A Survey About the Use of Educational Robots and Physical Computing Devices in Computer Science Lessons at German Secondary Schools

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Abstract

Educational robots and physical computing devices are steadily becoming a common sight in computer science classes, as they offer both motivating and illustrative access to a multitude of technical concepts. However, this versatility comes with the drawback that it is not a priori clear how such systems should be designed or how they are most effectively used during lessons. It's also unclear how much additional workload their maintenance incorporates. To help answer these questions, we conducted a survey at 114 German secondary schools from 11 different federal states. First, we asked computer science teachers about the current state of their lessons and the additional workload regarding the maintenance of the technical devices at their school. Afterward, we questioned our participants about how educational robots and physical computing devices are used in their respective classes, what positive and negative aspects they see in such systems and how much additional workload they add. We found that in 49% of the cases computer science teachers were responsible for the maintenance of the schools' technical devices, implicating that the use of additional digital devices would further increase their workload. Nevertheless, 65% of our participants used educational robots and/or physical computing devices during their lessons. The systems were also generally perceived in a positive light with the most stated use case being an introduction to programming and the most valued functionality being modular components. In this paper, we present the design and results of this survey.

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

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Introduction

As Computer Science education is becoming more important to schools, so are the tools we use for teaching it. An often discussed approach in the literature is the use of educational robots [3][4] and physical computing devices [5]. For this work, we define a physical computing device as a complete computer built on a single circuit board that focuses on measurements and interacting with other digital devices. In contrast, we define a robot as a machine programmable by a computer that acts either autonomously or guided by a control device and focuses on movements and interaction with its environment. Examples of both device classes are depicted in 1.

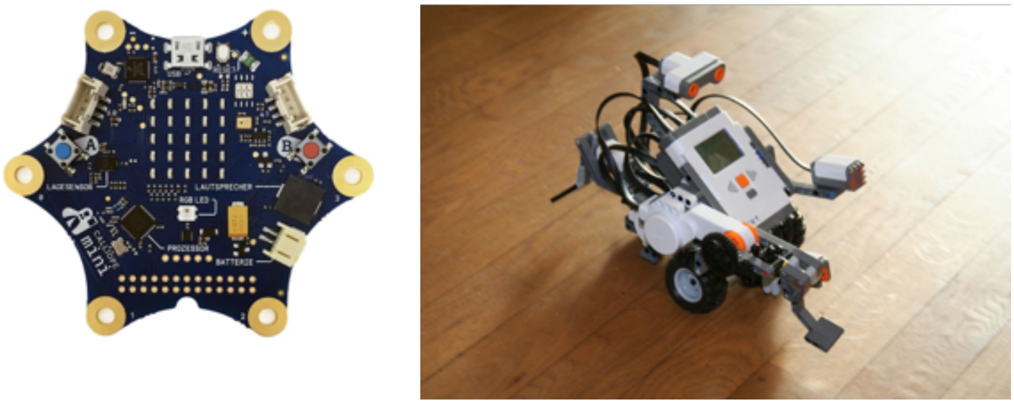

Figure 1: Left the physical computing device Calliope mini [18], right the educational robot LEGO MINDSTORMS NXT [19]

According to the literature, both device classes offer motivating and illustrative access to a multitude of technical concepts [3][4][5]. However, with a vast variety of use cases and available designs, it is not easy to see which devices are most useful for schools, how they can be efficiently used for teaching, and how much additional workload their maintenance and use incorporates.

In this paper, we try to answer these questions by looking at the current situation in German computer science classes. Therefore, we conducted a survey at 114 German secondary schools from 11 different federal states. First, we asked computer science teachers about the current state of their lessons and the additional workload regarding the maintenance and use of such devices at their school. Afterward, we questioned our participants about how educational robots and physical computing devices are used in their respective classes, what positive and negative aspects they see in such systems and how much additional workload they add. The design and results of this study are discussed in the following sections.
In summary, we try to answer the following questions:

1. Are educational robots and physical computing devices commonly used in German computer science classes and what use cases do they have?
2. How should robots and physical computing devices be designed to be most efficient during lessons?
3. How much additional workload do these systems incorporate for computer science teachers?

Related Work

By now, educational robots and physical computing devices are generally seen by the community as useful tools to increase the motivation and learning efficiency of pupils [1][2][3][4][5].

In contrast to our survey, most work in the literature is either concerned with the effects of educational robots or physical computing devices. The effects of both device classes are however often similar.

Zhong et al. published a systematic review of the use of educational robots in mathematics education. They found that most studies on this topic were conducted with LEGO robots, typically with small sample sizes, with a research focus on elementary or secondary schools. Robots were mostly used to teach and learn graphics, geometry, and algebra, often by using game-like interactions between the students and the robots [3]. A similar literature review was conducted by Belpaeme et al. They noticed that an increasing number of studies viewed educational robots positively, with a high potential for education and tutoring. However, they also noted that the large-scale introduction of such technical systems to the classroom poses a lot of technical and logistical challenges and will therefore likely take some time [4].

Regarding physical computing devices, Chung et al. published a study comparing the performance of two twelfth-grade programming courses. One with and one without physical computing devices. They found that the students of the physical computing course had a significantly higher learning efficiency and motivation in coding literacy than their peers in the control course [5].

Aside from functioning as examples of technical concepts educational robots can also directly interact with the students, e.g., to answer or ask questions. This naturally raises the question of how the robots should interact with the students.

Baxter et al. examined whether it is beneficial in such situations to personalize the behavior of the robots towards young students. They found an increase in the student's learning success with personalized robot behavior vs. neutral behavior [6]. Konijn et al. concluded in a more STEM-orientated study that while robots can be a significant aid for students to learn STEM tasks, the question of how social their behavior should be cannot be answered so easily. They found that more advanced pupils profited most from social behavior, whereas those below average benefited more from neutral robot behavior [7]. A similar study with a language learning focus was conducted by Kennedy et al. They again found a significant improvement in the learning success of their pupils while working with robots. However, they did not find any significant correlation between the learning efficiency of the students and the social behavior of the robots [8].

Regarding the view of young pupils towards robots, Alves-Oliveira et al. found that children often perceived a humanoid educational robot as a friend or classmate. This is especially the case if the robot possesses some kind of social behavior and/or is smaller than the pupils [9]. In the case of non-humanoid robots, Bungert et al. noted that children often first viewed robots as pets rather than inanimate objects [10]. However, in both cases, the exposal to the robots helped the pupils to understand that they worked with programmable machines rather than living beings.

The attitude of pre-service teachers towards such devices was explored by Kim et al. They noted that given a programming education, teachers generally looked positively at robots. The design and necessary assembly of the devices were the main negative points [11]. Concerning physical computing devices, Kalelioglu performed a survey of 50 computing teachers that worked with the micro:bit device. The author concluded that the most used teaching methods with it were live coding demonstrations, pair programming, discussion, collaborative work, and tinkering. Interestingly, strategies teachers used did not always align with what they felt was most effective, with design and code tracing being seen as effective methods but not popular methods [12]. One possible reason for this effect could be the often-described lack of available teaching material for educational robots [13] and physical computing devices [14][15].

Survey Design

We conducted an online survey with the tool Qualtrics [16]. The survey was split into three blocks. The first block focused on general questions considering the teacher's teaching experiences, starting with the question of who was responsible for the maintenance of the IT structure at their school with the multiple-choice answers "a teacher", "an external person or company", "an administrator at school who is not a teacher", and "I don't know". Afterward, we asked the participants a free text question to describe their positive and negative aspects of teaching computer science. We made clear that this question should be answered independently of the current pandemic. As the last question, we asked our participants if they know of any funding programs in their school that are focusing on girls.

The questions within the second block focused on educational robots and physical computing devices. We started by asking the participants to name the programming languages they were using for their lessons in the different grades they are teaching. This was a free text question. Afterward, we showed the participants a selection of different educational robots and physical computing devices. We asked them to select all devices they had seen before. Following this, we asked them to add in a free text question about all the educational robots and physical computing devices they knew for usage in class that we had not mentioned in the previous question. Then we asked a yes or no question if the participants had ever used a robot or physical computing device in their lessons. Depending on their answer some questions within this question block varied. We still asked all participants if the schools were using robots or physical computing devices in extracurricular activities or any other subjects but computer science. We also asked if robots or physical computing devices were used to participate in competitions and to name them if that was the case.

For every participant who was using a robot or physical computing device, we asked which one they were using. Additionally, we asked in which grade they were used and for which topics. This was a free text question. We also asked which positive and negative effects they saw in using these devices during their lessons and if they had any problems with them and suggestions for improving the devices. Afterward, we asked them to rate on a 5-scaled Likert scale both the influence of the devices on the student's motivation and learning process. The possible options were "very positive", "positive", "neither positive nor negative", "negative", and "very negative". We also asked them if they noticed a difference in handling these devices in the students due to their gender. Following this, we asked which kind of programming language the participants were using with the devices and which one they preferred. We differentiated between block-based programming languages, text-based programming languages, and both. Supplementary, we asked whether it was the software specified by the devices manufacturer or if they used another software and to name the software if they were. We also asked if they preferred software with an installation or without. Corresponding to the software, we also asked for the hardware the schools used with robots or physical computing devices. Therefore, we differentiated between desktop PCs, Laptops, Tablets, and Smartphones. Afterward, we asked which functions of the robots and physical computing devices were most important for usage in lessons. Lastly, we had the participants order given functions of robots and physical computing devices by their personal preference.

For the participants that hadn't worked with robots or physical computing devices in their lessons before, we asked if they would use devices like this if they were given the hardware by their school.

Lastly, in the final block, we collected personal data about our participants. We started with the Question about their type of school and the federal state in Germany they worked in. Afterward, we asked them how long they had been teaching given the options of "experienced", "newcomer", and "still in training". We also asked about their educational path and how they had achieved their teaching qualification.

Survey Results

For the survey, 114 teachers from different German secondary schools participated. The schools were from 11 of the 16 different German federal states. In Germany, the school curriculum differentiates between the different federal states. Therefore we considered this in our survey.

A majority of our participants (48 %) taught in the federal states of North Rhine-Westphalia, Mecklenburg-Western Pomerania, and Lower Saxony.

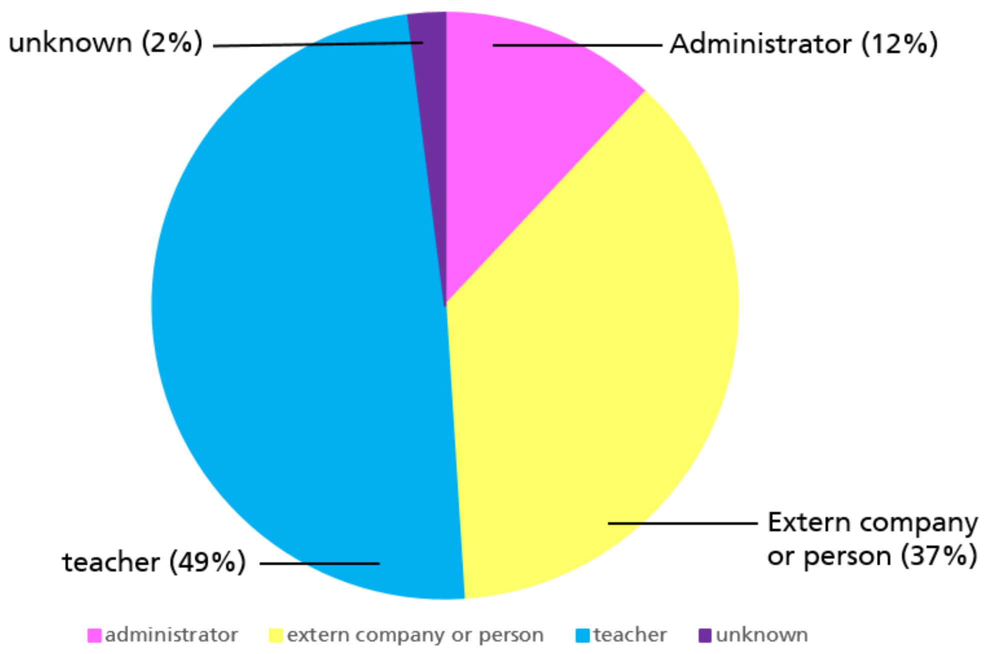

Figure 2: Results for the question: Who is responsible for the IT infrastructure at the school?

Regarding the responsibility of the IT infrastructure in schools, our results show that in most schools (49 %) a teacher is responsible for maintaining the IT infrastructure, as seen in Figure 2.

As positive aspects of teaching computer science, the participants stated that the students are often particularly interested in the subject because it is nonmandatory at most schools and thereby chosen by the students which usually leads to higher motivation than in mandatory subjects. The participants also welcomed the praxis-orientated focus of the subject.

For negative aspects, the teachers named the fact that there are not enough computer science teachers and the lack of proper technical devices at their schools. Also, they criticized that the subject is often used to teach basic IT skills instead of computer science.

77 % and therefore most teachers answered that they did not have funding programs for girls in computer science at their schools. Most of them also did not see differences between genders in their computer science lessons.

The most used programming languages in the teacher's lessons were "Scratch", followed by "Python" and "Java" and the most known robots for schools were the LEGO MINDSTORMS, Calliope, and Arduino. These results are shown in Figure 3. The LEGO MINDSTORMS were the most used robots or single-board computers as well. For the robots or physical computing devices, the participants used mostly block-based programming languages or a mix of block-based and textual programming languages. Mostly, the language depended on the programming environment that came with the device.

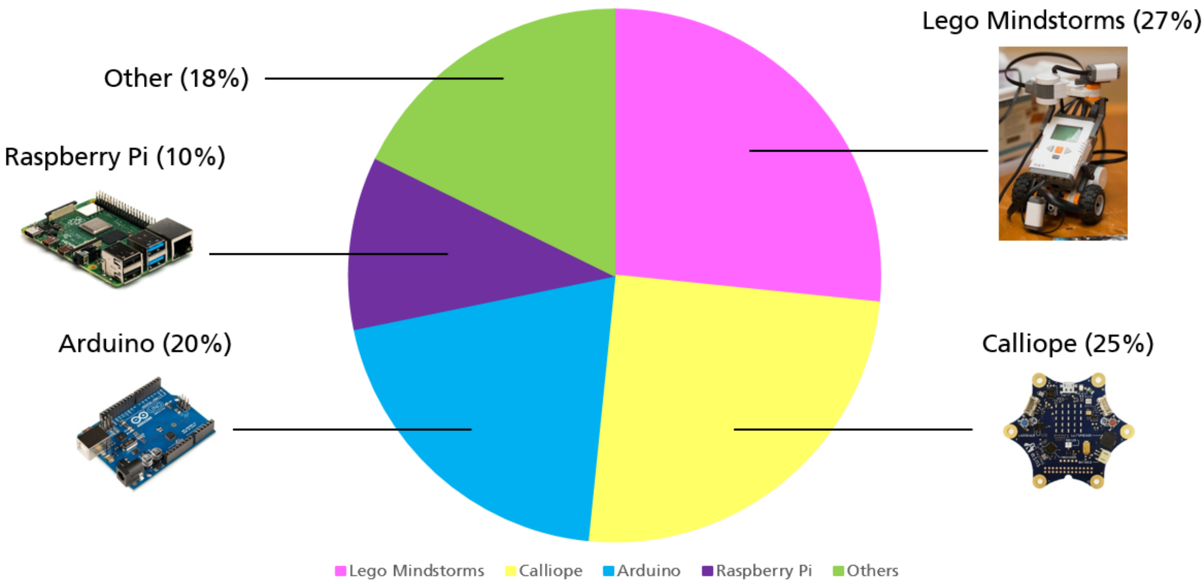

Figure 3: Most used physical computing devices and educational robots by our participants, in ascending order: Raspberry Pi [20], Arduino [21], Calliope [18], Lego Mindstorms [19]

65 % of our participants had used robots or other physical computing devices in their lessons before. The devices were rarely used for other subjects or extracurricular activities, but most schools that had robots did participate in robot challenges. Mostly, both device classes were used for younger grades and as an introduction to computer programming.

All in all, the teachers saw a positive impact from the devices on both the students' motivation and performances in class as shown in Figure 4.

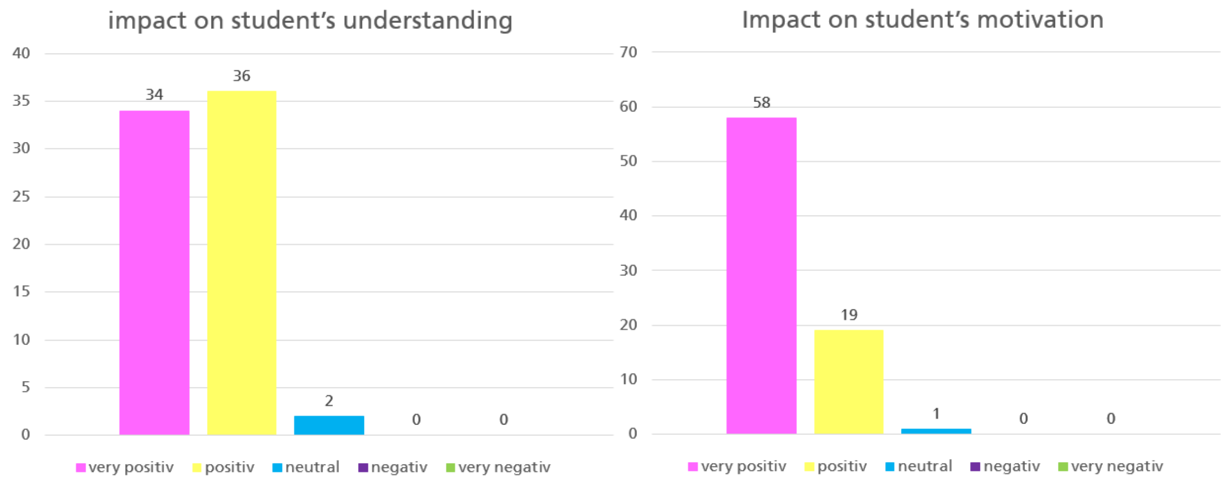

Figure 4: Results for the question about the perceived impact of physical computing devices and/or educational robots on the understanding of lesson-relevant information and motivation of the students

While working with robots or physical computing devices most schools used desktop PCs. Aside from them, laptops, tablets, or smartphones were used as well.

The most valued feature of the robots and/or physical computing devices were the sensors and actors. Our participants also preferred to have the option to change between block-based and textual programming languages and easy handling of both the device itself and the corresponding programming environment. The price of the device and connections via USB and Bluetooth were also criteria for choosing a device for their school.

The only negative aspects that were mentioned more than once in the results were the high costs of the devices and accessories and the high workload to establish the devices in lessons as well as maintaining the hardware.

Most participants (58 %) that had not worked with robots or other physical computing devices before would work with them if given the opportunity. They especially welcomed the practical approach given by the usage of these devices. The main reasons they did not work with robots already were the price and maintenance needed for the devices.

75 % of our participants stated to be experienced in teaching computer science. The others were either new to the job or still in training. 58 % had graduated in the educational branch of computer science, 7 % in general computer science, and 5 % graduated in both disciplines. The rest did not graduate in either of these subjects. After graduation, half of our participants became teachers by doing teachers training as common in Germany. The others were almost equally split between career changers and teachers who visited a certificate course to teach computer science in addition to the subjects they originally graduated in. The results of both questions are visualized in Figure 5.

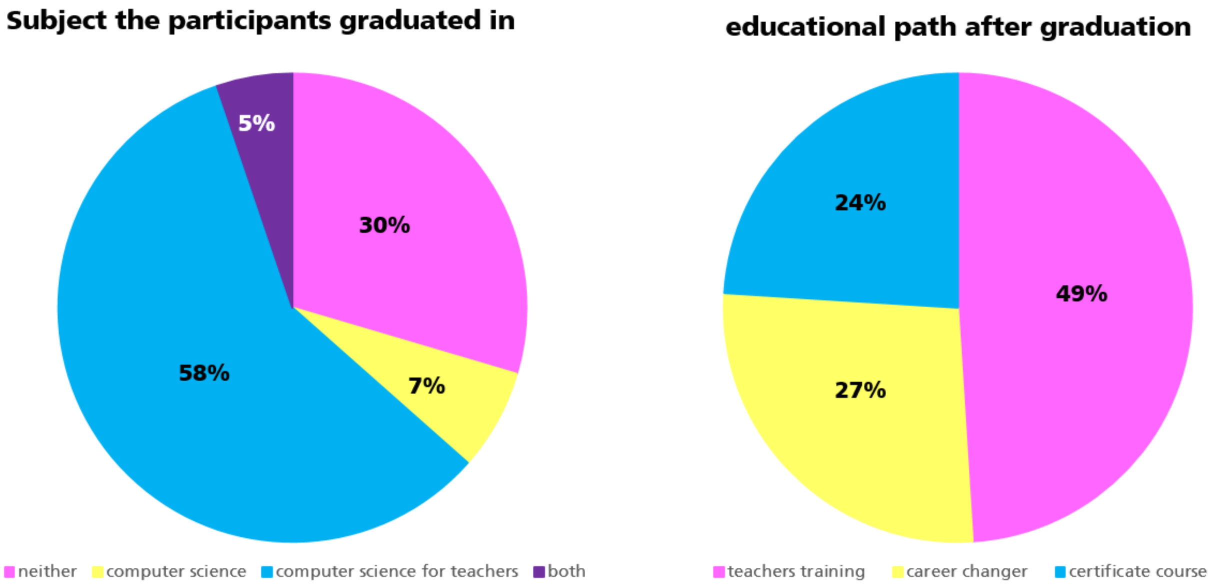

Figure 5: Results for the questions about the graduated subject and education path after graduation of our participants

Discussion

1. Are educational robots and physical computing devices commonly used in German computer science classes and what use cases do they have?

Robots and physical computing devices are used commonly in German computer science lessons. Mostly these devices are used in combination with desktop PCs or laptops. Some schools also use tablets or students' smartphones, but this seems to be a newer development, especially during the pandemic.

Most schools teach computer science as an elective subject in grades 8, 9, and/or 10. Most secondary schools also teach computer science in the higher grades until the students graduate, but usually as new starting courses, starting with the basics again. In some federal states, computer science is also a mandatory subject for grades 5 and 6 but this too is a newer development. Therefore, educational robots and physical computing devices are often used as a tool to introduce computer science concepts.

The most used programming language in computer science lessons is the block-based language "Scratch". This corresponds to the block-based programming languages being the most used type of programming languages for working with robots or other physical computing devices. Most of these devices have a block-based programming language given by the associated programming environment. The programming language from the programming environment for LEGO MINDSTORMS for example is based on "Scratch". Most teachers are using these associated programming environments. This also fits with the introduction to computer programming being the main topic for the usage of these devices because it is easy to access for the students' first experiences. Some of these associated programming environments also have the possibility of changing to a textual programming language. These are used more for higher grades and in more advanced computer programming courses.
Single-board computers are used more often than educational robots. LEGO MINDSTORMS is the most famous device overall. One reason for this is probably the price. Educational

robots are usually more expensive than single-board computers and most schools are not willing to pay as much for a non-mandatory subject like computer science without having any experience with these digital devices.

Our results support this theory. In the survey, a lot of teachers stated in different questions that the cost of the devices was a crucial factor. Also, single-board computers promise an easier setup and therefore less preparation for teachers. This also fits with our results where the teacher's workload was another crucial factor in both the decision to purchase robots or physical computing devices and which model was chosen for the schools.

The main reason teachers are not using educational robots or physical computing devices in their lessons was also the lack of hardware or the money to buy new hardware and the corresponding higher workload for maintaining the devices.

2. How should robots and physical computing devices be designed to be most efficient during lessons?

Educational robots and physical computing devices were mainly used for younger students and as an introduction to computer programming. They were also used in higher grades for new computer science classes. Therefore, the devices and the associated software must be easily accessible to users. Most teachers were already quite satisfied with the devices they got in their schools if they had them. They saw a positive impact on both the motivation and performance of the students working with these devices.

To teach the basic ideas of computer programming like branches and conditions, the robots or physical computing devices should be able to interact with their environment through sensors and actors.

It was also important to our participants that they could customize the robot or physical computing devices for their own needs or the needs of their study groups. It also personalizes the robots or physical computing devices to the students and therefore encourages a positive view.
Some teachers preferred to have the possibility to change between block-based and textual programming languages to use the robots or physical computing devices in further advanced classes.

Another important criterion is the connection to the school's hardware. The robots or physical computing devices should have an easy and preferred wireless connection with the given hardware.

The surveys' results were not elaborate enough to determine all criteria for educational robots and physical computing devices. To further distinguish the different models of robots and physical computing devices the models must be compared with the teacher's necessary features. Also, more practical tests are necessary to determine the advantages and disadvantages of the different robot and physical computing device models. Therefore, further research is needed to properly answer this question.

3. How much additional workload do these systems incorporate for computer science teachers?

First of all, the workload of teachers in Germany is already high. Mußmann et al. stated that a quarter of the teachers work more than 48 hours a week. This workload has furter increased during the fast digitalization during the pandemic by another half hour to an hour [17]. This is especially true for computer science teachers who often have additional tasks corresponding to their schools IT infrastructure. In our results, we found that most schools do not have an administrator. Mostly, these tasks are taken by teachers or an external company. Both of these options mean more work for the teachers. Even if they can contact an external company they still have to respond to them and give them access to the devices. A lot of the teachers also stated that the technical devices at their school are outdated and therefore more errors occur on a daily bases when the company is not present at the school.

Robots or physical computing devices and their introduction and maintenance mean even more work for the teachers. Especially a first setup in schools takes a lot of time that teachers usually do not have.

There is also not a lot of teaching material for working with these devices. So teachers have to prepare a lot more before lessons.

Another problem is the lack of computer science teachers. Not a lot of universities offer the possibility to study computer science for teachers in Germany. Therefore, there are very few graduates, too. At the same time, the subject becomes more important in schools and more schools want to teach this subject. In conclusion, a lot of computer science teachers are needed but there are only a few computer science teachers available.

As a consequence, many teachers choose to participate in a certificate course to teach computer science as an additional subject. A Certificate course is a course usually taught in evening schools for one year, with a full expenditure of time of 320 hours. These courses do only provide a very general overview of computer science topics. Therefore, teachers who choose to teach this subject additionally have a lot more work to catch up on than just participating in the course. As consequence, they often ask for help from their colleagues, resulting in more workload for both teachers.

Possible solutions for teachers' workload could be mandatory introductions of administrators at schools. By doing this the technical problems that increase more every year would be handled by experts and the teachers could focus on their main job in the lessons again.

Additionally, there should be more teaching material available for computer science teachers. Especially in the federal states where computer science is not a mandatory subject there are little to no materials available. In some schools, there is not even a textbook given to use in class.

Lastly, the universities need to focus more on educating computer science teachers. Teachers are needed in schools and therefore they need to be educated properly. Enhancing the certificate courses is another possible solution for this issue.

Conclusion

There are a lot of educational robots and physical computing devices already used in schools and they are mostly perceived positively by the teachers using them. They claim that the usage of such devices increases both motivation and performance of the students. Therefore, the increasing sight of these devices in computer science classes is supported by our participants and should therefore be further founded.

The most important criteria of these devices are the sensors and the corresponding programming environment. Ideally, the robot or physical computing devices should have multiple sensors to properly teach basic computer programing ideas and also have corresponding software that is both easy to set up and use and can also be used with block-based and text-based programming languages. The software should not need an installation.

Nevertheless, there are still a lot of obstacles for teachers to use these devices in their lessons. The biggest challenges to using educational robots or physical computing devices are the lack of hardware and maintenance of the given hardware as well as the relating workload for the teachers.

Although digitalization is advancing in schools a lot of teachers complain about outdated hardware and a small budget to buy new technical devices for computer science lessons. A lot of the existing hardware is also not properly maintained. This is mostly due to the lack of administration of IT devices in schools. This results in higher workloads for computer science teachers who often take these administration tasks on top of their teaching job. A solution would be to establish properly trained administrators in all schools.

The workload for teachers is already high. Computer science is also still a relatively new subject in most schools in Germany. Therefore, there is not a lot of teaching material and not many computer science teachers in general. On top of that, a lot of these computer science teachers teach computer science as an additional subject and achieved their teaching qualification for the subject through a certificate course that is not sufficient.

In general, while there is still a learning process in teaching the subject itself, physical computing devices and educational robots are a valuable tool for its teachers.

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