Chapter 8

Designing Hands-On Robotics Courses for Students with Visual Impairment or Blindness

Valerie Stehling, Lana Plumanns, Anja Richert,
Frank Hees and Sabina Jeschke

Additional information is available at the end of the chapter

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Abstract

School laboratories let students playfully experience the fundamentals of, for example, robotics, computer science, and technology-related topics. By working with LEGO Mindstorms, secondary school students get a chance to learn on a cognitive, emotional, and haptic level and gain experiences with the aid of even more advanced robotics. However, due to an impairment or lack of sight, it is hardly possible for some students to fully participate in a programming process or in building a robot. To overcome this unintentional discrimination, the interdisciplinary student laboratory "RoboScope" at RWTH Aachen University has teamed up with a group of experts to develop a barrier-free robotic course. Since then, the course has been tested and implemented based on concurrent evaluations and frequently held at RWTH and several other German schools. The presented work covers an overview of different kinds of visual impairment and lab settings and the development cycle of the courses at RWTH from design to testing, implementation, and further development regarding the evaluations. Evaluations show that students who are visually impaired or blind appreciate the opportunity to participate in the field of robotics. An insight into the evaluation concept that differs from "regular" courses in the "Roboscope," as well as the results are used for further development.

Keywords: visually impaired, blind, robotics courses, school labs, extracurricular robotics lab

1. Introduction

By introducing students to the fundamentals of robotics in an informal, playful setting, extracurricular school laboratories are an effective way to encourage interest in computer science or other technology-related topics. In working with LEGO Mindstorms, a set of soft- and hardware to build programmable robots, they get a chance to learn on a cognitive, emotional, and haptic level. Unfortunately, not every pupil is able to participate in courses like these due to a lack of accessibility. For example, Ludi states that “awareness of potential career paths and access to adequate preparation remain barriers to students who are visually impaired” [1]. For pupils who are visually impaired or blind, it is essentially impossible to fully participate in a programming process or in building a robot.

The Center for Learning and Knowledge Management, in conjunction with the Institute of Information Management in Mechanical Engineering of RWTH Aachen University and a group of experts, set out to develop a special and accessible course for the visually impaired and blind students. The experts consulted a group of psychologists, school and university teachers, and experts in the field of accessibility as well as in robotics. They took the original course design from an existing robotics course for high school students and transformed it into an accessible course design. The original course consists of theoretical input about building robots and programming as well as the subsequent practical phases, in which the students apply their knowledge on EV3 roboters. At the beginning of each course, the robotic equipment is explained and the problem that needs to be solved is presented. The students—in compliance with the supervisors—then analyze the problem and identify the necessary steps to be taken and in doing so, the desired outcomes of the experiment are met. The applied combination of both theoretical and practical factors has proven to facilitate an authentic learning environment and strong learning results [2]. However, developing a new and adequate course simply by applying technical adjustments is not sufficient. Therefore, all changes applied to the course went hand in hand with an adjustment of teaching and learning strategies.

When designing a programming course for pupils with disabilities, it is crucial to develop these strategies as well as a list of the required tools as a first step. From the gathered findings, the resulting new course design allows students who are visually impaired to participate in the same courses and benefit from the same experiences—such as programming and building a robot—as their fellow pupils. This paper will present an overview of types of visual impairment, different lab settings and an insight into the original course design. This will be followed by results from the expert design workshops in terms of technical and didactic adjustments to the course. Finally, the paper will conclude with the full development cycle of the courses at RWTH Aachen University from design to testing, implementation, and further development.

2. Visual impairment

Vision, as one of our five senses, enables us to learn about our environment. Being able to see not only helps us to orientate ourselves but also shapes our perception of the world and all it has to offer. Not everyone, however, possesses full vision. “Many people have some type of visual problem at some point in their lives” [3]. Some minor problems can occur, for instance: in seeing objects that are far away (near-sightedness) or that are extremely close or in very small print (far-sightedness). “These types of conditions are often easily treated with eyeglasses or contact lenses” [3].

According to the World Health Organization (WHO), apart from these minor eye problems, “285 million people are estimated to be visually impaired worldwide: 39 million are blind and 246 have low vision” [4]. Other key facts from the WHO about visual impairment state that around “90% of the world's visually impaired live in low-income settings,” “82% of people living with blindness are aged 50 and above” and that 80% of all visual impairment can be prevented or cured [4]. Many people worldwide are only visually impaired because they do not have access to reading aids or medical care in general; most people with visual impairment come from low-income or developing countries. “Globally, uncorrected refractive errors are the main cause of moderate and severe visual impairment; cataracts remain the leading cause of blindness in middle- and low-income countries” [4]. The risk of going blind is estimated to be 10 times higher in developing countries than in industrialized countries [5]. In comparison to persons with low vision, persons who suffer from blindness face additional challenges. These can manifest themselves in social challenges by the difficulty of participation in social activities and events, navigation and orientation in unfamiliar environments as well as difficulties in using technology such as computers and smartphones. Although many people with blindness use tools such as blind rods, screen readers, and other helpful measures, not everyone has the financial background or even enough self-esteem to counterbalance the previously mentioned disadvantages.

According to the National Eye Institute in the United States, “less familiar visual impairments include:

- **strabismus**, where the eyes look in different directions and do not focus simultaneously on a single point;
- **congenital cataracts**, where the lens of the eye is cloudy;
- **retinopathy of prematurity**, which may occur in premature babies when the light-sensitive retina has not developed sufficiently before birth;
- **retinitis pigmentosa**, a rare inherited disease that slowly destroys the retina (see **Figure 1**);
- **coloboma**, where a portion of the structure of the eye is missing;
- **optic nerve hypoplasia**, which is caused by underdeveloped fibers in the optic nerve and which affects depth perception, sensitivity to light, and acuity of vision; and
- **cortical visual impairment** (CVI), which is caused by damage to the part of the brain related to vision, not to the eyes themselves” [4].

In contrast, there are no reliable numbers of visually impaired children and teenagers in Germany. Nevertheless, visual impairment is a big issue and causes imbalances, particularly

Figure 1. Retinitis pigmentosa, http://www.rsb.org.au/retinitis-pigmentosa.

in education, higher education and career opportunities, especially in Science, Technology, Engineering and Mathematics (STEM) focused education. The robotics courses for students with visual impairment or blindness at RWTH Aachen therefore aim to overcome these inequalities.

3. Robotics laboratories

3.1. Student laboratories

The current technological developments being triggered by Industry 4.0—the combination of industrial production with modern means of communication—as well as digitalization in general pose major challenges for robotic education; hence, the demand for students from fields affiliated with science, technology, engineering, mathematics, and robotics in particular is steadily increasing. Due to concern related to this increasing demand for future engineers and the significance of qualitative scientific and technological education, universities and other seats of learning are focusing on secondary school students. Hence, since 1990, school labs have been an important component of German universities [6, 7].

Student laboratories are extracurricular educational institutions, which allow children, pupils, and students to experience science. New devices and technology can be used and tested for clear understanding and unconventional learning of modern research techniques. These laboratories often focus on natural science fields and foster insight from range of topics in a field of study. Extracurricular learning venues of universities, which are concerned with robotic science are often available exclusively for students and scientists. Furthermore, many schools do not have the resources to purchase devices and equipment in order to implement laboratories in class. The school laboratories of RWTH Aachen University, in contrast, focus on those pupils and younger students and enable them to discover distinct capabilities while learning by testing and playing.

3.2. Student laboratories in Germany

Around the globe, there are laboratories available that also work in equal or related fields of robotics, though very few are constantly available for secondary school students. This is largely due to the fact that equipment is often very expensive, difficult to acquire, and too conceptually complex for young persons to use. The special challenge of the RoboScope (http://www.robo-scope.de/home.html) of RWTH Aachen University is to give students—both sighted as well as visually impaired or blind—something that inspires them and makes them curious. By giving them an achievable, yet challenging task, it aims to foster a desire to work in a respective field of engineering. In the following, a few examples of robotics labs for students in different parts of Germany will be presented.

Other universities like the Technical University of Hamburg/Harburg cooperate with companies to encourage pupils to learn programming skills. For instance, they offer seven different courses based on interests and experiences at the university, which may consist of weekly meetings at the school or participation in a voluntary project team. In different modules, such as a trial course, pupils learn while using LEGO Mindstorms robots and basic graphic programming. In higher modules, they get introduced to programming languages like C and C++, soldering and building a LEGO-Mindstorm robot [8].

The concept of offering certain courses based on a student's interests and experiences is also common across other universities or institutions. The Technical University of Kaiserlautern provides three different classes, from basic programming to getting a robot to follow lines in a labyrinth up to a course in preparation for a robotics tournament. The main field of attention lies in sensor technology with the aid of tactile, light, and ultrasonic sensors [9].

The "TUMLab," the Technical University of Munich's lab situated in the German Museum, offers a similar course based on this technology. In five different modules, pupils get to know diverse sensors and how to apply them ingeniously. Herein, lies the main goal of getting a robot to find its way around autonomously [10].

The "Technikum29" in Kelkheim-Hornau in Germany offers a workshop for learning about and using sensors, branches, subprograms, busses, interrupts, and how to develop logical decisions and games using a Raspberry Pi and similar single-board computers. As a distinguishing factor from the robotics summer camp of the University of Darmstadt, which focuses on ages 10–14, the Technikum29 requires its participants to be at least 14 years old. At the robotics summer camp, younger pupils learn to communicate using Bluetooth technologies and to build their own robot with a LEGO Mindstorms packet. Older pupils get to discover and solve problems and tasks given from the instructors, who are computer science students at the University of Darmstadt. Both courses take place during 1 week of the summer holiday and have included children with disabilities since 2013 [11].

3.3. Student laboratories worldwide

In Switzerland, the ETH Zürich focuses on preschool children and offers a "Bee-Bot" kit that consists of a child-friendly bee-shaped robot. Teachers can rent six small robots, playing cards, and teaching accessories such as activity mats and charging stations for 2 weeks. The small robots are programmable with four buttons and can be moved over a map easily. Before renting those sets, teachers get a short workshop at ETH where they learn about basic robotic science.

Elementary schools can participate in a similar project. Teachers are trained by a research team from ETH, who also give advice and support while using the technology in the classroom. Topics of this project are the concept of computational thinking and the functionality of robots. Lessons are arranged as project-based learning, and pupils learn to program robots playfully.

A different project of the ETH is the "RoboMINT" in which children learn to build a robot. In a "Dancebot course," pupils learn to solder and program a dance-choreography for the robot they have built. A second course uses small lights attached to a robot and a camera with long time exposure to draw a picture. For the picture, the robot uses a coded paper to follow lines. The sets can be rented for free [12].

The DNA Learning Center (DNALC), which is promoted by the United States of America's Cold Spring Harbor Laboratory, a private, not-for-profit research and education institution at the forefront of molecular biology and genetics, offers class field trips and summer schools devoted entirely to public genetics education [13].

3.4. Student laboratories for disabled children

Besides RWTH Aachen University and the Technikum29, the Bayer Science & Education Foundation has provided Anna-Freud-School in Cologne with an accessible laboratory for pupils. Laboratory equipment and computerized workplaces were purchased with the budget of 22,000 Euros. These new features allow children with disabilities to work on projects independently and to identify and nurture talents early. In this way, the school is able to promote pupils who are physically disabled or have a chronic or psychosomatic illness. The Foundation supports projects, which are used to complement lessons in school and to draw interest in natural science and technology [14].

The Perkins School for the Blind in Massachusetts (USA) offers short courses in robotics for secondary school students (Grades 6–10), who can learn about the highly sought-after skills of mechanical and electrical engineering, computers, math, and science. Participants work with their peers and knowledgeable staff to build basic robots and program them to complete simple tasks. Inconveniently, though, this course is currently not offered on a regular basis.

Learning about robotics is an enjoyable and exciting way for students to increase knowledge in the areas of science, mathematics, and technology and provide students with an opportunity to gain first insights. Our extensive research has shown that around the globe, there are laboratories available that also work in equal or related fields of robotics, though very few are both constantly available for students and offering a chance at hands-on experience.

To foster an interest in STEM-fields, it is necessary to involve pupils in the process of programming a robot playfully. Technical universities in Germany and Switzerland already offer a broad range of courses for pupils to learn basic programming starting at a young age.

In recent years, reform efforts in science curriculum have stressed the integration of educational technology into teaching and learning purposes. Teachers and educators face the challenge and the chance to explore inventive ways in which new technologies can be utilized to improve accessibility to science for students with visual impairments. Integrating students with disabilities in student laboratories is an effort that not only encourages interest in STEM-fields but also shows these individuals opportunities for their future careers. Technological resources for people who are visually impaired, like Braille generating software, Braille printers, screen-reader software, and speech synthesizers, already exist.

Teachers, educators, and educational institutions need to realize the student-oriented benefits and put more effort into accommodating students with (visual) impairments in STEM education. An awareness, and furthermore, an understanding of the academic needs of students with (visual) impairments are essential in striving toward this goal. Unless many institutions and educators stress the need to integrate students with (visual) impairments in their scientific programs, there is still a long way to go. Fully accessible participation in science will be beneficial for all students and a rewarding experience for teachers.

4. Original course design: “Roborescue” and “Rattlesnake”

At RWTH Aachen University, high school students are given the chance to gain insight by using LEGO Mindstorms construction sets in a school laboratory and constructing and programming various robot models. They are using the graphical programming interface NXT-G to discover an easy introduction to programming, since it is suitable for nonprofessionals [15].

To prepare and motivate students for a future career in robotics, the course program allows students to try their hand at building, programming, and testing robots in a highly interactive and playful environment. In order to captivate students, the course allows them to create either a “rescue robot” [16] that can search for virtual victims in a simulated rescue mission or a “rattlesnake” that snaps shut when someone crosses its field of vision. The choice of the scenario is subject to the age of the students—lower grades create a rattlesnake, (which is easier to build and to program) while junior and senior classes go on a more complex rescue mission. The four main phases of the course are: the introduction, which gives basic information; the construction; the programming process; and the reflection or evaluation phase. To follow along a learning process, the underlying didactic course concept focuses on individual practical, experimental, and playful experiences [15]. In accordance with the feedback of the course participants, this course design was chosen to build up an extracurricular learning venue for students with visual impairment and blindness to give them first insights into robotics.

The educational laboratory is not located at the students’ respective schools; rather, it has been set up at RWTH Aachen University. This allows high school students to take a peek into the daily routine at university and is also meant to facilitate the decision-making process when it comes to choosing further steps after graduating from high school [17].

5. Enabling higher accessibility for visually impaired students

5.1. Expert design workshops

To facilitate the process of redesigning the robotics course in order to reach a higher level of accessibility for students with visual impairment as well as blindness, researchers from RWTH Aachen University invited a team of interdisciplinary experts to a series of workshops. The roadmap of the redesign was developed within these workshops. The main goal was defined as follows: to identify the key aspects of required adjustments.

During the workshops, the participants gradually developed a grid of these requirements. In a first step, they divided the course into its individual phases based on the established approach by Vieritz et al. [18]. They used the different phases of the course and analyzed the requirements and necessary adjustments for each individual part compared to those of the original course design. These phases consist of the introductory part, the construction phase, the programming phase and the phase for reflection. Combining their different experiences and testing single elements by simulating specific eye dysfunctions, the experts came to results in terms of requirements for each phase. These results are presented and discussed in the chapters below, which are divided into technical as well as didactic adjustments. At the end of chapter three, the developed grid gives a summarized overview of the results from the workshops.

5.2. Technical requirements

According to the results of the design workshops, the identified requirements especially include auxiliary means, which can be summed up as objects, software, and computer settings. There are a lot of different eye dysfunctions which call for support by varying objects, for example, magnifiers and common magnifying glasses. Other important objects for different phases of the course are cameras and reading devices, printed handouts for every phase, additional lighting for the building process, and sorting boxes for robot components.

In terms of software, screen readers such as JAWS or Dolphin, graphic programming using, for example, NXT-G [14] as well as textual programming using, for example, JBrick [19, 20] should be provided in the programming phase. Additionally, the computers and provided worktables should allow adjustments of graphic contrast on computer screens. Nevertheless, there is no "universal remedy" for increasing accessibility. In preparation of the course, the teaching staff needs to communicate with the participants to be prepared for any special requirements the students might have.

5.3. Didactic adjustments

Since not every measure taken is helpful for every sort of handicap and not all changes can be made at once, it is necessary to differentiate between the types of visual impairment. In the presented case, a fundamental distinction between different degrees of visual impairment up to sightlessness has been the essential groundwork for further research and course development. To reach full accessibility for the pupils, advancements and changes must be made gradually. This methodology has proven to be a very helpful approach in the process of designing the new course. Some degrees of visual impairment, for example, are even contrary to one another [1], so there is an increasing demand for different technical as well as didactic approaches in each course to reduce or extinguish existing barriers for all participating students.

As a first result and requirement, printed manuals with regard to font size should be provided within the first three phases: the introductory part, the construction, and the programming phase. This allows students with less severe visual impairment to be able to reread instructions at their individual pace.

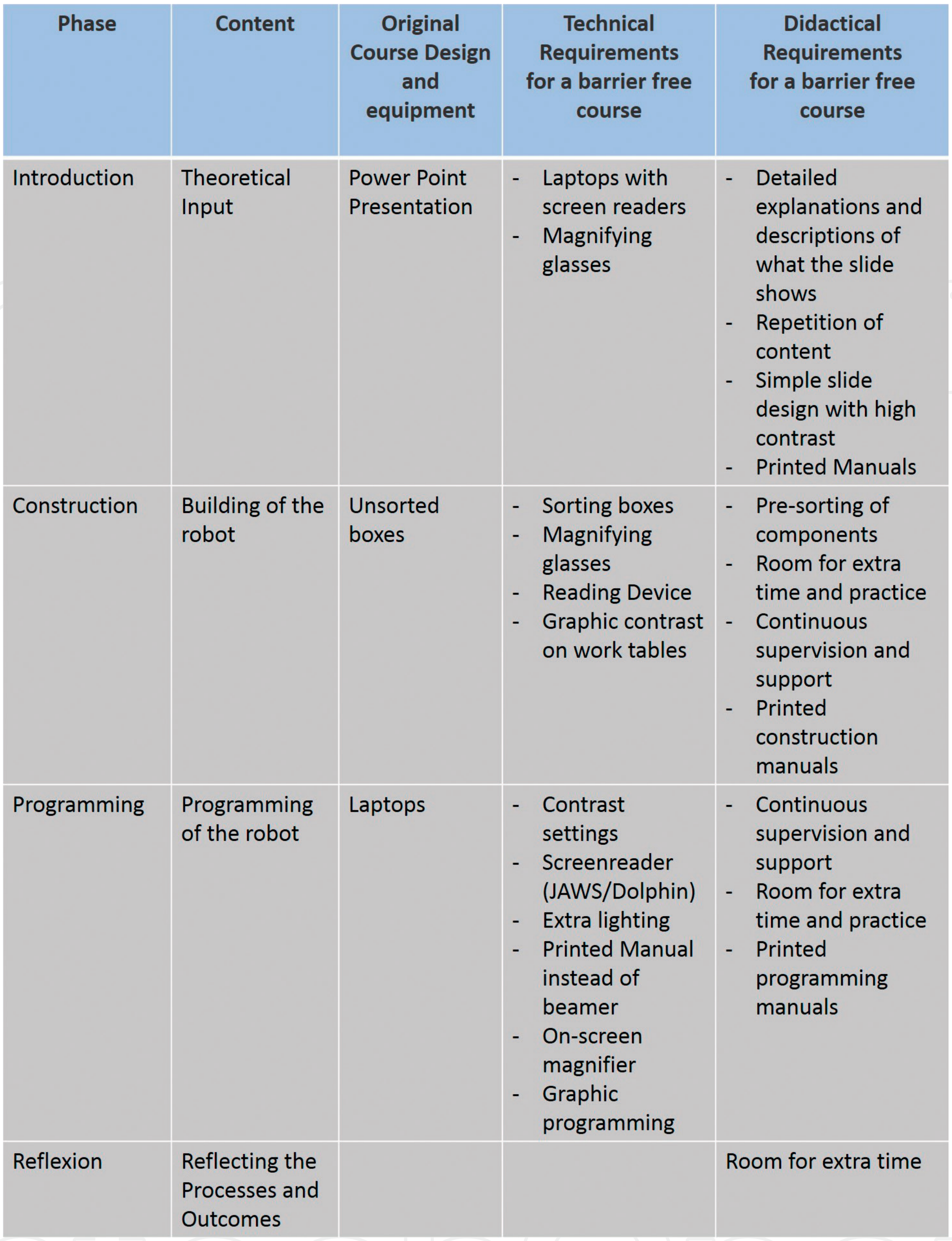
Time has also proven to be one major but often underestimated factor [21]. Students who have visual impairments need to be given more time to work on their tasks in terms of reading instructions, following presentations as well as building and programming. The more severe the impairment, the more time will be needed to finish a task. Kabátová et al. [21] found that test participants who were wearing glasses that simulate an eye dysfunction needed four times as long to finish the assigned task without the glasses. Therefore, they come to the subjective conclusion that the time necessary for a traditional course design should be multiplied by a factor of at least four. Further research and evaluations of the course will have to prove whether that factor needs to be adjusted.

Another important adjustment relates to the teacher-student ratio. It has to be increased compared to traditional course designs, which of course takes up additional time and resources on the teaching end. The required ratio can differ vastly, as students have very diverse needs in terms of support. As we also know from Silva et al., even students without handicap perceive and process experiences in different preferred ways [22]. As a result, the instructors need to provide a high level of flexibility regarding supervision and must provide support throughout the course. Lastly, the supervisors identified pre-sorting the sorting boxes used in the construction phase as a helpful measure in the building process, which no longer excludes students with visual impairments from the haptic and tangible experience of building a robot themselves. Every course is highly influenced by diverse aspects, and a thorough preparation and awareness of all possibilities and influences as well as a pre-analysis of the expected target group of each course proves to be the key to a successful course design. **Figure 2** sums up the results from the workshop in a grid.

5.4. Further development of the courses

After an implementation of the workshop and the guidelines, robotics courses were conducted in cooperation with the Berufsförderungswerk Soest and teenagers of the Johannes-Kepler-School in Laurensberg. An excursion into the mode of operation and programming of industrial robots was made for the course's participants.

The robotics courses for visually impaired teenagers were perceived very well and were therefore asked to be offered to young people who are blind. Since the robots could not be programmed with the LabView-based programming language NXT-G, a different setup was required for the course. The "Blindenstudienanstalt Marburg" was visited for preparation



Phase	Content	Original Course Design and equipment	Technical Requirements for a barrier free course	Didactical Requirements for a barrier free course
Introduction	Theoretical Input	Power Point Presentation	- Laptops with screen readers - Magnifying glasses	- Detailed explanations and descriptions of what the slide shows - Repetition of content - Simple slide design with high contrast - Printed Manuals
Construction	Building of the robot	Unsorted boxes	- Sorting boxes - Magnifying glasses - Reading Device - Graphic contrast on work tables	- Pre-sorting of components - Room for extra time and practice - Continuous supervision and support - Printed construction manuals
Programming	Programming of the robot	Laptops	- Contrast settings - Screenreader (JAWS/Dolphin) - Extra lighting - Printed Manual instead of beamer - On-screen magnifier - Graphic programming	- Continuous supervision and support - Room for extra time and practice - Printed programming manuals
Reflexion	Reflecting the Processes and Outcomes			Room for extra time

Figure 2. Results from the workshop: requirements for the new course design.

in June 2014. Since the sense of touch system is the most important part for people who are blind, the "burrowing" in Lego boxes and the "building" of the robots are the most important components of the course regarding blind-pedagogical aspects. On top, a spoken construction guide is provided to the students as an audio book. The written construction manual was examined by the teachers of the "Blindenstudienanstalt Marburg" and was then tested in the course. **Figures 3–6** show impressions of the prepared soft- and hardware as well as students in the course programming a robot.

In 2015, the robotics courses for students who are blind were implemented in cooperation with the Blindenstudienanstalt Marburg. The building instructions, which were previously unusably for people who are blind, were converted into a spoken building instruction. The

Figure 3. Prepared Lego Mindstorm system for students who are blind.

Figure 4. Secondary school student who is blind programming a robot.

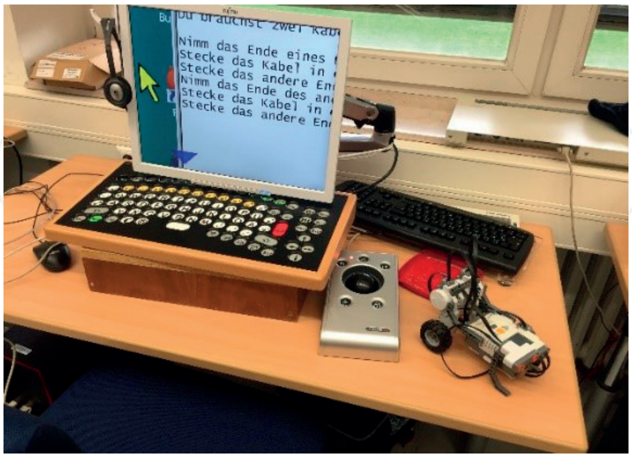


Figure 5. Prepared software for the robotics course for students who are visually impaired: textual instructions.

instructions themselves were then read out by a free screen-reading program NVDA via a voice output system to create real-world conditions. The program code was read out or put out via a Braille display reader, which allowed even the programming and integration

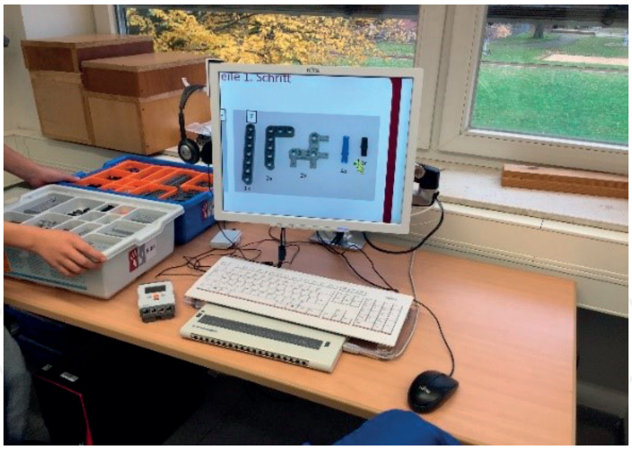


Figure 6. Prepared software for the robotics course for students who are visually impaired: illustrated instructions.

of sensors with conditions, loops, and queries. The robotics courses for pupils with visual impairments are frequently requested by different classes and are met with great enthusiasm. Usually, the course takes place between two and five times a year. Furthermore, teachers can request the developed materials, rent LEGO Mindstorm robots, and ask for advice on how to conduct the courses on their own.

6. Evaluations of the course

The evaluation of the courses took place verbally and was later put onto paper. With the help of statistical evaluation methods, feedback can be recorded quantitatively in order to validate the success of the measure or to adapt it. In addition to inquiries such as “How did you like the lecture/the programming/the difficulty of the tasks/the course schedule?” (6-degree scale from 1 = very good to 6 = not satisfying) or “How did you like the day?” (3-degree scale from 1 = too easy to 3 = too difficult), the questionnaire includes open questions that allow room for comments and suggestions for improvement.

The pupils (n = 8) mentioned, on a 6-degree scale, that the presentation was very exciting (Median = 1.25), that the programming had been very good (M = 1) and that they learned something (M = 1.13). Every pupil also said that they enjoyed the course and that he/she would like to visit the course again. Some of the students mentioned in the open questions section that they wanted a successor program, which will be developed as a consecutive step. Due to the small sample size, the statistical power of the results is reduced and statistical relevance of the quantitative data needs to be discussed. However, from a qualitative point of view with regard to the frequently given feedback, the analysis showed that the students’ enthusiasm, interest, and appreciation for the courses were high among both teachers and students.

7. Conclusion and outlook

To keep up the interest in STEM-fields, it is necessary to involve pupils in the process of programming playfully. Technical universities in Germany and Switzerland already offer a broad range of basic programming courses for pupils starting at young age. Additionally, to encourage applied computer science in school, some institutions offer robot kits and teaching materials. Integrating students with visual impairment or blindness in student laboratories is a chance to not only encourage interest in STEM-fields but also to show these individuals opportunities for the future. Science curriculum reform efforts have emphasized the integration of educational technology into teaching and learning purposes in the past years. Teachers and educators are asked to explore further ways in which new technologies could be utilized to improve access to science for students with visual impairments.

The paper has described the process of redesigning of a robotics course from an educational robotics laboratory to increase accessibility of the course for students with visual impairments. The evaluation of the workshop has informed a concept for the redesign, which has been implemented and is currently being tested in a second run with various groups of students with visual impairments. The developed grid of the workshop suggests that adjustments to the designated phases of the lecture can provide a higher level of accessibility. A first anecdotal but enthusiastic assessment from the students who participated leads to the assumption that the applied suggested changes were successful.

Nevertheless, a huge part of the adjustments requires a consideration for the unique needs and requirements that the specific dysfunctions of the target group bring about. At this point in the research, there is no catch-all solution to the challenge. The evaluation of the designed courses will allow for a thorough analysis, serve the pursuit of continuous improvement, and be the key to future research. Additionally, to broaden the range of accessibility, further research will have to focus on full accessibility not only for those students who are blind but also for those with other impairments, such as hearing and physical disabilities.

In conclusion, teacher, educators, and educational institutions should realize and promote the student-oriented benefits and devote additional effort toward accommodating students with (visual) impairments in STEM education. An awareness, and furthermore, an understanding of the academic needs of students with (visual) impairments are essential in striving toward this goal.

Though many institutions and educators stress the need to integrate students with (visual) impairments in their scientific programs, there is still room for improvement. Ensuring that full participation in science is possible for everyone will be beneficial for all students and a rewarding experience for teachers.

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Author details

Valerie Stehling[1,2,3]*, Lana Plumanns[1,2,3], Anja Richert[1,2,3], Frank Hees[1,2,3] and Sabina Jeschke[1,2,3]

*Address all correspondence to: valerie.stehling@ima-zlw-ifu.rwth-aachen.de

1 Institute of Information Management in Mechanical Engineering of RWTH Aachen University, Aachen, Germany

2 Center for Learning and Knowledge Management of RWTH Aachen University, Aachen, Germany

3 Associate Institute for Management Cybernetics, Aachen, Germany

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