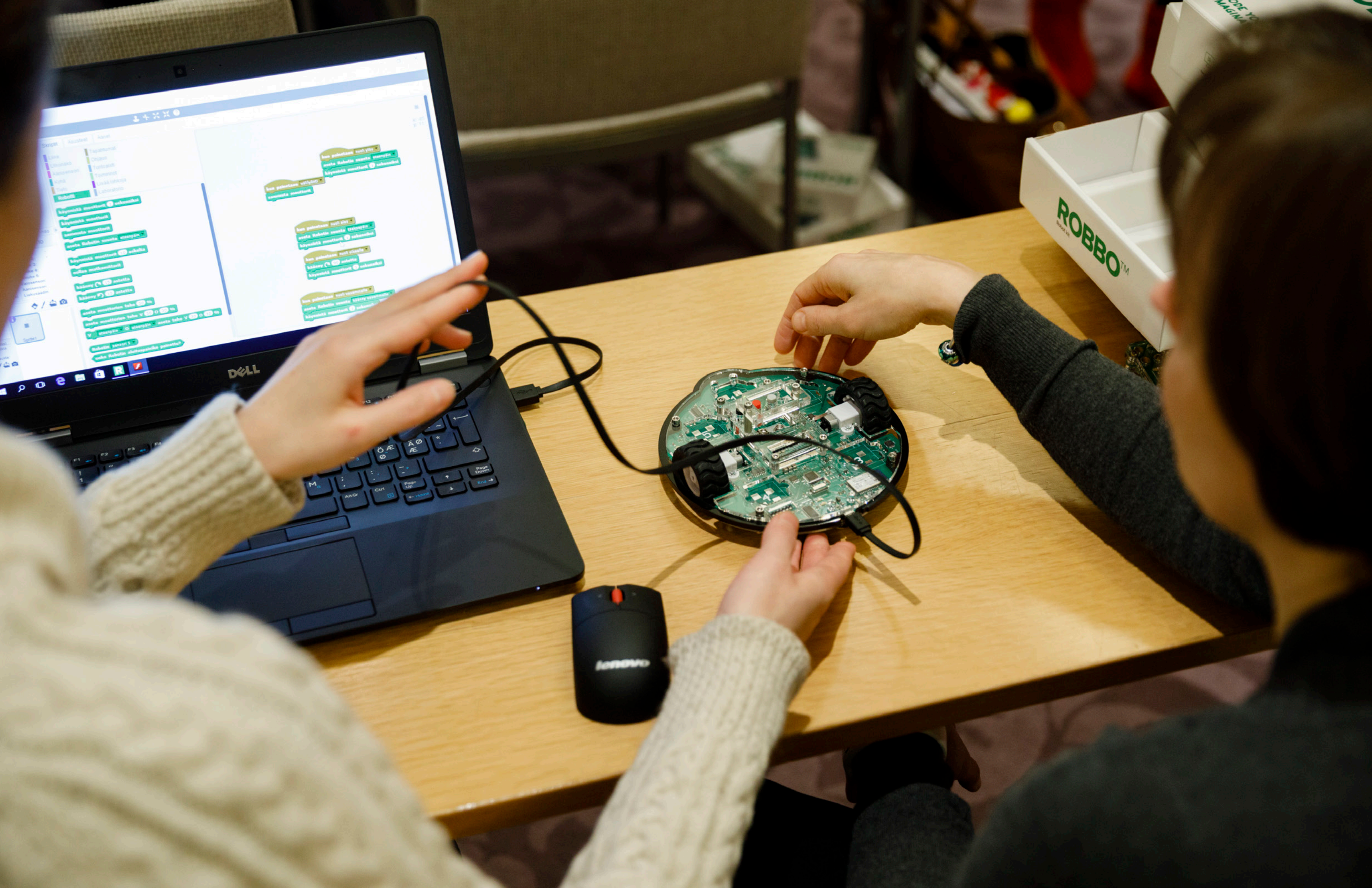

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Development of the ROBBO pedagogical material – Design Based Research Approach

Project report from Fall 2015 to Spring 2016

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Summary

The aim of this co-operative design-based research project between ROBBO and Innokas Network (Department of Teacher Education, University of Helsinki) was to develop a pedagogical guide for the ROBBO robotic platform. The goal was to produce material that supports both pupils' learning and teachers' instruction in programming and robotics. This material can also be used by parents and other interested persons.

Altogether, 174 pupils, age 9-16 years old, and nine teachers from Innokas Network participated in the project. After providing basic training for the teachers and installing the software, the participants worked together to determine how the use of ROBBO Robot kit and ROBBO Lab would be integrated into the design-based research (DBR) project and its two phases. After each phase, the outcomes were interpreted in the context of usability research.

During the first phase (Fall 2015), five teachers and 69 pupils learned the principles of the Robot kit and developed corresponding exercises. Teachers' email correspondence, meetings and blog posts, along with questionnaires completed by the pupils were used to track the development process and identify the pupils' learning stages of programming skills. Pupils' engagement in the programming and robotic exercises was also assessed. The first drafts of the pedagogical guide and quick guides for the Robot kit and Lab were produced based on these findings.

During the second phase (Spring 2016), the aim was to test, in practise, how the pedagogical guide worked in schools. In addition to pedagogical guide, the pupils' exercise cards were created. The exercise cards were designed to support pupil groups' or individual pupil's learning at their own pace. The most active teacher from first phase and the first author of this document created the exercise cards for the Robot kit based on the experiences and completed programming tasks from the first phase. For the Lab component, an Innokas Network teacher with extensive experience in Scratch created challenges based on the concept of developing a game controlled by Lab. The exercise cards were tested with three teachers and 105 pupils. They were also used in one in-service training session with 12 teachers.

There was an assessment of the technical and pedagogical aspects in both phases. The participants gave valuable feedback on the pedagogical guide's content, as well as on the development of the hardware and software. The users' feedback of the technical usability of the hardware and software in the first phase was essential for developing a pedagogically useful device. According to the findings from the data, in classes with 20 to 30 pupils, the exercise cards were practical and addressed learners' needs. In this DBR process, the pedagogical guide with the introduction to the ROBBO Scratch programming environment and Robot kit exercises were thoroughly tested with multiple user types. However, the time restriction did not allow for proper testing of the lab exercises.

Project Partners

This project was conducted in collaboration with Innokas Network, the Department of Teacher Education at the University of Helsinki and ROBBO. Innokas Network researches and develops methods for the use of robotics and information technology (IT) in the teaching and learning of twenty-first century skills in the classroom, shares best practices, and promotes the use of technology in education. Innokas Network resources include practicing classroom teachers who develop technology use in the classroom, as well as university researchers and professors. ROBBO robotic platforms are educational tools for learning the basics of technology, engineering and programming. ROBBO is built around Arduino microcontroller, and the kit includes one LED (flash light), one light sensor, one touch sensor, one proximity sensor and two line sensors. Sensor modules are magnetic-mount, allowing fast and easy reconfiguration and customization of the robot. The Scratch user interface gives a visual representation of the designed program, placing each command in a single colour block and highlighting them as the command is being executed. Advanced users can dive deeper into programming the Robot kit utilizing Arduino IDE.

The Innokas Network pedagogical and research knowledge, particularly that concerning innovation education, informed the robotic platform used and pedagogical materials developed in this collaborative project with ROBBO. The project team included five Innokas Network schools, the Innokas coordinator, the head of the Innokas Network, the head of the Department of Teacher Education at the University of Helsinki, ROBBO personnel and a marketing company. The material was developed in Innokas Network schools in a pedagogically meaningful way and as part of normal school work. The Innokas coordinator was primarily responsible for organizing this pilot project.

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Theoretical Background

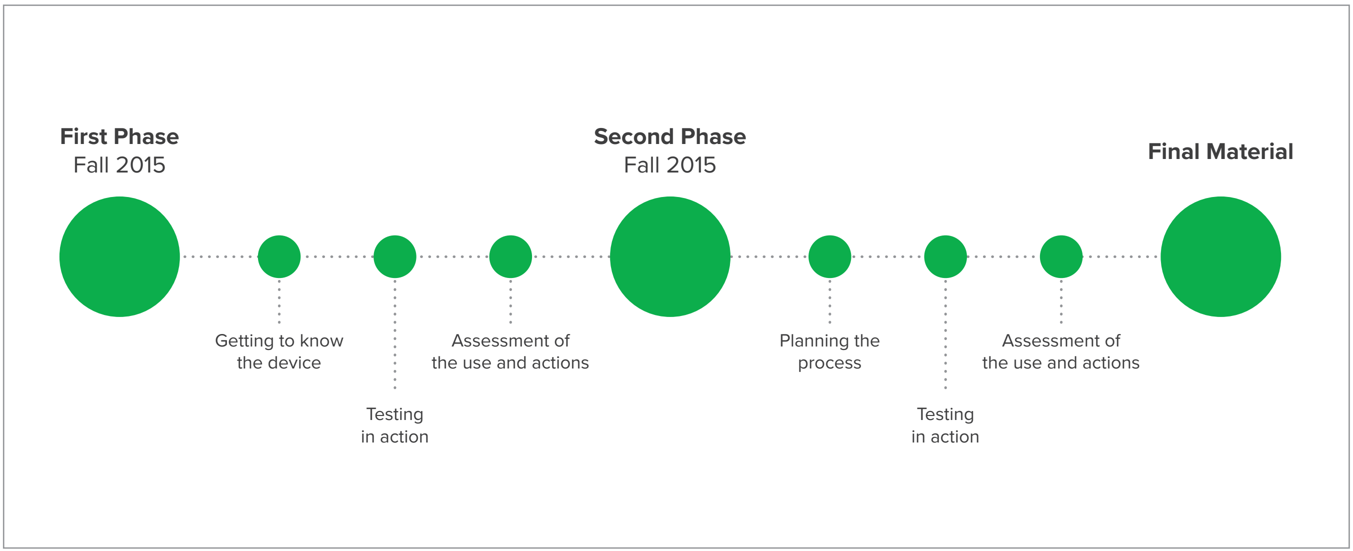

Figure 1. The phases of the DBR project

The project was conducted according to the principles of design-based research (DBR) (Sandoval, 2013) in order to acquire novel educational knowledge concerning pedagogical programming and robotics teaching material. DBR is a general framework for the design, development, implementation and evaluation of learning or educational activities within a pragmatic framework. DBR emphasizes three aspects: (a) a design process is essentially iterative, starting from the recognition of the need to practice change; (b) it generates a widely usable artefact, such as learning or teaching material, learning activities or a learning environment and (c) it provides educational knowledge for more intelligible practice (Design- Based Research Collective, 2003; Bell, Hoadley & Linn, 2004). DBR is comprised of a combination of theory development, prescriptions for successful design processes and prescriptions for successful design solutions (Reeves, 2006).

This DBR project consisted of two primary design phases, both of which encompassed smaller process phases (Figure 1). Both phases aimed to develop pedagogical learning material to support the development of programming skills, which can be beneficial for professionals, parents and other users, including children.

The outcomes of the DBR project were analysed and interpreted in the context of the adoption of innovation and usability research. The resulting ROBBO platform and pedagogical material can be categorised as educational innovations (Rogers, 2003). Rogers (2003) defines the adoption of innovation as the mental process that an individual completes from the point of first hearing about an innovation to final adoption. According to Fullan (2007), there are two types of factors that may affect adoption, the first of which refers to the properties of the innovation. In this case, the properties are the technical and pedagogical usability of the developed ROBBO platform and pedagogical material. However, the nature of this innovation is complex. For example, Watson (2001) argued that adoption requires change in teaching style, learning approaches and information access.

The second category emphasises local characteristics, such as the pedagogical orientation of the teachers, nature of collaboration and reflection between teachers, school management and leadership, teachers' beliefs about the usability of information and communications technology (ICT) tools, perceived lack of time or the need for additional time to experiment with ICT tools and the availability of technical and pedagogical support (Fullan, 2007). This category also considers external factors, such as funding, nature of training or staff development, as well as the nature of development projects in the use of ICT (Fullan 2007). These teacher characteristics should be considered when designing support mechanisms for teachers.

Furthermore, external factors also affect innovation adoption. National level curriculum and how it emphasises the use of ICT tools in education, as well as how this emphasis has been realised in learning materials, such as textbooks and laboratory manuals, also influence innovation adoption (Osborne & Hennessy, 2003). Therefore, the development and use of the ROBBO platform and pedagogical material should be planned and developed based on the curriculum and integrated into, not added onto, teaching and learning (McFarlane & Sakellariou, 2002).

Perceived usefulness of the ROBBO platform and pedagogical material describes whether it could be used for reaching the wanted goals. Based on the specified needs and goals, usefulness could be divided into the sub-attributes of utility and usability. Nielsen (1993) describes utility as the amount of provided features that are needed to reach the required goals, while usability is the user's ability to use these features (i.e., a measure of the features' quality). Therefore, utility answers the quantitative question of what the user can do, and usability addresses the qualitative question of how the user can do it. Here, we focus on usability and how features are used.

While planning the pedagogical material, several decisions were made concerning teaching approaches, learning materials and use of the ROBBO platform. Consequently, it is possible to use different dimensions of the platform's usability as selection criteria and to develop a planning frame in technology education. Usability of the platform indicates to what extent pupils can employ it in order to achieve a goal (e.g., the goals the curriculum and designers of the platform set for the use of the kit). In human-computer interaction and computer science, usability usually refers to the elegance and clarity with which the interaction with a computer program or a web site is designed (Nielsen, 1993). Nielsen has approached the concept of usability from the perspective of adoption and acceptability of an artefact. Thus, the usability of an artefact could be defined through five quality components: (a) *learnability* (i.e., how easy it is for users to use a new artefact), (b) *efficiency* (i.e., how quickly a user can perform tasks or organize learning activities once they have learned to use the artefact), (c) *memorability* (i.e., how easily a user could re-establish proficiency when returning to use the artefact), (d) *error-free* (i.e., how few errors users make when using the artefact) and (e) *satisfaction* (i.e., how pleasant it is to use the artefact or how easy it is to change elements/avoid monotony or modify the artefact individually).

Factors related to these components include how an ICT application or an ICT tool is convenient, practical and usable for a user or a learner; these factors are referred to as technical usability components (Buzzetto-More, 2007; Nielsen, 2000). However, there is variation in what is considered to be technical usability. For example, Nokelainen (2005) names accessibility, learnability and memorability, user control, help, graphical layout, reliability, consistency, efficiency, memory load and errors as technical usability components. When a user starts to use an ICT application, the adoption is easier if the application is similar to other applications and the designed based on a metaphor, like working table (Nokelainen, 2005).

Consequently, technical usability is a quality attribute concerning how easy it is for a user to accept or to start using the artefact and reach the usage aims. From the perspective of teaching and learning, it is also appropriate to evaluate the pedagogical usability in addition to the technical usability (Squires & Preece, 1996; Tergan, 1998). Squires and Preece (1999) propose the idea of usability heuristics, which take into account a socio-constructivist learning perspective in order to integrate technical usability and learning issues. Hadjerrouit (2010) relates the concept of pedagogical usability to learning utility. Nokelainen (2005) approaches pedagogical usability through theoretically analysing meaningful learning and then validating the developed model through Bayesian dependency modelling and reliability analysis. Consequently, the pedagogical usability of an ICT tool could be approached by analysing the kind of learning and motivation development that could be created through the use of the ICT tool. Therefore, the usability of an ICT tool should be analysed based on the technical and pedagogical aspects of usability. In summary, the usability of an ICT tool addresses how easy and engaging it is reach the aims, which are determined by the activity where the tool, in this case the ROBBO platform and pedagogical material, is used.

First phase – Fall 2015

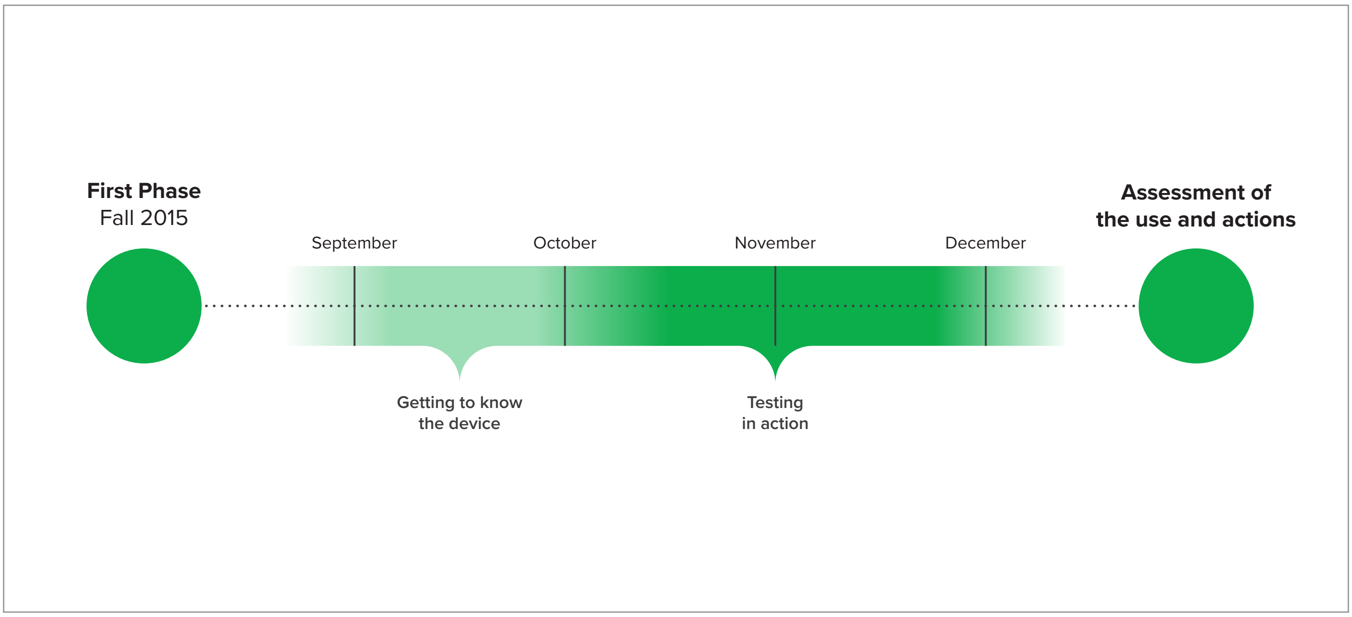

Figure 2. The first phase of DBR project

In the first phase (Figure 2) the main goal was to learn and become familiar with the ROBBO platform and test the product in schools with pupils and teachers. The aim was to produce the draft of the pedagogical guide based on the pilot schools' experiences.

School	Profession details	Experience
Primary School 6th grade (age 12-13 years)	Teacher 1 (primary school teacher)	Long robotics and programming experience with pupils and in- service training for teachers
Comprehensive School 6th Grade (age 12-13 years) 8th Grade (age 14-15 years) 9th Grade (age 15-16)	Teacher 2 (primary school teacher)	Brief robotics experience with pupils and in-service training for teachers
	Teacher 3 (subject teacher in secondary school)	Long technology and robotics experience with pupils and in- service training for teachers
Primary School 5th and 6th Grade (age 11- 13 years)	Teacher 4 (primary school teacher)	Long experience with ICT education with pupils and in-service training for teachers; almost none with programming and robotics
Primary School 4th Grade (age 10-11 years)	Teacher 5 (primary school teacher)	Long experience with technology education; brief experience with programming and robotics

Table 1. The participating schools, classes, and teachers

Participants and Data Gathering

During the first phase (Fall 2015) there were five teachers from four different schools from Innokas Network. The teachers were chosen based on their dissimilar experience with ICT and technology education, as well as programming and robotics skills (Table 1). All teachers had good technological skills, which was valuable in this kind of pilot and development project, as there was the possibility of difficulties with hardware or software. In addition, teachers had previous experience with running in-service teacher training, which allowed them to have some perspective regarding what inexperienced teachers would need when starting to teach programming and robotics in their schools. This experience and perspective was essential for determining the structure of pedagogical guide.

Altogether, five teachers and 69 pupils learned the principles of the Robot kit and developed corresponding exercises. Teachers' meetings, emails and blog posts, as well as questionnaires for pupils, were used to monitor the teaching and learning situations and material development process and to identify the learning stages of programming skills. Pupils' engagement in the programming and robotic exercises was also monitored. The pedagogical guide and quick guides for Robot Kit and Lab were produced based on the findings from these data. Teachers were interviewed after the project to help provide deeper into their experiences.

Getting to Know the Devices

At the beginning of the first design phase (September 2015), teachers participated in training, where they learned how to download the ROBBO software, do basic programming with RobboScratch and use it with the robot. They each received one Robot kit (Figure 3) and one Lab (Figure 4) for their own learning. At this meeting, teachers learned how to program the robot to move with arrow keys and independently without steering with keyboard. They also explored how the sensors work and brainstormed how to teach pupils robotics.

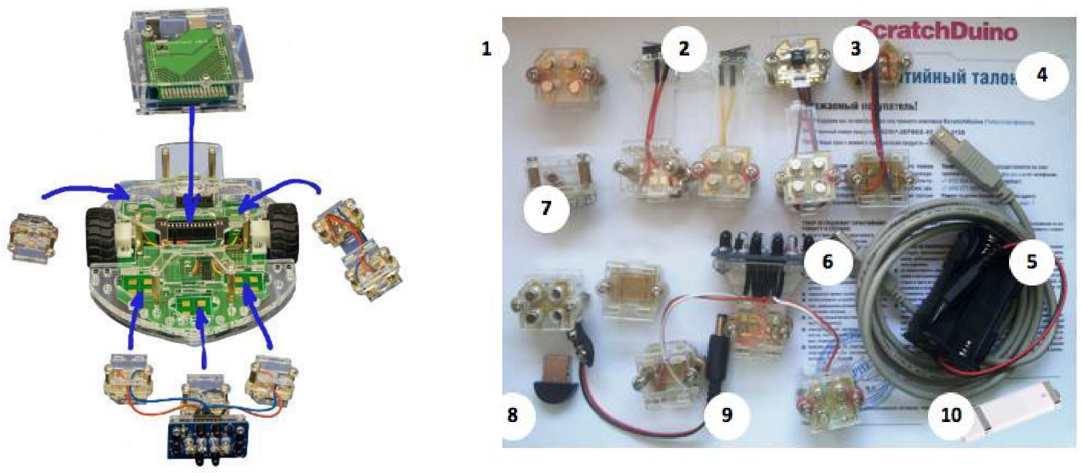

Figure 3. Robot kit and the accessories (1. light sensors, 2. touch sensors, 3. light reflection sensors, 4. cable, 5. battery case, 6. infra-red sensor, 7. empty sensor modules, 8. Bluetooth adapter, 9. battery connector, 10. USB stick)

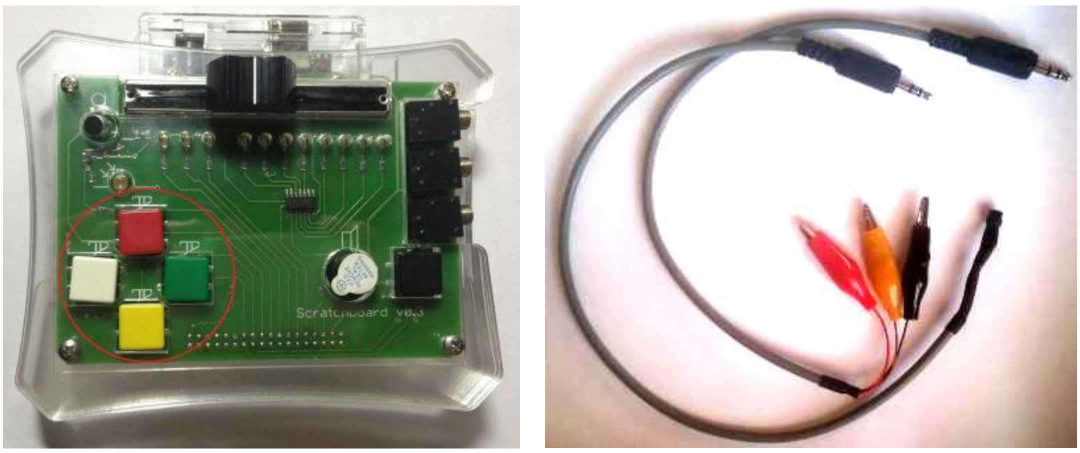

Figure 4. Lab kit with crocodile wire and temperature sensor

Within 2-3 weeks, 10 Robot kits for each class were delivered to the schools. The ROBBO personnel helped teachers download the software to their schools' computers and made sure that the Robot kits worked properly. This required an administrative user or such operating licenses in every school. In Teacher 5's school there were major problems with downloading the software, and they were not able to download the software at all. The school's technical support was poorly available, and after several attempts to co-operate the teacher decided to default her class' participation in the project (November 2015). In the her interview, it became evident in this stage, strong support is needed, even if the teacher has good technological skills:

"*In the start-up phase really clear instructions and videos are needed. It is important that the installation is easy and you know where to put which cable or how to settle the switch.*" (Teacher 4)

In October 2015, the teachers participated in the second training, which focused on programming with Arduino IDE and product development with ROBBO personnel. At the end of the session, teachers had a short introduction to how to use Lab. They also received ten Labs for each class. The main focus was intended to be training with Arduino IDE and Lab, but the teachers and ROBBO personnel both desired a discussion of product development. In order to meet everyone's needs, the content of the training was changed. The Robot kit's testing was still under process in the schools, and the teachers felt that they needed more depth knowledge of the kit. Thus, we decided to focus on using Arduino IDE programming environment with Robot Kit and do a brief review of Lab. On the other hand, the ROBBO's personnel wanted to hear teachers' experiences with the device in order to make obligatory alterations for it. The company's interest was to create an appealing package and product name for both Robot kit and Lab. In that session, the product name and visual appearance was decided. In a beneficial DBR process, it is essential to listen every stakeholder's view and modify the process according to their needs.

Testing in Action

The Robot kit testing in action began with the same structure that was used in the first training. After learning basic programming skills with ROBBO Scratch and using arrow steering, the teachers learned how to make longer programs. Using these programs, the robot performed programs independently without keyboard steering. During Fall 2016, all teachers proceeded in a different phase and using different teaching methods.

Teacher 2 used the devices in only a few lessons. The pupils learned the basic skills and arrow steering. The pupils in **Teacher 1**'s class had a lot of previous experience with programming and robotics. They had worked with robots (Lego EV3) and programmed with block-based visual languages since the third grade. Scratch was also familiar to them. This experienced teacher first showed the pupils the model of the desired performance. Then, he differentiated the lesson according to the pupils' needs by giving them easier or more challenging tasks.

"*I have a principle that first they learn a skill, and the more they have skills the more open and demanding the task can be ... At first when the skills are very low, the tasks cannot be very demanding.*" (Teacher 1)

The pupils quickly learned how the device operated, how to program it and how to use sensors. Their previous experience with robotics helped them substantially with learning, and they proceeded to complete two lessons (each 90 minutes) about sensors. According to the questionnaire in the first lesson the pupils were interested, had the skills to complete the lesson and enjoyed working with the robots. On the other hand, the teacher felt that after their initial enthusiasm, the pupils were not as motivated.

"*My pupils had a lot of know-how, so there was no need to prolong it further. The fact that the robot was attached to the computer by cable, pupils felt it and it annoyed me too, that you have to run around the class with a laptop. It restricted our work.*" (Teacher 1).

He thought that he should have had more time prior to the lessons to study the devices' full potential himself. Then, he would have had more knowledge to give pupils advanced tasks. He also felt that the product should be developed further, and at that time, it had many deficiencies. Even though the teacher experienced pupils' lack of enthusiasm, according to the questionnaire, the pupils were still highly interested in working with the device.

Teacher 3 worked in a secondary school with eighth and ninth graders in optional courses. The eighth graders had a course in electronics, and the ninth graders had a course in technical work. Both classes had programmed before. In the lessons, Teacher 3 gave open tasks to the pupils, who started to solve them. In Teacher 3's class, the pupils and teacher explored how the robot worked together. There were not teacher-guided lessons, since the environment was also new to the teacher. They learned by testing different codes, from moving the motors to receiving information from the sensors. They also arranged competitions in which they used their new skills. Teacher 3 felt that it was the best way for secondary pupils to learn.

In the technical crafts course with the ninth graders, the pupils quickly proceeded from basic use to the sensors. The ROBBO Scratch software was easy to learn and use, so in the second lesson, they held competitions with line follower robots. The teacher felt that the pupils were motivated for two lessons (each 90 minutes), and that this was enough for pupils this age:

"Scratch programming environment is more for primary pupils. It was good to see how open minded the ninth grades were with this. It didn't feel too childish to them, the programming environment I mean. The majority of them I mean. Of course there were also those who just laughed through whole thing." (Teacher 3)

The responses from the pupils' questionnaires demonstrate similar findings. In the first lesson, they felt that the lesson was fairly interesting, and they either enjoyed working with it or had a neutral opinion of it. However, the attitudes regarding the second lesson decreased in neutral and positive claims (Figure 5).

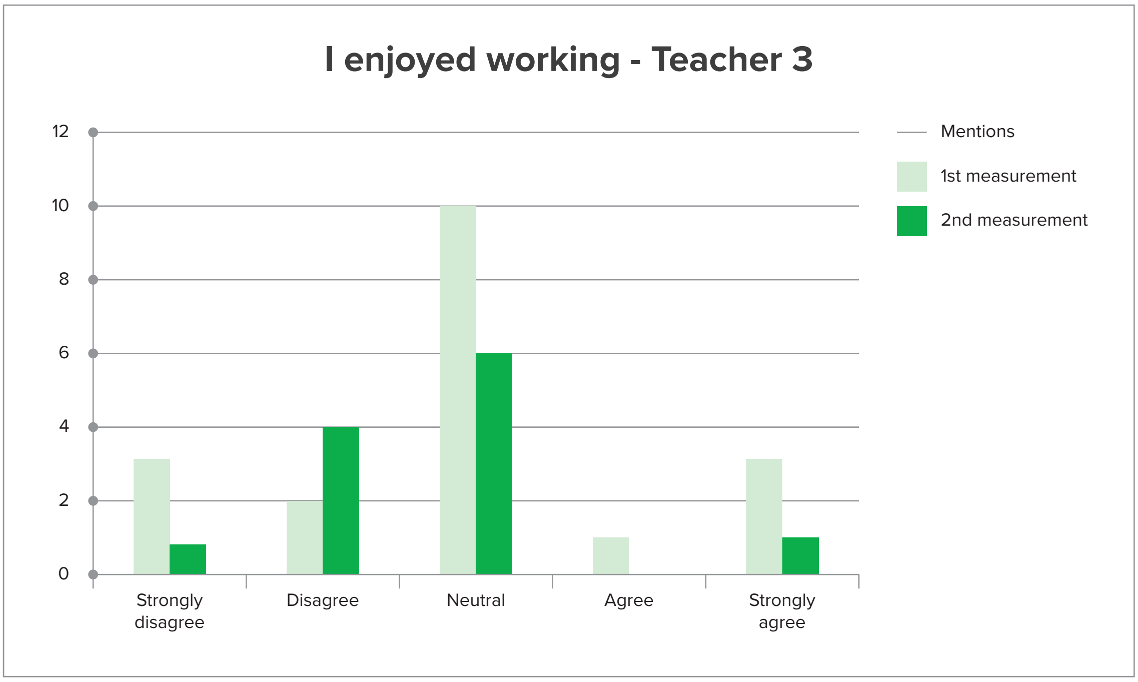

Figure 5. Teacher 3's classes enjoyment in both measuring times

In the electronics course with eighth graders, the class started the programming with ROBBO Scratch, but they quickly switched to the Arduino IDE, based on the pupils' desires. They searched for learning materials on the Internet, and in the first lesson they succeeded in moving the other motor of the robot.

"*The robot was spinning around in circles, and the joy of success were truly great!*" (Teacher 3)

In the second lesson, they proceeded to move the robot forward, to stop the robot and read a sensor. The teacher felt that the ROBBO was a good tool for getting to know the Arduino IDE platform.

"*The motivated pupils were really excited about programming and the fact that even with such little practice they learned the basic skills of C programming language and made robot move … I feel that programming this robot is better than working directly with Arduino hardware at first. You can get easier in to the programming environment with it. After that it is easier to start to fabricate something that have more functions.*" (Teacher 3)

Teacher 4, who had only a brief experience with programming and robotics, taught pupils the basic skills. After that, she allowed pupils to independently try different commands and sensors. Teacher 4 used the robots as a differentiation tool. The robots were available for pupils when they wanted to use them. Pupils who were most interested in the robots and had good skills to use them used the robots weekly. The teacher felt that one pupil who had difficulties in learning benefitted from robots.

"*The thing that he saw some real thing moving compared to movement on the screen was really important to him. It could happen in the middle of math lesson that he went to program the robot for ten minutes and then came back to continue with math exercises … It (the robot) became part of our working. We have that kind of ways, which allows you to prosper at school. Ways that allows you to take breaks and then continue working.*" (Teacher 4)

In Teacher 4's class most of the pupils were interested in the robot for a short period. They used it as part of their weekly tasks. The teacher felt that she did not have enough skills with the robot at that time to guide and engage these pupils more.

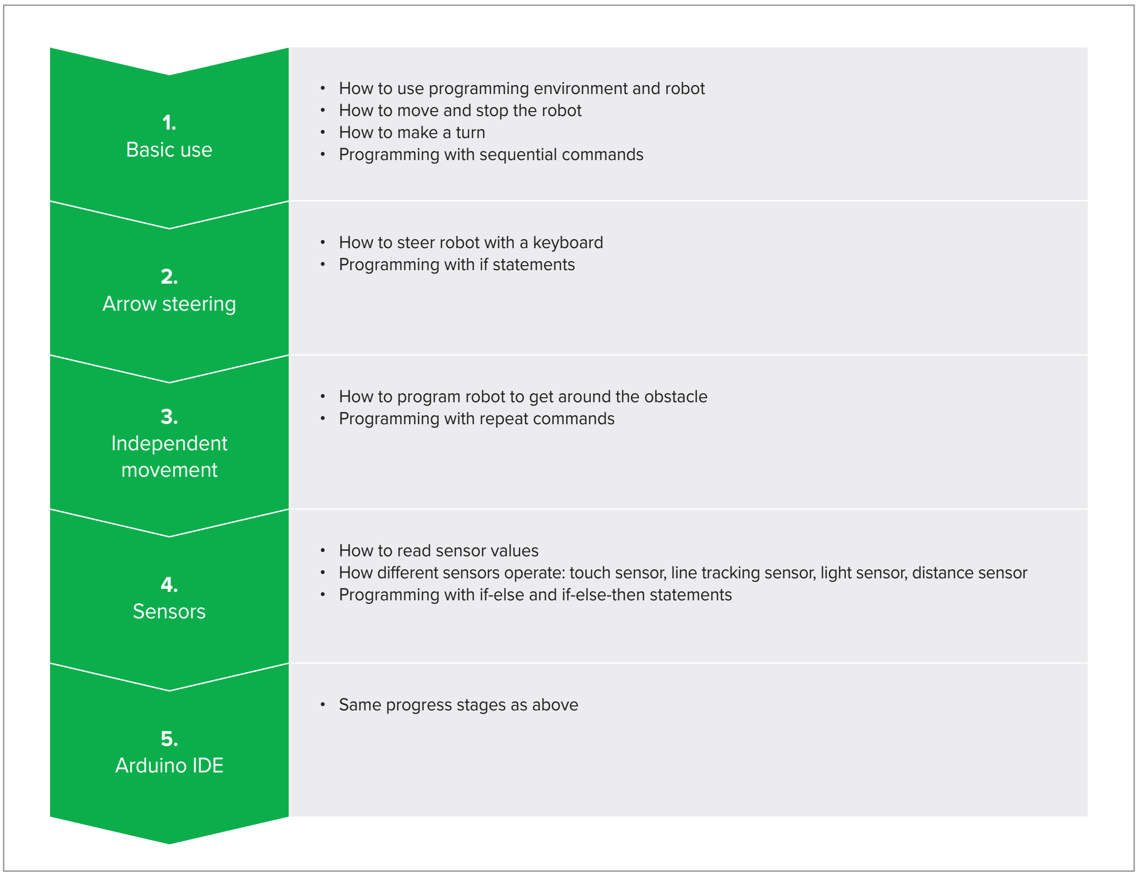

Figure 6. Programming path with the Robot Kit

Assessment of the Use and Actions

During the first phase, the participants tested the ROBBO platform and, primarily, the Robot kit in school. The teachers evaluated the device and made lesson plans and created new exercises for it. The pupils' experiences and opinions were determined using questionnaires. With this data, both kits were assessed separately, with the aim of creating pedagogically practical content for the pedagogical guide. In addition, the data were interpreted through both technical and pedagogical usability.

The Robot Kit

Programming Path

Based on the collaborative DBR process and analysed data, we suggest the following path for learning the basics of programming with ROBBO Scratch or Arduino IDE and the Robot kit (Figure 6). Depending on the pupils' grade level and previous experiences, how to use the time used for learning programming varies.

The classes begin by teaching the basics of the programming environment and the simplest commands for use with robot. Then, they proceed to arrow steering, where the pupils learn to use if statements.

Third, pupils learn to program the robot to move independently and use repeat commands. Finally, they start to use sensors. Pupils learned how different sensors operate, how to read their values and program with if-else and if-else-then statements. The secondary pupils are also able to proceed to the next programming language, Arduino IDE, where they use the same learning path that they used with ROBBO Scratch.

Learning and the Engagement of the Pupils

The pupils completed two questionnaires during the process. The first measurement was completed during the first lesson, and the second one was completed at the end of the project. In the questionnaires, the pupils answered yes/no questions about ways of working, and reflected their feelings in responses to items about

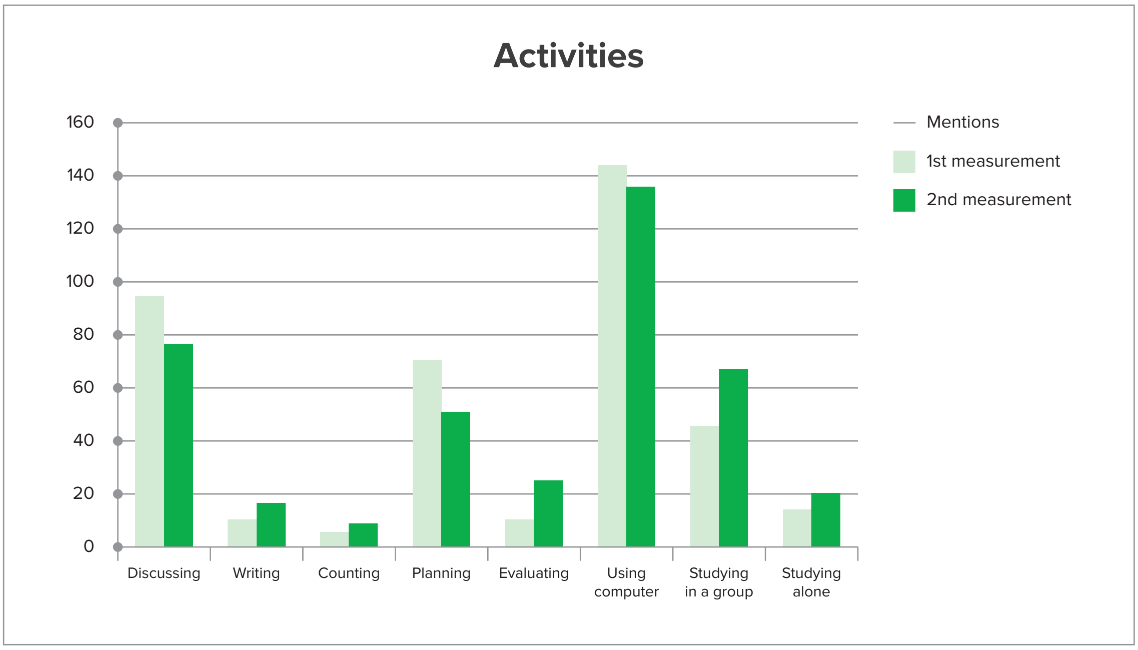

Figure 7. Pupils' activities when working with ROBBO Robot kit

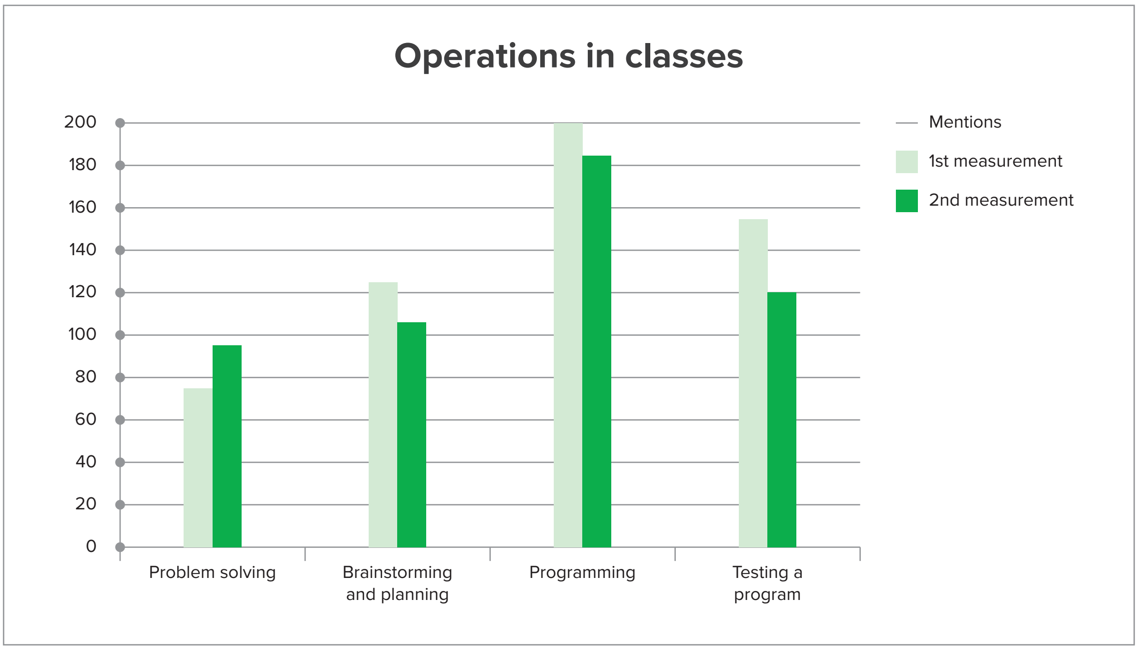

Figure 8. Pupils' operations when working with ROBBO Robot kit

interest, self-efficacy and enjoyment. These items were supplemented with open-ended questions. The questionnaire provided valuable information about pupils' learning with a robot. The aim was to find what pupils felt that they learned and what operations they used when they were doing programming tasks. Figures 7 and 8 illustrate pupils' activities and operations when working with the ROBBO Robot kit. Pupils feel that they mostly used the computer, discussed and studied in the group when working with the robot. In the beginning of programming practice they felt that they purely used the computer for programming and testing the programs. However, when activities became more difficult, the pupils started to evaluate, write and count more.

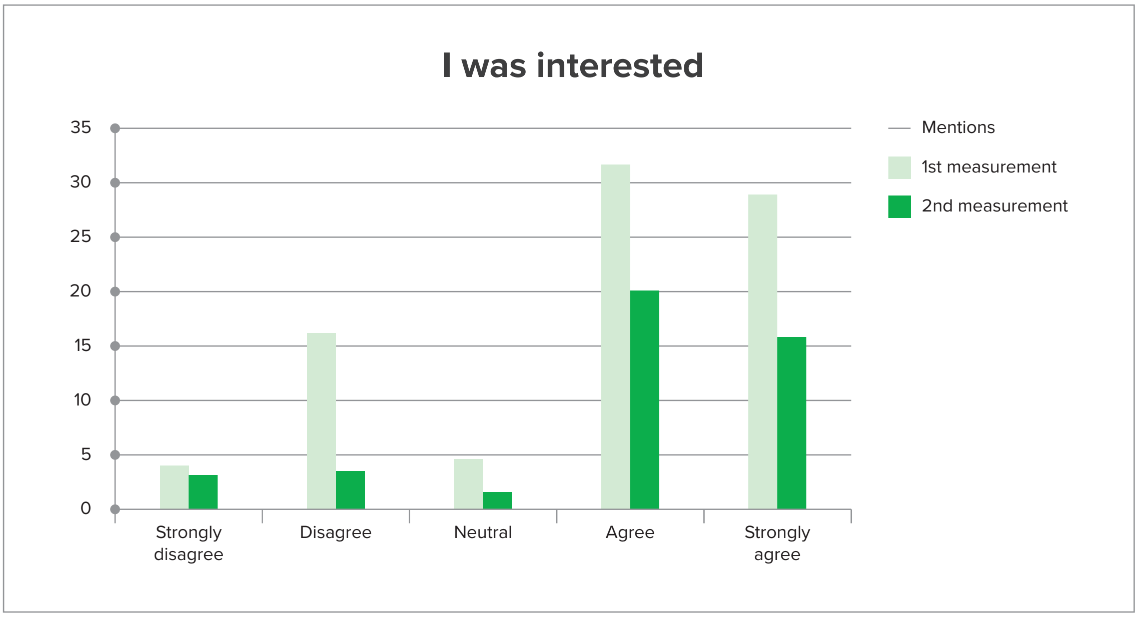

Figure 9. Pupils' opinions of how interested they were when working with ROBBO Robot kit

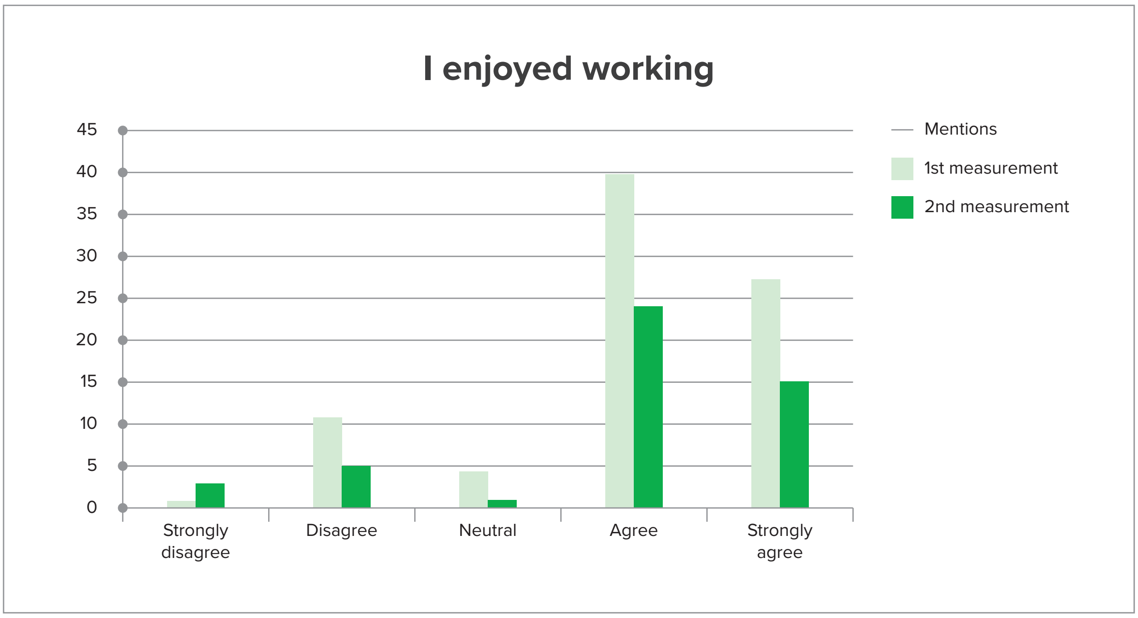

Figure 10. Pupils' opinions of enjoyment when working with ROBBO Robot kit

Their problem-solving tasks seemed to increase as well, which is presumable when transferring from teacher guided basic practices to open-ended problem-solving tasks.

During this process, we noticed that when working with ROBBO Robot kit, pupils were not only learning computational, programming, robotics and science concepts, but also twenty- first century competences.

While pupils engage in programming tasks, they generate and evaluate ideas related to the code. This develops critical and creative thinking and cultivates skill building. Programming, constructing a robot, and debugging a code are activities similar to inquiry and problem solving, and, consequently, develop inquiry and problem-solving skills. Finally, programming and building a robot helps to develop the skills needed for acting in the world in both the global and local contexts.

Ohjelmoinnin eteneminen ROBBO -robotilla

Aihe	Tavoitteet	Ohjelmointikäskyt	Komennot	ScratchDuino komennot
Näppäinohjaus Harjoitukset 2-4	• Ohjelman rakentamisen periaatteet • Robotin saaminen liikkeelle • Yksinkertainen lineaarinen käskyketju	• Ohjelman aloitus ja lopetus • Moottorin toiminta: ○ suunnat eteen ja taakse ○ kääntyminen • aika	kun klikataan kun painetaan välilyönti odota 1 sekuntia pysäytä kaikki	moottori päälle moottori pois päältä moottorin suunta tähän suuntaan laita motor päälle 1 sekunniksi
"itsenäinen" ROBBO-robotti Harjoitukset 5-6	• Lineaarisesta käskyketjusta toistorakenteeseen	• Moottorin toiminta • Toistorakenne ○ TOISTA x- kertaa ○ TOISTA ikuisesti	toista 10 kertaa ikuisesti	
Kosketussensori Harjoitus 7	• Toistorakenteen vahvistaminen • kosketussensoriin tutustuminen • Sensoreiden toimintaperiaatteeseen tutustuminen	• Odota kunnes • Toistorakenne ○ TOISTA kunnes • Aikamääreet ○ Pienempi kuin ○ Yhtä suuri kuin ○ Suurempi kuin	odota kunnes < = >	Analoginer Robotti 0
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Valoheijastuksen sensori	• Ehtolauseen käyttäminen • Väri- / valosensorin käyttäminen			
valosensori	• Valosensorin käyttäminen			

Figure 11. Programming process with Robot kit in the pedagogical guide (Content, goals, programming commands, Scratch commands and ROBBO Scratch commands)

Therefore, working with ROBBO Robot kit supports pupils' learning of twenty-first century competencies (see 21st century competences definition in Binkley et al., 2012).

All of the participating teachers noted that pupils were motivated to work with the robots. Figures 9 and 10 show that most of the pupils were interested in what they were doing. They also enjoyed working with the Robot kit. There were fewer responses in the second measurement, but the trends were similar. All of the pilot classes' figures had resemblances, and the differences were minor. Only Teacher 3's class with secondary pupils at the second measurement was not so enjoyable (Figure 5).

The Lab

ROBBO Lab was used in the secondary teacher's (Teacher 3) class. They used it to measure temperature. The lack of Lab's use might have been due to teacher's limited time to train with the device. During the interviews, it become clear that in-service teachers do not have enough time to learn new things by themselves.
The second organized training time was meant to be for Lab, but as mentioned earlier, the plan was changed based on the needs of the teachers and ROBBO company's personnel.

Conclusions After the First Phase

The first phase of the project clarified that the pedagogical guide should be designed to address every kind of user and different abilities and knowledge levels. Following Nielsen's (1993) quality components, the need for gradually progressing material is obvious due to different user levels. The beginners need simple instructions on how to get started and how to proceed with pupils. The beginners benefit from clear and structured material that is pupil activated and instructs pupils to learn independently. Further, the advanced users need new sights. In addition to these sights, the exercises should be rousing and motivational to pupils.
According to the collected feedback and reflections during collaborative meetings, especially feedback related to acquired information from the device and programming environment, we decided together with ROBBO's personnel to make quick guides that made it easy to start using both Robot kit and Lab The quick guides contained basic information about the device, software installation instructions and initial programming exercises. In order to provide pedagogically usable material, and in response to the need for pedagogical guidance at the beginning, as well as the ability to differentiate programming tasks easily, we decided to produce a pedagogical guide with exercise cards. The idea of the cards was established in conversations during the training sessions when participants were brainstorming the form of the material. The aim of these self-learning materials was to support pupils and adults with different interests and skills. In contrast, the experienced teachers do not need a thorough pedagogical guide, but they would benefit from the material (i.e., exercise cards), which gives new kind of insights and presents new kinds of tasks. These insights should be applied with both the Robot kit and Lab. At the end of the first phase, we created the first draft of the pedagogical guide. It contained background information of educational perspective of the guide and exercises that the pilot teachers and classes used and invented during the fall (Figure 11).

Second phase – Spring 2016

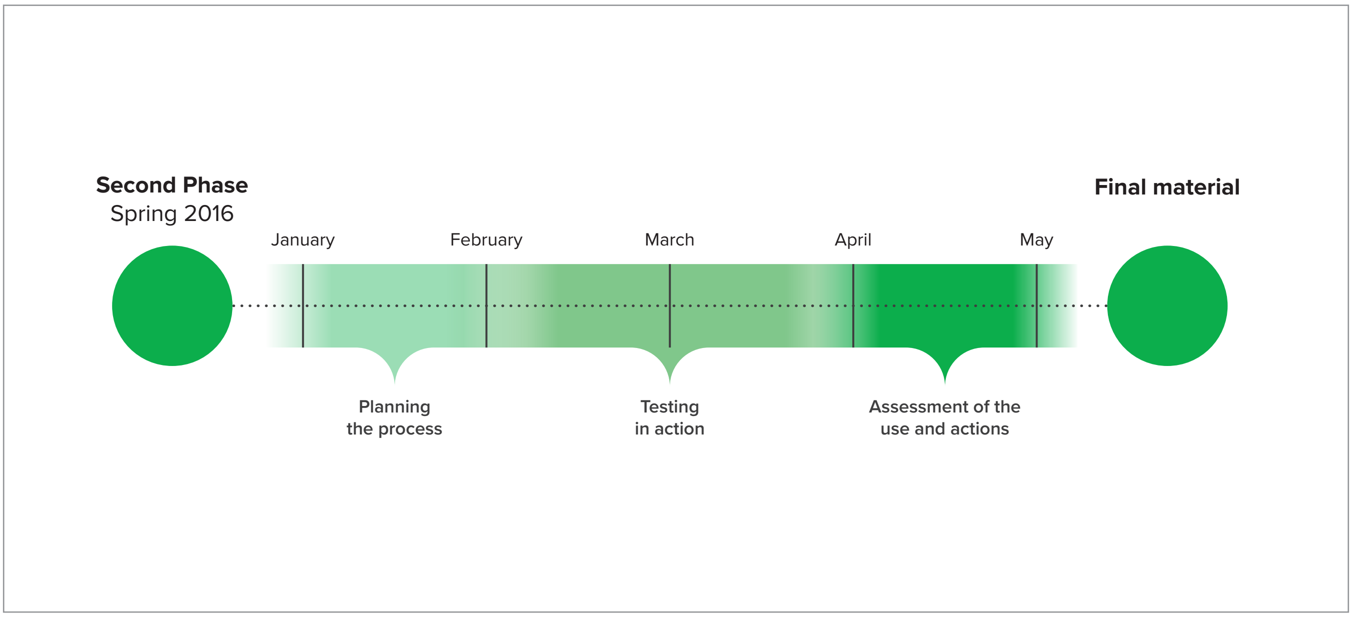

Figure 12. The second phase of the DBR project

In the second phase (Figure 12), the main goal was to test the draft of the pedagogical guide and exercise cards with two kinds of groups. First, our goal was to test the materials with pupils that had previous experience of working with educational robots with an experienced teacher. We those tests were completed, we wanted to test the material with inexperienced teachers and pupils. Our aim was to provide materials that benefit users with different programming skills, and establish the pedagogical usability. At the end of the second phase, the final version of the pedagogical guide was delivered to the ROBBO.

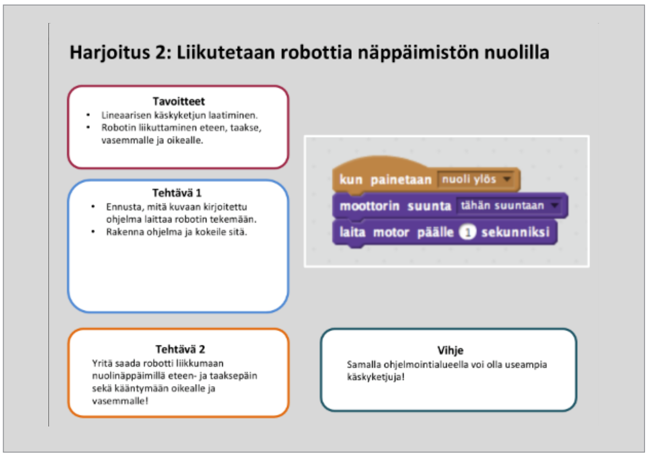

Figure 13a. The first version of a Robot kit exercise card: The exercise

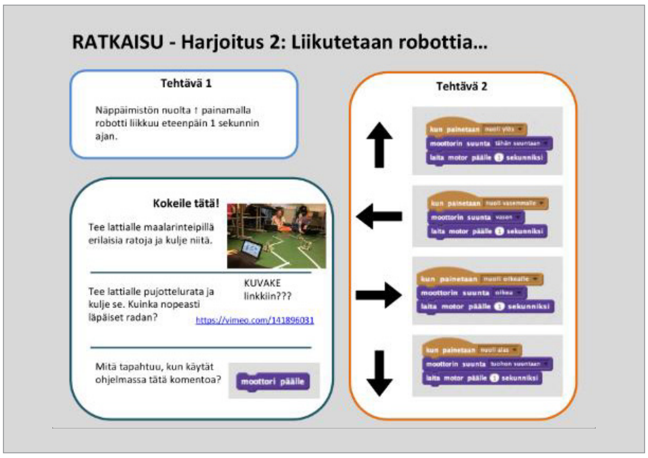

Figure 13b. The first version of a Robot kit exercise card: The solution

Planning the Process

At the beginning of the year, the design process was assessed and restructured. In January 2016, Teacher 1 from the first phase was recruited to produce more exercises for the pedagogical guide. Exercises for different sensors were especially needed, as well as exercises in which pupils would be required to apply their knowledge. Teacher 1 and the Innokas Coordinator planned and formed the final structure of the pedagogical guide in close co-operation with ROBBO's personnel and marketing company. The existing exercises were transformed into cards (Figure 13). The exercise card contained two sides. On one side were goals, one to three assignments, possible hints and an informative picture. On the other side were solutions and a few extra assignments.

One of Innokas' trainers with significant Scratch experience was recruited to develop the ROBBO Lab kit material, which had a connection to games and gamification. Altogether, the development process lasted three months, and it was tested as soon as they were completed.

School	Profession details	Experience
Primary School 3rd to 6th grade (age 9-13 years)	Teacher 6 (primary school teacher)	Long robotics and programming experience with pupils
Primary School 2nd grade 6th grade (age 9-13 years)	Teacher 7 (primary school teacher)	Long experience with ICT education with pupils and training for teacher-students; almost none with programming and robotics
	Teacher 8 (primary school teacher)	Long experience with training for teacher-students; almost none with programming and robotics.

Table 2. The second phase's participating teachers and their backgrounds.

Participants and Data Gathering

During the second phase (Spring 2016), the test group consisted of three teachers from two different schools from Innokas Network. The teachers were chosen based on their dissimilar experience with ICT and technology education, as well as programming and robotics skills (Table 2).

Altogether, three teachers and approximately 105 pupils used the produced materials for teaching and learning the principles of the Robot kit and Lab. Meetings and emails with teachers and questionnaires for pupils were used to follow the development process. Also, pupils' engagement to programming and robotic exercises was followed. Based on these findings, the final pedagogical guide with exercise cards for the Robot kit and Lab were produced.

Testing in Action

The participating schools started with different kits. The testing of Robot kit material began with **Teacher 6**. Our hypothesis was that for material development, it would be beneficial to use exercises first with a teacher that had good knowledge of teaching programming and robotics. With **Teacher 7** and **Teacher 8**, we started with Lab, because it was developed for classes that have never programmed before. After testing eight Lab exercises, they continued with Robot kit exercises.

The Robot Kit

Teacher 6 received a brief training on how to use the platform and kit. He did not have any problems with downloading the software. The Innokas coordinator held the first lesson, where she introduced the material to 22 fifth and sixth grade pupils. Then, Teacher 6 held lessons until most of the pupils had completed all of the exercise cards. For a teacher with this type and level of experience, the technical usability was high. It was easy for him to learn to use the platform. The efficiency of the tool was high; the experienced teacher could quickly perform tasks (i.e., organise learning activities) once he learned how to use the platform. Moreover, memorability and satisfaction were high. The teacher did not meet challenges or errors while using the tool. However, he did have technical problems with one robot when one of the support structures of the motor and the plastic part of the light sensor broke down. He also had problems with reading sensor values, even though he had updated both software and hardware. The ROBBO's personnel fixed the problem quickly.

Teacher 6 was pleased with the material, as he thought, "*in the material has been realized many of the key issues for successful learning of programming.*" He also felt that "*the pupils are excited to work with the ROBBO*". He continued testing the material with three other classes (ages 9 to 12 years old) in his school with the same conclusions. In his opinion, the exercise cards were usable and motivating to the pupils of all ages. "*Overall, the programming tasks were meaningful and appropriately challenging from third grade to sixth* *grade.*” Consequently, the material and platform were supportive for meaningful learning, and it engaged pupils in learning. The pedagogical usability was recognised as being high.

Based on Teacher 6’s feedback and his pupils’ evaluation of the exercise cards, we decided to continue testing with created exercises. At the same time, we continued producing more exercises emphasising more challenging programming tasks. The produced material was tested with the classes of **Teacher 7** and **Teacher 8**. As mentioned, both of the teachers had almost no experience with programming and robotics in education. They had implemented few lessons with Lab material before. We agreed to test the material without any teacher training to find out if the exercise cards were clear enough for pupils’ self-use. After the first lesson, the pilot teachers implemented the lessons by themselves leaning to guidance on exercise cards. We interpreted that both the technical and pedagogical usability were high for non-experienced teachers.

The Lab

Since the **Teacher 6** started the testing with Robot Kit, he did not see working with the Lab as being beneficial to his pupils’ learning. For **Teacher 7** and **Teacher 8**, the Innokas coordinator downloaded the software with the school’s ICT support. The first versions of Lab exercises were challenges in Scratch file format (.sd). The idea was that a pupil downloads a file to a computer, opens it in the ROBBO Scratch environment and creates an assignment. The file contained written instructions and blocks that the pupil had to join together (Figure 14). The structure was based on Scratch-club (www.teromakotero.fi/scratch-klubi), which is a course for learning the programming language Scratch.

The challenge files were shared with the pupils via Google Drive. The Innokas coordinator held the first lesson with the pupils, where she taught them the procedure. It took a lot of time for the pupils to learn how to download and open a file. Pupils were also not sure if they had done the challenge as expected. They did not continue to the next challenge, but instead, they started to modify characters. The critique for the challenges and the procedure was, from the teacher’s perspective, harsh:

“*This has an unappealing background and unmotivating event. Where is the joy? Where is the feedback? Where is the “yes” feeling”? Everything is ready for the pupil. They just join the blocks together.*” (Teacher 8)

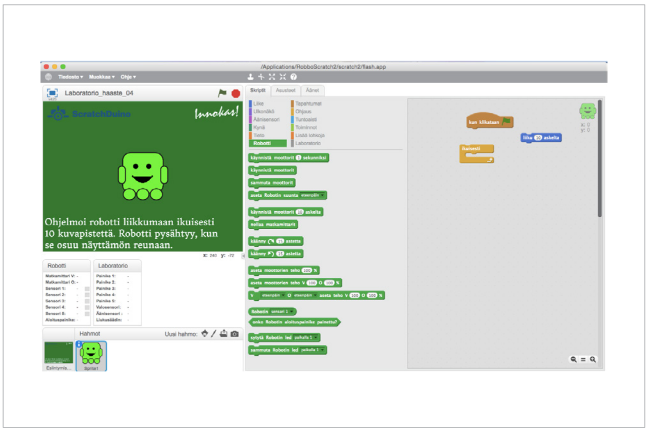

Figure 14. The screenshot of a Lab challenge

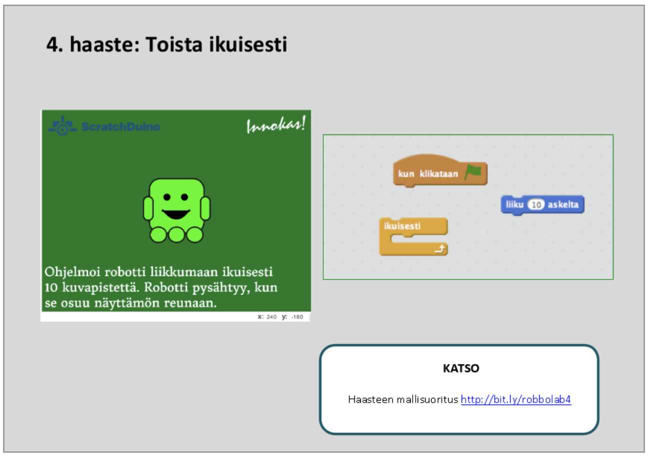

Figure 15a. The first version of Lab Kit exercise card: The exercise

Figure 15b. The first version of Lab Kit exercise card: The solution

Figure 16. Sheet for monitoring completed exercises

Based on the first lesson's feedback, the pedagogical usability was recognised as low. We decided to transform the Lab challenges into exercise cards for the second lesson, because the high pedagogical usability of the Robot kit exercise cards indicated that the exercise cards are usable in the lessons and motivating to the pupils. The ideas of the person who developed the challenges was respected as much as it was possible (Figure 15) when files were transformed into cards. In addition, the teachers requested some kind of follow up system to support pupils' progression and to ease teachers' monitoring. We made a sheet on which pairs make a mark when they have completed their task (Figure 16). These arrangements were adequate for the teachers and pupils, and they continued testing the exercise card until everyone completed them. At the same time, they evaluated the material by questionnaires (pupils) and through email (teachers).

Assessment of the Use and Actions

During the second phase, all of the participants evaluated the material. In both of the second phase's schools, pupils' experiences and opinions were assessed using questionnaires. In addition, the teachers shared their perspectives by email. At this point, the first the constancy of the pedagogical guide was verified. Then, both kits were assessed separately.

The Robot Kit

In the second phase, we were mainly interested in how challenging it was use the cards for pupils (Figure 17) and how much the pupils need guidance from the teacher (Figure 18). We tracked the exercises that were too challenging and a pupils needed a lot of guidance from the teacher. Altogether, the exercise cards were usable, and most of the pupils managed to work without guidance. Based on questionnaires pupils felt that especially with exercises 3 (*Circumventing an obstacle*) and 5 (*Turning robot with touch sensor*), they needed the teacher's guidance. Also, exercise 4 (*Circumventing a box*) was difficult, but most of the pupils needed only some help or managed by themselves.

We carefully reviewed every exercise card based on the pupils' evaluation and made the requested alterations. For example, pupils felt that they needed more instructions for the third exercise, so the instructions were altered and clarified. Pupils' perspectives on exercise similarities were also taken into consideration. In those cases, we altered the assignment. In addition, based on the feedback, we added evenly to the material exercises in which pupils are driven to apply learned programming skills.

Pupils were also allowed to evaluate the device in the questionnaires. They felt that there were still problems with the connection between computer and the device. The pupils also reported that the cable that connected robot to the computer interfered their work. ROBBO's personnel replied to this feedback, as well as to teachers' and pupils' proposition of ability to program both motors separately and adjust the motor speed. These proposals were implemented in the next version of the ROBBO Robot kit.

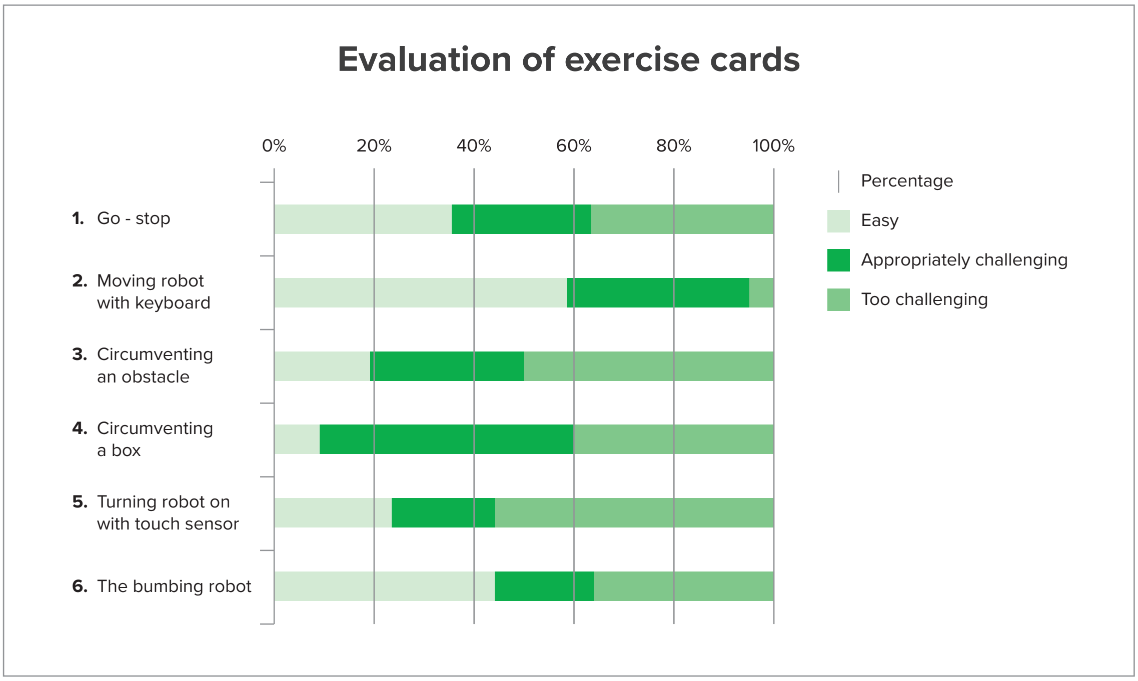

Figure 17. Pupils' answers to the evaluation of tested exercise cards

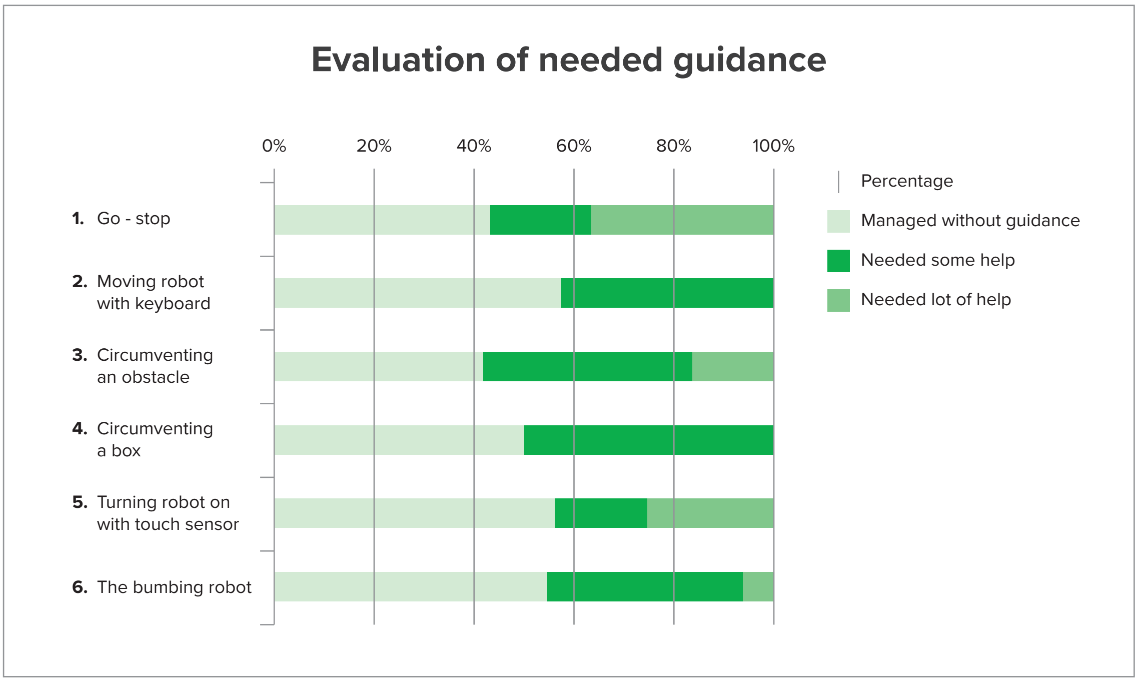

Figure 18. Pupils' answers to the evaluation of needed guidance

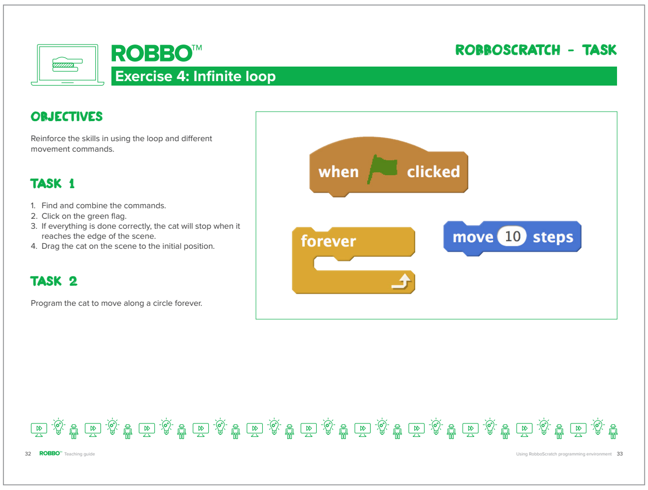

Figure 19a. Final version of Lab kit exercise card: The exercise

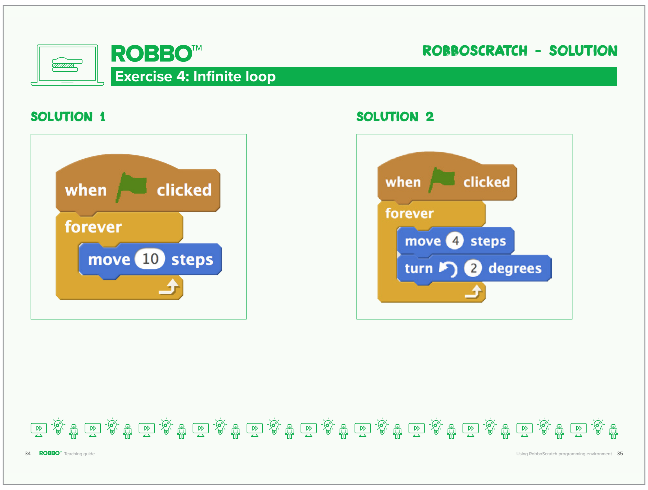

Figure 19b. Final version of Lab kit exercise card: The solution

The Lab

In the second phase, the Lab's exercise form was changed several times during the testing phase. Because we had strict schedule, the alterations had to be made instantly. Similar to the Robot Kit evaluation, the pupils answered the questionnaires, but the information received could not be analysed, as the learning settings varied vastly. However, we received valuable information about the instructions needed for the exercise cards. First, there should be an exact description of the task. Second, clearer instructions are needed. Third, the pupils need some kind of feedback so they know if the assignment is completed. Based on these remarks, the final form of the exercise cards was developed (Figure 19).

Conclusions After the Second Phase

The final material was developed in close collaboration with the Innokas coordinator and ROBBO's personnel and the marketing company. At this final phase, the pilot teachers and pupils' opinions were assessed carefully. The teachers noticed that the pupils were not motivated with the easier tasks if they had programmed with Scratch before. We noted this when writing final version of the pedagogical guide. We added guidelines about which exercise should be the starting point if pupils had programmed before. In the very last meeting with ROBBO's personnel, we decided to move the first Lab exercises to the very beginning of the pedagogical guide where the programming environment was introduced to the users. In addition, we decided that the Lab should be before the Robot kit in the pedagogical guide, because the Lab kit exercises developed many skills that are beneficial when working with the Robot kit. Teachers' enthusiasm to use Lab after working with the robot also affected this decision. After the Lab and Robot exercises, we added a section in which both Lab and the Robot kit could be used together. By the end of the second phase, we came to the conclusion that both the technical and pedagogical usability of the Robot kit were high. The testing process of the Lab Kit was unfinished at this point. For that reason, we cannot make valid conclusions about it.

Conclusions

In this collaborative design-based research project, a pedagogical guide was created for ROBBO Robot kit and Lab. Their technical and pedagogical usability were evaluated through feedback from teachers and pupils. The two design phases made it possible to create optimal teaching and learning material for programming and robotics. Our project showed that this requires a structured development and research-oriented process with actual users who have different abilities and knowledge levels. In the first phase, we gained information about how important it is for schools to have proficient technical support that has both knowledge of computer environments and technical devices that are controlled with computers. Identifying the technical support is not enough; the person also has to be available for the teachers and have knowledge about educational software and devices. In addition, the experiences of the first phase highlighted the fact that every pupil learns basic skills eagerly. However, to go further, they need more guided and personalized challenges. It is easier for the advanced teacher, but a teacher who has limited knowledge of the device or programming in general needs more support.

In the second phase ideas presented in the first phase were clarified when the testing continued with new users. Regarding the Robot kit, the received knowledge deepened during the process. We were able to produce material, which supported the development of pupils' programming skills gradually. The exercise cards are usable for different teaching methods. Pupils can either proceed from one task card to another at his/her own pace, or the teacher can use exercises from the cards in frontal teaching. It gives a teacher the ability to modify the methods and use the pedagogical material to meet the needs of the class. This inference was used also with Lab. We received valuable information from the pedagogical structure of the Robot kit, particularly regarding Lab's programming process. During the testing in action phase, we found out that the Robot kit's pedagogical structure was usable also with Lab. We assume that the users expected the structure stays same throughout the guide. Working from the different angle would have implicated users. The efficiency during the entire artefact is essential for usability. However, we recognise that the time restriction was too tight for proper testing of Lab's hardware and exercise cards.

In addition to the pedagogical guide, in-service teacher training or other support for adoption is needed. The deeper teachers' knowledge, the more likely he or she will be able to support pupils' engagement and learning. Even the experienced teachers felt that training or the support of skilful colleague is needed.

"It would be great if there is someone to help you in the first lesson. When you start working with the robots it is needed. After that the skilful pupils begin to support teacher and the other pupils. It is important to get the feeling that we will overcome this together." (Teacher 1)

Overall, this project indicates that for the companies that are developing pedagogical tools for school, it is beneficial to work in close collaboration with researchers and actual users, such as schools, teachers and pupils following the DBR method. In this case, the process was beneficial for developing the material and platform, even though developing the platform was not the original goal. Product's first versions had deficiencies that affected the use and usability of the platform at schools. Participating teachers and students insights were heard by the company, and also the product was developed further during this project.

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