Design-based Action research in the World of Robot Technology and Learning

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***Abstract*—Why is design-based action research methodology important in the world of robot technology and learning? This article explores how action research and interaction-driven design can be used in the development of educational robotic tools. Our case study is the development of "Fraction Battle" which is about learning mathematical fractions in primary school. An outdoor digital playground is taken into the classroom and then redesigned to create the game. The article argues for interaction design taking precedence over technology-or goal- driven design in the development of educational tools.**

Keywords: Action research; design; educational tools; robot technology

I. Introduction

The purpose of this research article is to explore and describe experiences with action research methodology [1] [2] used both in (1) the design of robot-based educational tools and didactics; and (2) obtaining deeper knowledge of reflected and empowered learning where robot technology is a partner in the learning process.

Developers and researchers who design new educational technology must choose how to balance (1) goal-driven [3] [4]; (2) technology-driven; and (3) interaction-driven development [5] [6] [7]. Each has its own advantages and disadvantages. If the researcher focusses too much on the required learning goals, then the potential of the technology and user might not be taken fully into account. On the other hand, if technological innovation has highest priority, then the users have no input before the final stages e.g. in a beta test. If an interaction-driven approach is taken, then the technological innovation can suffer. And developers risk losing sight of the overall goals if users get too much influence.

In our study we focus on the interaction-driven approach, discussing both its potential and the drawbacks that we found. Action research methodology is chosen here because it supports the interaction-driven design method and because it also enables us to focus qualitatively on the characteristics of the learning process.

The methods are described theoretically and are illustrated by an actual example of interactive driven design combined with action research methodology.

The example "Fraction Battle" is based on robot technology and is actually a digital playground which is transformed into an educational tool. The specific learning characteristics of this tool are described in my paper entitled "The Playground in the Classroom" [15]. Its development and didactical use is inspired by previous research in the field of physical serious games by e.g. Papert [8] and Resnick [9]. This tool was originally designed to encourage children to be more physically active and explorative during learning. It can be considered to be a physical serious game or "exertainment" [16]. The concept developed in this paper integrates the tool and didactics.

Empowerment is an important and pervasive design guideline for us, using the term "empowerment" as developed by Gee [10]. The idea is that the learner is the master of his own learning process: he is a co-designer in the actual design process. The same class of 8-year-old children and their math teacher from Rosengårdsskolen in Odense participated in all our sessions, so they saw the design process through from start to finish.

Development was carried out in cooperation between the Mærsk Mc-Kinney Møller Institute, Knowledge Lab at the University of Southern Denmark and the company PlayAlive (www.playalive.dk). PlayAlive contributed the technology from their outdoor digital playground. Robotic portions of the playground were taken into the classroom and these parts became the basis of the development process. This development is a part of a larger project "Robots at Play", itself part of Robot Festival 2009, held in Odense, Denmark.

The question explored in this paper is: How to plan and conduct action research in the world of robot technological design and learning? – How to bring awareness into the design process? And how to create a research process where the focus is on empowerment of the learner?

First three different approaches to design are introduced and discussed, and the interaction-driven iterative approach is chosen. Then action research is described and its choice as our methodology justified. This is followed by a description of the research plan for the project and of the evolution of our game "Fraction Battle". Finally the research and design methods are evaluated.

II. GOAL-, TECHNOLOGY- OR INTERACTION-DRIVEN DESIGN?

Developing a new technology requires developers to balance conflicting priorities. For educational tools, the learning goals obviously have high priority, but learning only works if the students interact correctly with the tool and the technology is appropriate (and cheap enough for schools to afford). In the next few paragraphs, short examples of goal-, technology-, and interaction-driven approaches and their consequences are examined.

A goal-oriented strategy is exemplified by Design-based Research [4][11]. This method is based on user involvement from day one in the design process. The design process is iterative and is normally conducted in the classroom over a 4-12 month period. This method is used for designing educational technological tools and especially theories that can be used to understand and support learning, and also in curriculum design. The method consists of three phases: (1) Preparing the experiment, establishing learning goals and research goals; (2) Iterative development; (3) Retrospective analysis of videos gathered during the classroom testing sessions. The goals are clear before starting experiments in the classroom and should ideally not be changed during the iterative development phase [11].

A technology-driven design process is where exploration of innovative technological goals and potentials are the core of the project. This may involve new types of technology that have to mature before being introduced to a target group. Typically, several months of technological development occur before the technology is finally subjected to a small amount of user testing. An example could be the development of a video-based bare-handtracking device for 3D gaming [12]. This late involvement of the user is often seen in e.g. game development [13].

In interaction design, the target group is involved from an early stage of development. The desired learning goals and the design of the necessary technology are somehow secondary to user involvement. User interventions have a direct influence on the tool, including the development of learning goals and technology [5].

The strengths of the goal-driven approach are that the designers know exactly where they are aiming and when to stop, and development continues until the goals are reached. The disadvantage of this approach is that the developers are stuck with the learning objectives that they are given, and are unable to adjust the goal(s) according to feedback from users and the potential discovered in the technology.

The advantage of the technology-driven approach is the opportunity to explore new and untested technological breakthroughs. The disadvantage, on the other hand, is that the users don't get involved in the early development and the resulting product might be useless.

The advantage of the interaction-driven design is that the final product developed is interesting, useful, and/or enjoyable for users. In addition, meaningful interaction is designed in from the beginning. The user involvement also creates a sense of ownership for the user. Disadvantages include that the willingness to adjust learning goals means that the resulting learning is not determinable in advance, and if all the development time is spend on the user interface the underlying technological functionality might suffer.

III. INTERACTION-DRIVEN DESIGN

The project described in this article is interaction driven and the users are co-creators with us of the resulting robotic educational tool. Key ideas in interaction-driven design are: interaction in the design process, interventions, flexible learning, innovation, and adaptive expectations.

Users influence both the process and product and furthermore develop an understanding and knowledge of design processes.

Learning objectives were flexible, and because of the age of the target group learning potential is also taken into account. The learning potential in the technology is recorded through the interactions as well.

The robot technology used in this project is already existant and ready for use. No new sensors and effectors are developed, but the existing technology is instead utilised in new ways. This innovation makes it difficult to predict how the audience will interact with the technology. And since it is also difficult to assess the actual learning potential from the beginning, it makes sense to adjust project expectations during the development process.

Our design techniques have been inspired by interaction design methods [5] and also by techniques such as Extreme Programming [6] and Scrum [7]. Scrum is a so-called agile technique used in software engineering, characterized by being adjustable during the development process. The techniques are also characterized by short iterations where the target group tests the latest version of the product in each iteration [6], [7]. These techniques focus on production of the software rather than production of documentation. They are subordinate to the action research methodology.

The iterative cycle is shown in Figure 1. Each iteration began with an intervention which was then evaluated. Learning goals were adjusted and new ideas were generated. The adjusted learning goals and operationalized ideas were then implemented in the educational tool or in the didactics. After the implementation phase, plans were made for the next intervention. The plans consisted of roles, activities and objectives.

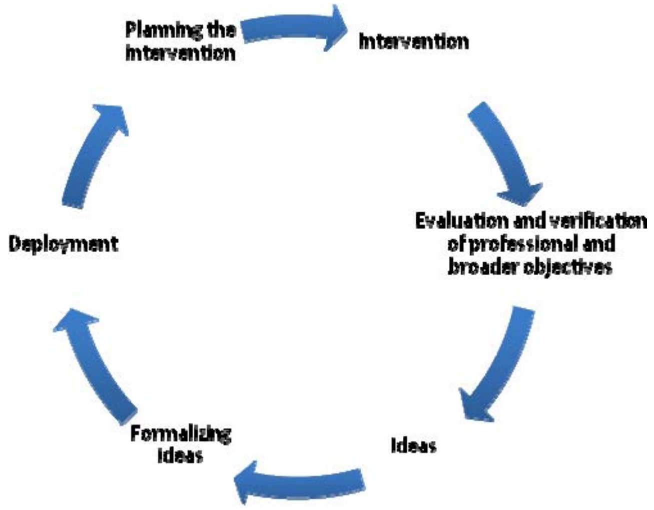


Figure 1. Sketch of each iteration

IV. WHY CHOOSE ACTION RESEARCH?

The purpose of action research [2] is twofold: (1) to design prototypes of educational tools and didactics which empower the user; (2) to obtain deeper knowledge of reflected and empowered learning when robot technology is part of the learning process.

An interaction-driven methodology covers purpose 1. However, a more overarching research method is needed in order to allow focus on the learning process during the design of both tool and didactics. This research method also needs to be of a qualitative character, since it is the quality of the technology-centered learning processes whichis our primary focus. Additionally, the methodology should complement the focus on innovation and change.

Action research is our method of choice because it fulfills all the requirements outlined above. It (1) supports an interaction-driven design methodology; (2) supports iterative cycles of intervention and reflection; (3) is a qualitative hermeneutic method; (4) supports permanent change in learning processes.

These points are explained further in the following sections.

V. WHAT IS ACTION RESEARCH?

Action research is a collaborative inquiry process where a change is initiated into an interactive field in order to uncover basic patterns and mechanisms of this field, and these insights are used for improvements. The method brings change in behavior of the target group in focus. The method is used in various fields such as information systems [17], collaborative learning and technology [18], and design of technology [19].

Experiments and critical reflection is the core of action research, allowing learning from and through practice [2]. Empirical material is constructed and analyzed during the experiments. The method is qualitative and is based on users being involved as participants.

Kurt Lewin [1] was the founder of the method [2] and he describes the research process as a spiral of steps each of which is composed of a circle of planning, action and fact-finding. "Action" is the physical intervention with the target group and takes place in the target group’s domain. "Factfinding" has four phases: (1) the action is evaluated; (2) the evaluation gives the planners a chance to learn and to obtain new general insights; (3) these insights serve as the basis for correct planning of the next step; (4) the facts found also serve as a basis for modifying the “overall plan” [1]. This type of research is supposed to result in permanent changes in social behavior.

What is needed in this experiment is a changed approach to technology in the classroom. In this project children and their teacher are participants in the design process and their approach to robot technology as a learning tool is supposed to change as a part of the design process. A meaningful change in behavior is also a synonym for learning.

Action research has also been described as a hermeneutic science [2]. This refers to the development of the researchers' understanding of the target group and of the research field as a whole during the research and the changes in interpretation that result. This evolving understanding affects the planning and implementation of the actions.

In the research described in this article our field is the characterization of learning found in technology-centered learning processes. Each time an intervention is conducted and evaluated an addition is made to current knowledge about technology-based learning in classroom teaching. In the next our version of design-based action research will be introduced. Type fonts are preferred. Please embed symbol fonts, as well, for math, etc.

VI. OVERVIEW OF OUR DESIGN-BASED ACTION RESEARCH PROCESS

Our experimental research involved a development process which was conducted in four phases. These will be described individually in section VII: (1) Pre-analysis and planning, (2) Interaction driven iterative design, (3) Concluding interviews, (4) Analysis of the empirical material obtained. All operations with the target group were recorded on video to facilitate subsequent retrospective analysis.

Pre-planning resulted in a master plan for the number of interventions, a preferred target audience, and the decision to work with the same group of children throughout the experiment. It was considered acceptable to work with the same group of children, since it was learning and not learning effectiveness which was being investigated. The necessary permission to work with the children was also obtained.

VII. Summary of the Development Process

Our technological starting point was an outdoor digital climbing frame which was situated in the schoolyard, where it was well-known to the children who took part in our experimentation. Copies of the electronic parts of the climbing frame were placed in a big suitcase and named the robotic octopus (see figure 2). The octopus consists of 12 waterproof "intelligent satellites". Each satellite consists of a touch sensor, 16 programmable light diodes, a loudspeaker and a microcomputer. The satellites are physically interconnected by power and data communication wires.

The software architecture is distributed, with one satellite being the server and the rest clients. The clients execute the client part of the code and the server executes control code where scores are maintained, the game menu controlled, etc. The code is written in the third generation language C. The system was developed by PlayAlive and has previously been used in an outdoor playground [15].

The octopus initially contains the games developed for the digital climbing frame. The first game is the "red-green game" where two teams compete to press buttons showing the team's color as quickly as they can. The second game is in the same genre. The third game is a memory game where the player is supposed to remember where specific color pairs are hidden. These initial games are used as inspiration for the new educational games.

The target group for our educational tool is children between eight and ten years old. The idea is that the game should be used as a supplement to the math curriculum. A class from Rosengårdsskolen in Odense, Denmark was chosen. The class and their teacher participated in game development by testing each new prototype and by suggesting ideas for new educational games.

The games and the associated didactic were developed in four iterations. In each iteration an intervention was planned, executed and evaluated as shown in figure 1. Interventions involved the children and their teacher testing and commenting on the games. Each session lasted approximately two hours and was taped on video (see figure 2).

The themes of each intervention:

- (1st) Evaluation of the technological starting point (the octopus and its original games);
- (2nd) Brainstorming for ideas and choosing a game to work with;
- (3rd) First evaluation of the chosen game (two variants of a fraction game);
- (4th) Evaluation of the revised game (four variants in total) and a didactic framework was developed and evaluated in concert with game development.

Figure 2: The octopus in action

A. First and second iterations: Analysis, brainstorming and decision-making

The first and second sessions focused on familiarization with the starting conditions and obtaining ideas for the educational transformation of the tool. We read the math book the children use, to familiarize ourselves with their academic basis, and we reviewed their curriculum. We also explored the capabilities of the octopus. No new games were developed during these two iterations.

In the classroom, the children played the "red and green" game in competing teams, then the brainstorming took place. The target group was very dedicated and involved throughout the whole process. Children came to school even though some of them were ill. They had a lot of ideas for educational games. These ideas fell into three categories: 1) numbers and letters, 2) computer games which could be converted to robotic games, and 3) narratives.

Their ideas about numbers and letters were restricted to what they already knew e.g. addition, subtraction and number series. From the world of digital games they suggested known game puzzles such as Memory Game and interactive Scrabble. They also had narrative game ideas about princes and princesses, people on the prairie, angels and devils, war games and so on. The math teacher had ideas about number series, telling the time using a clock with hands, adding and subtracting with carry, etc.

Ideas involving converting well-known puzzles from computer games were rejected, because the learning objectives were too far from the curriculum. The narratives were interesting but they were hard to operationalise in the context of a math curriculum and this type of technology. A clock with hands was a great idea which could be implemented on the existing hardware with only a few changes.

The idea of introducing fractions was also ideal. It used much of the potential already existent in the hardware and was on the curriculum for the following year. Since the fractions option did not require any immediate change to the hardware, fractions was chosen as the subject for development.

Schoolchildren of this age in Denmark do not normally work with fractions. They are only introduced to division in the following school year, moving on to fractions later.

B. Preparation for the third iteration: Development of the first version of "Fraction Battle"

Consequently the first version of our educational game involved fractions. The fractions were represented as pieces of the circular satellites. See figure 3 for the formal structure for one of the game variants.

Two variants of the game "Fraction Battle" were developed. The goal of variant 1 was for the players to construct one whole one by adding and subtraction fractions in different colors. The second variant was similar but the target could be specified to be any proper fraction e.g. the goal was to add and subtract fractions until 8/16 was reached.

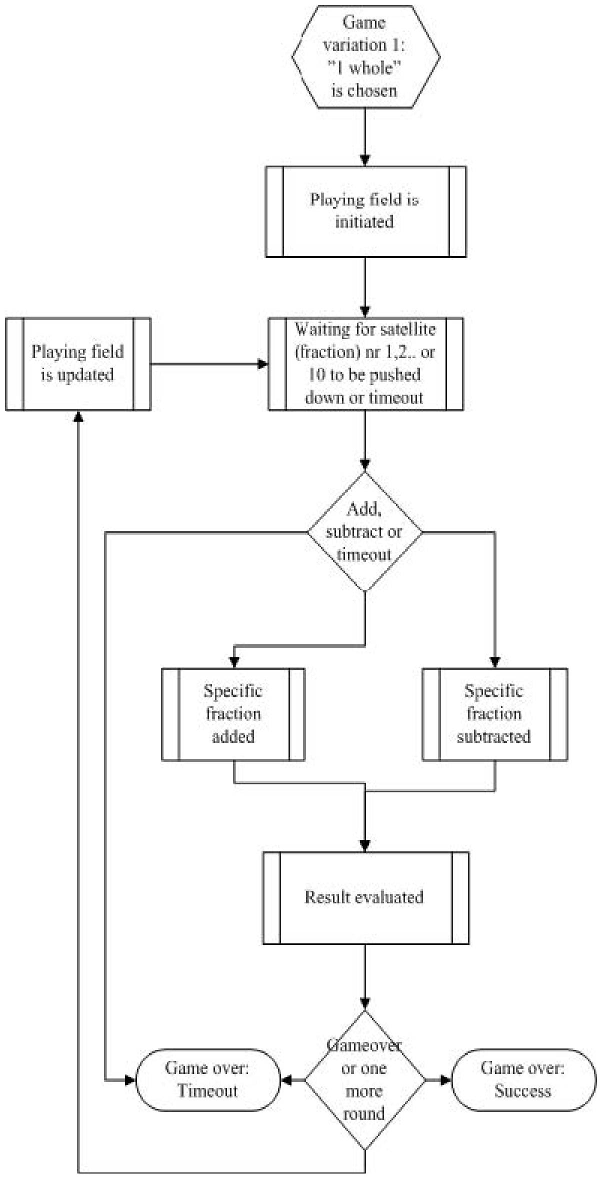
C. Lessons learned during the third iteration: Hardware limitations and their consequences

During the evaluation of the two "Fraction Battle" variants described above it became clear that a didactic approach and more game variations were needed.

No inherent didactics were built into the octopus, so it was up to the teacher and researchers to decide how to relate the fraction games to the objectives and how to plan a meaningful lesson involving the tool. This required designing a meaningful context for the robotic learning sequences.

After the third intervention the learning objectives became clearer. The overall objective was that the children should understand the concept of fractions. The children should: (a) understand graphical and numerical representations of fractions and be able to transform fractions from one representation to the other; (b) be able to add and subtract fractions that had the same denominator;
(c) be able to express a fraction as numerator and denominator. These objectives became clearer with each run.
It also became clear that the educational tool was not able to represent the fractions as numbers. It was best at graphical representations, because of the physical nature of the robotic octopus. Special numbering caps could have been made for the satellites but the final decision was to use the satellites just for graphical representation and to develop a didactic context around the tool.

Figure 3: Formal structure for the game variation "a whole one"



D. Preparation for the fourth intervention: didactic plan and two extra variants of “Fraction Battle”

Two extra levels of Fraction Battle were added, resulting in four versions of the game at different challenge levels.

We wished to demonstrate and test various different didactic approaches, to explore the tool's full potential. Very often serious games are like a straightjacket for the teacher because a narrow didactic path has to be followed. In a classroom, many different things are going on. Children have very different ways of learning and are often at different academic levels. We wanted both to explore the potential of the tool and to set the teacher free. We wanted to combine different didactic approaches in order to test what worked and also to test the combinations.

It was important to manage the class so the children did not spend the lesson waiting for their turn at the octopus. We had also noticed that the children got excited and inspired to do physical exercise when using the octopus. In order to keep the children’s minds focused on fractions it was decided that the lesson plan should comprise periods of working at the octopus interspersed with periods of seated absorption and reflection.

It was crucial for the children to reflect on fractions. Therefore the children were made to use the same fractions in different contexts. We also wanted them to plan ahead and encouraged them to reflect by using the experience they had already gained. These ideas of reflected learning are based on Bateson’s notion of different levels of reflection in learning [14].

To promote a deep and reflected learning we aimed at a didactic design combining many different approaches to learning in order to help the children to understand the many ways they can learn and to develop their own learning strategies.

The didactic scenario was built up using elements for intuitive and pre-conceptual understanding, sensomotoric understanding, deductive learning, inductive learning and transformative learning. The scenario was wrapped in a sandwich of warming up and playing at the end. See figure 4.

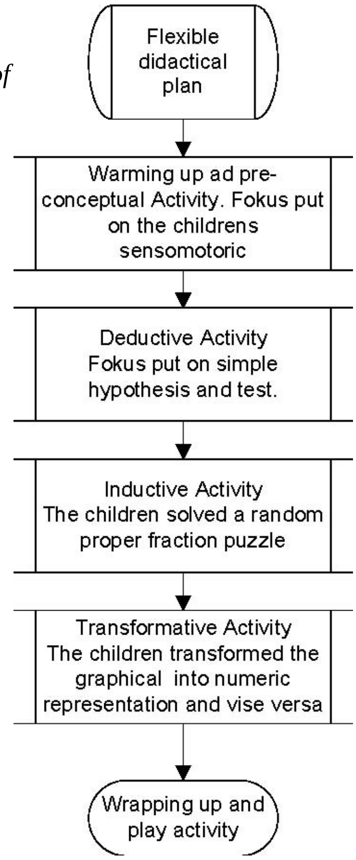


Figure 4: Overview of the flexible didactical plan

The warming up was an introduction to fractions where the children play and explore without knowing anything about fractions yet. During the warming up the children got a pre-conceptual and sensomotoric understanding of fractions. The experience is physical because the children communicate by pressing the satellites and the satellites respond to the children’s actions. The idea is that that the children should get an embodied fraction experience before knowing the actual concept.

In the deductive learning process the children were to plan solutions and then test them on the octopus. When using the deductive method the child is creating a hypothesis and then testing it. In other words, they plan and describe an experiment and then conduct a test. This method was supposed to force the children to reflect on their learning process by thinking ahead and planning the next step.

The next part of the didactic plan was inductive because the children are supposed to calculate the solution in the process without any prior planning. The children are presented with a random fraction and they have to add its parts. The induction should be understood as the process of the children developing the solution.

The children also learned to transform fractions into different representations. The knowledge of fractions the children developed using the satellites was transformed into representative paper sketches and into numerical and fraction line representations. The change of representation is a change in context which also forced the children to reflect. Testing the didactic scenario took almost two hours with the children working together in pairs.

E. The fourth iteration

This intervention showed that the children found it easy to transform embodied and pre-conceptual experiences into conceptual knowledge and transformative knowledge. Some of the children found the numerical and fraction line representations quicker to use than the sketches. Most could easily draw the sketches and make transformations between the different forms of representation. Some children could also “see” that 8/16 was the same as ½ and that 4/16 was the same as ¼, but this was the limit of knowledge acquired about fractions in that lesson. The math teacher was a bit surprised how easily the children picked up the concept.

Evidence of reflection: the children spent time discussing how to solve the fraction puzzles e.g. in which order they wanted to push the satellites in order to meet the target fraction.

The test showed both the potential of the tool and the potential of a meaningful and well prepared didactic.

F. Final interview and presentation of knowledge obtained

The process of analysis is still going on. We visited the class four months after the fourth intervention, showing them some of the video material and interviewing them as a group.

The children remembered the fraction game and thought it was great fun to watch themselves on video. The video made them remember fractions and all the commotion that took place in the class when we visited them.

When asked, the children could describe the games and give some detail about graphical representation of fractions. It was a bit harder for them to remember the numerical representation. But we believe they have a sound knowledge base on which to add more about fractions and division later.

We also asked them if they thought they had actually influenced game development and if we had listened to their ideas. Most of them thought that we didn’t listen to their actual ideas, but still felt they had some influence on game development. It was a bit hard for them to describe how they had influenced the process. We tried to make them understand that they had contributed in an innovative process. The children acknowledged this and one of the boys said: “I want to be an inventor when I grow up”.

VIII. Evaluation of the Research and Design Methodologies

The approach to design used here differs from both goal- and technology-driven design. If a goal-oriented approach had been chosen the potential of the technology wouldn’t have explored sufficiently. We would have had to settle for the predefined goals. Pre-defined goals might on the other hand have forced us to revise the hardware in order for the satellites to show other fractions not expressible in sixteenths.

If a technological approach had been chosen we would have had no experience with developing and executing different didactic plans around the “Fraction Battle” game, and the actual learning goal would still be unclear. Beta testing carried out at the end of a separate development process might reveal some learning goal but is very unlikely to reveal the full potential of the game.

We were pleased that our research produced a unique tool for learning fundamental fractions, especially one with accompanying didactics which is so well tuned to the target group. In the beginning the learning goals were very unclear but gradually we produced some very precise learning goals. During the iterations we developed a very good idea of the potentials and limitations in the hardware. The hardware turned out to limit the learning goals, due to the limited graphical representation of fractions. However, the gameplay built into the software of ”Fraction Battle” can still be improved and has unexplored potential.

The overarching action research methodology made us more open to exploration amongst the target group because this research method is well characterised. The concluding interview in the class is also a standard part of action research methodology. Explaining the results of the research process to the children and the teacher and showing them videos also contributed new information to the research process e.g. the long term impact of the interventions and new knowledge of how children learn; it also gave us ideas for new research.

IX. Perspectives

If we want to take “Fraction Battle” further we would probably wish to upgrade the hardware. Another interesting option would be to integrate the childrens' mobile phones into the tool.

Most children in this target group have mobile phones: only two or three children in this class were without one. One of the technological perspectives of this project was to use some of the computing power already present in the classroom for educational purposes -mobiles nowadays contain significant computing power and are readily available. We asked the children if they had any ideas about how to integrate mobiles into the “Fraction Battle” game. They suggested sending smileys, sounds, numbers and calculations to the robotic system. They were rather enthusiastic when elaborating on sounds and smileys.

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