and evaluated at a later point in time. 8 participants were interviewed. All of them were members of the University of Bonn. The age of the participants ranged from ages 18 to 35. In the interviews the preferences of the participants regarding both the appearance and the behavior of household robots were queried. The results were the basis for the online survey with 247 adult participants of a cross section of the German population. The online survey primarily dealt with the question how service robots should be designed. For this purpose, the test subjects were asked about the behavior and appearance of a service robot. A detailed overview of this survey can be found in [33].

In the interviews as well as in the online survey participants explained that the optic of the robot was not as important as the efficiency, but, in the interviews, we found out that the optic is not irrelevant either. In both studies the participants preferred an anthropomorphic robot, human like but distinguishable from real humans. Models like Kuri, LEGO BOOST and NAO (see Figure 3) were most popular within the online survey.

Figure 3: Kuri robot [34], LEGO BOOST robot [35], and NAO robot [26].

In the interviews the participants had the chance to describe their ideal robots besides choosing one from given options. They described the ideal height of the robot to be between 50 and 70 cm. The robot should not be too small, so that they could accidentally step on it, but not too big either, so that it is not frightening. They also wanted a closed design for the robot without loose wires or sharp edges. Another important aspect was movement. The participants wanted the robot to move in such a way that the robot would not show up in front or behind them, so they would not be surprised by them. Most important for the interview participants was that the robot obeys its owner and does not act on its own accord. This suggest that the adults had a much more technical concepts of the robot than the students. Going even as far as specially demanding that the robot should be optical distinguishable from humans. In comparison the students see robots as a mix of technology and living beings.

Observations and evaluations of communication between students as part of a teaching unit on robots

To solidify the results of the previous study and examine the influence of robots on learning programming skills we designed and conducted a study in a computer science course at a German high school in grade 6. The course had 22 participants between the ages 11 and 13 (all boys, except one girl) and was carried out by two teachers. The observed teaching unit about robotics and first steps into programming lasted 6 weeks with two teaching units per week. Most students had never programmed before. For this unit the school used the NXT-G from the LEGO EDUCATION series with the program LEGO MINDSTORMS EV3 [36] (see Figure 4).

Figure 4: LEGO MINDSTORMS NXT-G robot [36], LEGO MINDSTORMS EV3 sample program.

During the unit the course was split in small groups with 2 or 3 members that shared a robot. The groups were selected by the teachers. They sorted the students by their performance level. All programming was executed within these groups. In the teaching unit the time was split in frontal instructions about the constructions of the robot and explanations for the programming. In the small groups the students tried out programming by themselves. The programming exercises were not explained in the frontal instructions. Details to the study and results can be found in [37]. For our study we used 3 different approaches.

1) The questionnaire from the previous study at the beginning and end of the teaching unit.

2) Observation and audio recordings of the teaching unit.

3) Interviews with the students after the teaching unit.

1) The questionnaire based on our previous work (Chapter: Robot conceptions of primary school children) tested the student's point of view towards robots. We analyzed if the students humanized the robots or if they compared it to a machine. We also asked them to draw or describe their ideal robot. Both surveys were analyzed after the teaching unit. For the results we only considered the surveys from the 16 students who participated in both surveys.

2) Within the teaching unit, we studied the way students talked about robots and programming. We compared the differences in their conversation from the beginning of the teaching unit to the end. For clearer results we concentrated on 3 small groups for the observation. We chose one group the teachers identified as high performing students, one group with low performing students and one group of students in between.

3) In the end of the teaching unit we interviewed 6 students about their experiences in the teaching unit and their opinions on robots. We also tested their knowledge about programming and technical terms from robotics. For the interviews we chose the students from the small groups we closely observed in the teaching unit, and, additionally, one boy the teachers identified as low performing in the beginning with very good results within this teaching unit. The interviews occurred in a separate room, were recorded and afterwards translated into transcripts. Our results are based on those transcripts.

The observation of the teaching unit, the audio recordings, paper survey and interviews result in the following conclusions:

1) The student's view of the robot changed from pet to toy or tool during the teaching unit.

2) The students were able to use the LEGO MINDSTORM program but could not transfer their knowledge.

3) The children in this course preferred an anthropomorphic robot design. They wanted the robot to protect and to obey them.

1) The students' behavior and thoughts towards the robot changed proceeding the teaching unit. At first a lot of students thought the robot was alive and acted on its own will. Most of the students treated the robots like a pet. They decided to give them names, pet them and asked others to pet them, too. While testing a program the students did not understand why the robot failed the given tasks. Most students blamed the robot and not the program. Many students also thought that the robots had feelings like fear and anger.

In the later course of the teaching unit more and more students understood the controllability of the robot. They started to humanize the robot less. The petting stopped almost completely, and the names were used more rarely. Also, the association with human feelings decreased. At the end of the teaching unit most students understood that robots are controlled by humans via programming. Therefore, the students started their search for mistakes in the program instead of the robot itself. The students with previous knowledge of programming were an exception. They did not change their behavior during the teaching unit. In the beginning of the teaching unit they already acted the way their classmates acted at the end.

2) At the end of the teaching unit the pupils understood how to use the LEGO MINDSTORMS program. Most students were able to program the majority of the given tasks. However, the students seemed to find it difficult to transfer what they had learned. Even at the very end of the teaching unit they were not able to explain the different technical terms. Most students were not sure how to explain the term ‘robot’. They used definitions, mostly compared to humans or computers. To explain the different parts of the robot (sensors and actuators) the students also used human body parts or described the visual appearance. The students hardly ever used the actual technical terms. Something similar was observed in regard to computer programming technical terms. The students usually used examples to explain the term ‘loop’ and were only rarely able to explain an algorithm. The terms ‘command’ and ‘branch’ were not understood at all by the students, although they were used in the context of the assignments.

3) The students were relatively unanimous about the wishes for their personal household robots in the results of the questionnaire. Before the teaching unit most students already wanted an anthropomorphic robot. They stated that the robot should be like a human and able to speak. 56,25% robot representations had two eyes, comparable to those of a human. But most robots used wheels instead of legs. The children also wanted the robot to be able to protect them. Therefore, the robot should be able to fight and use guns. In the results of the second paper survey the preferences towards an anthropomorphic robot were even more present. 75% of the children drew a robot with eyes like a human and most robots used legs instead of wheels. However, the students now wanted the robot to be able to do much more than a human. For example, they wanted the robot to fly or teleport. Regarding the behavior of the robot, the children only stated that the robot should help and obey its owner.

After school learning experience with two different robots

In a German high school, we planned and carried out a robotics course in the afternoon program. The course had 14 participants (all girls) between the ages 11 and 13. The girls chose freely to participate and were not graded. The students had no prior knowledge about robots or programming. The course had 7 lessons and one excursion in a span of 10 weeks. Within the lessons the students worked with the NXT-G from the LEGO MINDSTOMS series and the associated program LEGO MINDSTORMS EV3 [35]. They worked mostly in small groups of 2 students. The groups were chosen by the students themselves. In the beginning of every lesson the students got a small introduction to the program and tasks to solve during the group project. At the end of the lessons the possible solutions were discussed. Within the teaching unit the students explored the basics of programming. They got to know the technical terms ‘command’, ‘loop’ and ‘branch’ and learned the use of parameters.

For the excursion, the course visited our Humanoid Robots Lab at the University of Bonn. We conducted a 70-minute lesson there with the NAO robot from Aldebaran Robotics and the program Choreograph [38] (see Figure 5). For this lesson the course was split into 3 groups. 2 Groups worked with an actual NAO robot and one group worked with a simulation. The NAO and simulation groups were changed halfway through the lesson. Within this lesson the students explored the remote control of the NAO, learned how to use commands, loops and branches in Choreograph and witnessed demonstrations of programs designed by computer science students of our department.

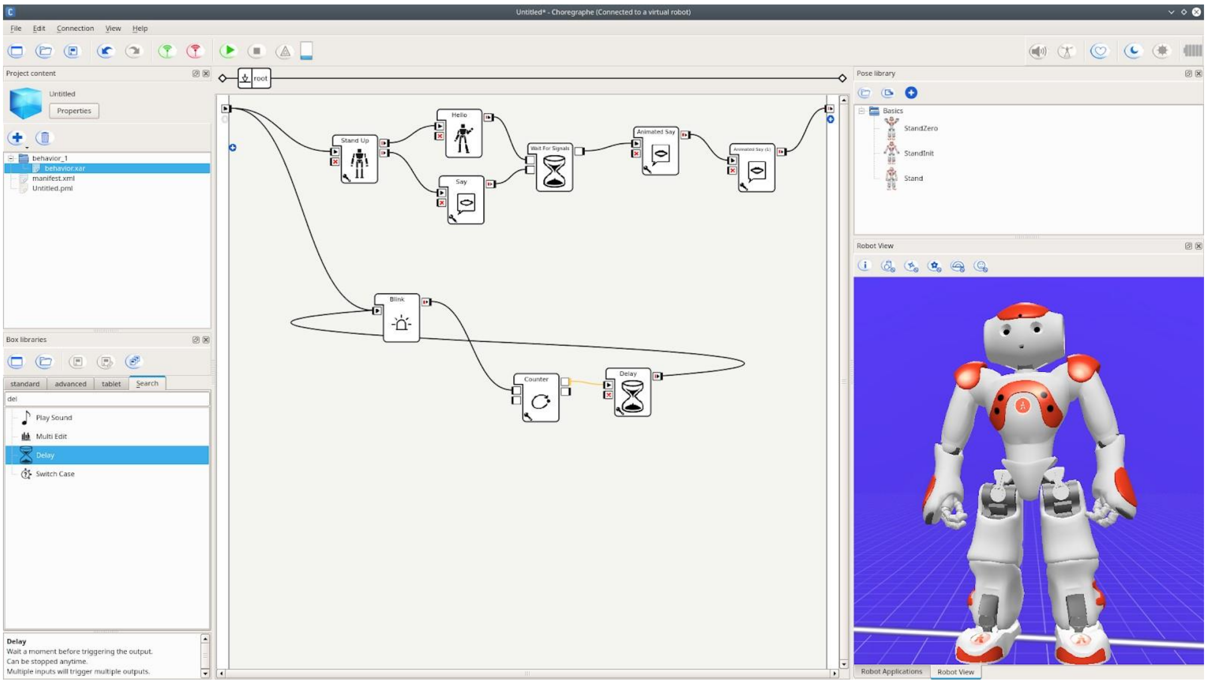

Figure 5: NAO robot [26], Choreograph sample program [38].

At the end of the course the students participated in a test to assess their performance on programming. They were tested on their knowledge in terms of the LEGO MINDSTORMS, the NAO and a hypothetical unknown robot. The details regarding the teaching unit and the test results are explained in [39].

11 of the 14 students participated in the test at the end of the teaching unit. The results are shown in Table 2.

As completely solved counted the answers with correctly programmed solutions for the tasks 1.1 to 2.3. For task 3 all completely explained algorithms counted as completely solved. Half solved answers and answers explained in words counted as partly solved. Therefore, unanswered questions and wrong programs counted as not solved. In the first part of the test it quickly became clear that the students relied heavily on the LEGO MINDSTORMS program EV3. Most of the students explicitly explained how they would proceed in the program and which programming modules they would use.

Task	Completely solved	Partly solved	Not solved
Task 1: Explain in your own words how you can get the Lego MINDSTORMS robot to perform the following actions:			
Task 1.1: drive a straight line	**72.73%**	27.27%	0%
Task 1.2: drive towards a wall and stop in front of it	**54.55%**	45.45%	0%
Task 1.3: reacting to noise with a sound	27.27%	**63.64%**	9.09%
Task 2: Explain in your own words how you can get the NAO robot to perform the following actions:			
Task 2.1: lift the right arm above their head	0%	**81.82%**	18.18%
Task 2.2: walk a straight line and dodge an obstacle	27.27%	**45.45%**	27.27%
Task 2.3: tell how often someone pushed their hand	9.09%	27.27%	**63.64%**
Task 3: Explain how you would proceed in the following task with an unknown robot:			
The robot should run up to a wall (this is always straight in front of it) and collect all battery packs on the way. If there is no battery pack in a field, it should put a screw there.	**54.55%**	27.27%	18.18%

Table 2: Results of the programming test at the end of the after-school teaching unit

For task 1.1 all students wanted to use the standard control block (the main control within the LEGO MINDSTORMS EV3 program). Six students explained how the parameters must be set on this programming module. This task was completely solved by 72.73% of the students.

In task 1.2, all students were aware that they needed a sensor. 63.64% referred directly to the ultrasonic sensor used in the teaching unit in connection with the programming module "Wait". 27.27% of the students suggested the use of an infrared sensor instead. 54.55% of the students described how the parameters of the various programming modules must be set for this task.

Task 1.3 shows that the students adapt themselves on the tasks from the teaching unit. 54.55% of them did use a noise sensor here in order to be able to record the ambient noise, even if not all pupils named the sensor as such. 54.55% students also want to use the "Wait" module again. It becomes clear here that the answers for this task were significantly more incomplete than for the previous tasks.

The second part of the test was about the NAO used in the excursion. For the first sub-task, it can be clearly seen that the students all described the remote control of the NAO from the program Choreograph. The students did not give any suggestions on how to solve the task with programming instead of the remote control. Therefore, no student solved this task completely.

In task 2.2, again 45.45% describe how the program was presented during the excursion and not how they would write such a program themselves. Only 27.27% of the students correctly suggested programming of this task by describing which type of programming modules they would use to solve it.

Task 2.3 was not completed by 27.27% of the students, the remaining students tried to explain that they would look at the given programming modules in Choreograph and then put them together. Only one student indicated a possible program, 27.27% others indicated which types of programming blocks they would need for the task.

In task 3 of the test, the computer programming of an unknown robot should be described. Here, the students' answers can be roughly divided into two groups. The first group described which actions the robot has to carry out in which order to be able to cope with the deposit that was given in the task. The other group described how the robot could follow any path according to the solutions described. Both groups of students would be able to solve this task with the appropriate set of programming modules, although the majority only used simple instructions, and only a small number of the students used control structures. These control structures were not named by any student. Overall, very few pupils described what kind of programming blocks they would need for their program. For example, only 2 students mentioned that they needed a sensor that would be able to detect the batteries and one student wanted to use something like the standard controls of LEGO MINDSTORMS EV3 to make the robot move straight ahead.

Conclusion

In the different studies with students and adults we discovered that their ideal designs for robots vary. The students wanted a robot looking and acting as human-like as possible. They also wanted the robot to be big and strong to be able to protect them. Some of the students even wanted the robot to use weapons. The adults on the other hand seemed more afraid of the idea of a big, very human-like robot. They preferred a smaller model between the size of 50 cm and 70 cm. But more important to them was that the robot could be distinguished from a human. They preferred anthropomorphic robot designs but wanted to have a hint that the robot was still a robot. The main difference between the students and adults seemed to be that the students were not afraid of robots, but wanted them to be their tool, while the adults were more afraid that the robot might think by itself. On one point, however, both groups agreed: they wanted the robot to obey its owner. This point was very important to the majority of the participants in all studies.

In both teaching units from our studies we observed grade progress from the students in the field of programming. At the end of the teaching units most of the students were able to program the NXT-Gs and solve at least some of the given tasks. Within the after-school course it was noticeable that the students were able to use their knowledge from the LEGO MINDSTORMS EV3 program and transfer it to the unknown program Choreograph.
However, in the interviews of the high school course and tests of the after-school course it became clear that the students were unable to explain their programs as algorithms or use the proper technical terms for the basic programming ideas like loops or branches.
In the beginning of the courses the students considered their robots to be pets and gave them nicknames or petted them in the lessons. Later, this behavior changed. The students started to treat the robot more like a toy or a tool.

In summary, we conducted 3 studies to determine ideal robot designs for students and the influence of robots on programming teaching units. We found that there is a clear difference between the perception of robots in adults and young students. Also, contact with robots helps students to gain a sense of familiarity towards digital concepts. Students were able to transfer knowledge from the known robot to a new programming task. Thereby, robots generally had a positive influence on the learning experience of the students in our studies for their first steps in programming.

References

[1] Bojanova, I., 2014. The Digital Revolution: What's on the Horizon?. IT Professional, 16(1), pp.8-12.

[2] Markets and Markets. Service Robotics Market by Environment - Global Forecast to 2025. https://www.marketsandmarkets.com/Market-Reports/service-robotics-market-681.html, 2020. last visited 2020-07-13.

[3] Lohse, M., Hegel, F. and Wrede, B., 2008. Domestic applications for social robots: an online survey on the influence of appearance and capabilities.

[4] Ardiny, H., Witwicki, S. and Mondada, F., 2015. Are autonomous mobile robots able to take over construction? a review.

[5] Bogue, R., 2019. Strong prospects for robots in retail. Industrial Robot: the international journal of robotics research and application.

[6] Conti, D., Di Nuovo, S., Buono, S. and Di Nuovo, A., 2017. Robots in education and care of children with developmental disabilities: a study on acceptance by experienced and future professionals. International Journal of Social Robotics, 9(1), pp.51-62.

[7] Zhong, B. and Xia, L., 2020. A systematic review on exploring the potential of educational robotics in mathematics education. International Journal of Science and Mathematics Education, 18(1), pp.79-101.

[8] Mubin, O., Stevens, C.J., Shahid, S., Al Mahmud, A. and Dong, J.J., 2013. A review of the applicability of robots in education. Journal of Technology in Education and Learning, 1(209-0015), p.13.

[9] Saerbeck, M., Schut, T., Bartneck, C. and Janse, M.D., 2010, April. Expressive robots in education: varying the degree of social supportive behavior of a robotic tutor. In Proceedings of the SIGCHI conference on human factors in computing systems (pp. 1613-1622).

[10] Han, J. and Kim, D., 2009, March. r-Learning services for elementary school students with a teaching assistant robot. In 2009 4th ACM/IEEE International Conference on Human-Robot Interaction (HRI) (pp. 255-256). IEEE.

[11] Mubin, O., Bartneck, C., Feijs, L., Hooft van Huysduynen, H., Hu, J. and Muelver, J., 2012. Improving speech recognition with the robot interaction language. Disruptive science and Technology, 1(2), pp.79-88.

[12] Mukai, H. and McGregor, N., 2004. Robot control instruction for eighth graders. IEEE Control Systems Magazine, 24(5), pp.20-23.

[13] Riedo, F., Rétornaz, P., Bergeron, L., Nyffeler, N. and Mondada, F., 2012. A two years informal learning experience using the thymio robot. In Advances in Autonomous Mini Robots (pp. 37-48). Springer, Berlin, Heidelberg.

[14] Carpin, S., Lewis, M., Wang, J., Balakirsky, S. and Scrapper, C., 2007, April. USARSim: a robot simulator for research and education. In Proceedings 2007 IEEE International Conference on Robotics and Automation (pp. 1400-1405). IEEE.

[15] Magnenat, S., Shin, J., Riedo, F., Siegwart, R. and Ben-Ari, M., 2014, June. Teaching a core CS concept through robotics. In Proceedings of the 2014 conference on Innovation & technology in computer science education (pp. 315-320).

[16] Merkouris, A., Chorianopoulos, K. and Kameas, A., 2017. Teaching programming in secondary education through embodied computing platforms: Robotics and wearables. ACM Transactions on Computing Education (TOCE), 17(2), pp.1-22.

[17] Fagin, B.S. and Merkle, L., 2002. Quantitative analysis of the effects of robots on introductory Computer Science education. Journal on Educational Resources in Computing (JERIC), 2(4), pp.2-es.

[18] Çankaya, S., Durak, G. and Yünkül, E., 2017. Education on Programming with Robots: Examining Students' Experiences and Views. Turkish Online Journal of Qualitative Inquiry, 8(4).

[19] Serholt, S. and Barendregt, W., 2014. Students’ attitudes towards the possible future of social robots in education. In Workshop proceedings of Ro-man.

[20] Kim, S.W. and Lee, Y., 2016. The effect of robot programming education on attitudes towards robots. Indian Journal of Science and Technology, 9(24), pp.1-11.

[21] Kaburlasos, V.G., Dardani, C., Dimitrova, M. and Amanatiadis, A., 2018, January. Multi-robot engagement in special education: a preliminary study in autism. In 2018 IEEE International Conference on Consumer Electronics (ICCE) (pp. 1-2). IEEE.

[22] Robins, B., Dickerson, P., Stribling, P. and Dautenhahn, K., 2004. Robot-mediated joint attention in children with autism: A case study in robot-human interaction. Interaction studies, 5(2), pp.161-198.

[23] Fong, T., Nourbakhsh, I. and Dautenhahn, K., 2003. A survey of socially interactive robots. Robotics and autonomous systems, 42(3-4), pp.143-166.

[24] Duffy, B.R., 2003. Anthropomorphism and the social robot. Robotics and autonomous systems, 42(3-4), pp.177-190.

[25] Reich-Stiebert, N., 2019. Acceptance and Applicability of Educational Robots. Evaluating Factors Contributing to a Successful Introduction of Social Robots into Education.

[26] RoboLab.com. Nao. https://www.robotlab.com/store/nao-power-v6-standard-edition, accessed 05.26.2020.

[27] Lego.com. Lego boost cat. https://www.lego.com/de-de/product/boost-Creative-toolbox-17101, accessed 06.07.2020.

[28] Ideaing.com. Buddy family companion robot. https://ideaing.com/product/buddy-family-companion-robot, accessed 06.07.2020.

[29] Robotsepeti.com. Turtlebot waffle. https://www.robotsepeti.com/turtlebot-3-waffle, accessed 05.26.2020.

[30] Oliveira, M., Bitencourt, C., Teixeira, E., & Santos, A. C., 2013. Thematic content analysis: Is there a difference between the support provided by the MAXQDA® and NVivo® software packages. In *Proceedings of the 12th European Conference on Research Methods for Business and Management Studies*., pp. 304-314.

[31] Müller, K., Schulte, C., 2018. Are children perceiving robots as supporting or replacing humans? first empirical results and classification of preconceptions within a theoretical framework. In *Proceedings of the 13th Workshop in Primary and Secondary Computing Education* pp. 1-4.

[32] Charmaz, K. and Belgrave, L. L. . Grounded theory. The Blackwell encyclopedia of sociology, 2007.

[33] K. Bungert. Untersuchung der menschlichen Wahrnehmung für die Interaktion mit Servicerobotern, Master's Thesis, Universität Bonn, 2020. https://www.hrl.uni-bonn.de/papers/bungert_master_thesis.pdf

[34] Spectrum.IEEE.org. Kuri. https://spectrum.ieee.org/automaton/robotics/home-robots/mayfield-robotics-announces-kuri-a-700-mobile-home-robot, accessed 26.05.2020.

[35] LEGO.com. Lego boost. https://www.lego.com/de-de/product/boost-creative-toolbox-17101, accessed 26.05.2020.

[36] THE WORLD OF ELECTRICAL ENGINEERING http://web.tecnico.ulisboa.pt/~ist187121/wordpress/2016/12/10/nxt-robot/mindstorm/, accessed 30.03.19

[37] Bungert, K.. Beobachtungen und Auswertungen zur Kommunikation der Schülerinnen und Schüler im Rahmen einer Unterrichtseinheit zu Robotern im Informatikunterricht der Jahrgangsstufe 6. Bachelorarbeit, Universität Bonn, 2017. https://www.informatik.uni-bonn.de/de/abteilungen/arbeitsgruppen/didaktik/abschluss-und-studienarbeiten/bachelorarbeit-roboter-in-der-jgst.-6.

[38] Brainary interactive. https://www.brainaryinteractive.com/nao-in-education, accessed 30.03.19

[39] Bungert, K.. Eine Roboter-AG für Mädchen der Jahrgangsstufe 6 in der zwei Arten von Robotern verwendet wurden. Studienprojekt, Universität Bonn, 2019. https://www.informatik.uni-bonn.de/de/abteilungen/arbeitsgruppen/didaktik/abschluss-und-studienarbeiten/studienprojekt-roboter-im-ag-bereich.

Contact email: kira.bungert@web.de