Enhancement of 7th-10th Graders' Understanding of Equations with Tangible Representations

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ABSTRACT

This project examines the possibility of heightening the understanding of math equations by means of physical objects. The target group is students in 7th-10th grade. A certain part of the students in a Danish elementary school class has problems dealing with the complexity of equations and the rules that apply in the solving of them. Therefore the equation is made "physical" so the students feel that they can grab the individual parts of the equation and manipulate them. This will also make sure, that the students achieve a closer relation to the equation. In connection with the project a product has been made to alleviate the students' giving-up attitude. To examine whether the product presents a value to the students, it was tested and evaluated in the right environment with a representative user base. From the tests and evaluations it is concluded that the physical objects are instrumental in giving students a better understanding of equations. This understanding is created through equation parts affiliation shown in color and elements from gamification. Furthermore the conclusion is built on statements from the users dealing with the value of having the equation elements in their hands, and the fact that the users in the following equation exercises on paper use the acquired methods in their calculations.

Author Keywords

Math, Tangible User Interface, Learning, Dyscalculia, Gamification, Sifteos.

1. INTRODUCTION

Over the last couple of years the PISA worldwide evaluations of students in elementary school as well as high school have shown that the level of the Danish students in natural science does not match the level of other European countries which we in Denmark usually compare ourselves with.[1] In addition to this, there is a major need in society that the youth raises their interest in the natural science professions.[2] Therefore the Danish government has a goal of increasing the academic level in the Danish elementary schools. This is a lengthy process and it is a significant challenge for the teachers to elevate the ability to learn among their students. Especially, it is difficult for the teachers to reach the weaker students when these have passed through the lower grades and now find themselves in the end of elementary school, lacking the required skills. Today, the teaching methods in the Danish elementary schools imply that several students are left behind. This can result in demotivation when they encounter problems, and some begin to take on a despondent attitude towards tasks handed to them.[3]

One of the pioneers within tangible user interfaces(TUI) is Hiroshi Ishii, professor at MIT Media Laboratory. He had the idea of representing digital information in physical form.[4] This way of working with information gives new opportunities to manipulate objects, which can be exploited within the learning process. A series of scientific studies[5, 6] conclude that some children by means of manipulation of physical objects increase their learning ability, opposed to more common methods like the use of pen and paper, regular teaching from the blackboard and working on simple graphical user interfaces.

As of today the term gamification increasingly appears in various contexts. This element has become very popular to include because it has been proved that minor rewards can affect the user's behavior. There is focus on the rewarding of the user according to the progress he or she goes through, and thereby adjusting the level of further challenges. This makes sure that the user is focused on the purpose of the exercise, and that he or she will continue until the purpose is reached.[7] In this paper gamification is used as an experimental element for motivating students and giving confidence in situations of learning math.

In this paper the three fields mentioned above - learning, TUI and gamification - will be examined. Semi-structured interviews, think aloud tests and prototyping was used in researching these three areas. The collected data was used in the process of creating a product that embraces the findings. This product was then used to test whether it was possible to alleviate some of the problems addressed above.

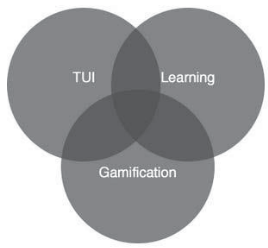

Figure 1: Overview of involved areas of research

2. RESEARCH QUESTION

How can tangible interaction enhance 7th-10th graders' understanding of equations?

3. OUR CONCEPT

3.1 Concept Requirements

On the basis of the empirical data, which was collected through semi-structured interviews with a math teacher and two think-aloud[8] sessions with two students, a series of requirements for the product were established. In the empirical data a psychological aspect of math was encountered. This was seen when students are stuck in an exercise. Here they have the mindset that they "cannot figure out math". If you have the feeling that you can figure out how to solve the equation, then you really can solve it. It is important to feel confident in everything you do, and in this case you should always know that no matter what you do in the equation, you will not be stuck, because you are in a safe environment where your actions are controlled. The following requirements should be fulfilled in order to meet the needs of the case class in their current situation:

- Better ability to solve and understand equations while using the product and after
- Motivating the students and heightening self confidence
- Supporting those students who have a reduced understanding of the basics in math

3.2 The Concept

In the higher grades of today's elementary schools there are some students who have problems in the area of understanding mathematical equations and the calculations which take place in that respect. The teachers do what they can but sometimes the students have a "giving up" attitude towards exercises containing equations. Moreover some students profit the most from doing practical exercises and physically touching the elements involved when learning. These students experience problems because they do not obtain the maximal outcome of the traditional teaching which is practiced in the Danish elementary schools.

By looking at TUI, gamification and the present teaching our concept will help the students to better understand which rules are applicable when it comes to equations. At the same time it shall motivate them to learn math while getting rid of the "giving up" attitude.

Our concept has the intention of making the equation physical and digital. The equation is presented so the students themselves can move and manipulate each link of the equation. The purpose is to have the student see the consequences of their actions and to give them the possibility to explore how equations are solved. Furthermore the students are allowed to examine the rules of the equation. By taking in gaming elements the students will start out on a low degree of difficulty and slowly move closer to their actual level and beyond. Along the way the students will take over some of the actions, e.g. sign changes, and have the ability to receive hints so they will not stall and thereby become frustrated during an exercise.

3.3 Product Description

The product itself consists of six Sifteo [9] cubes and an application running on a computer. The Sifteo cubes can detect when they are placed side by side, when they are tilted, and when the screen on the cube is pressed down. When starting to use this product, the student chooses the first badge on the computer and the first equation will then appear on the cubes, when they are put together in a horizontal line. Now the student's task is to move the cubes around to solve the given equation.

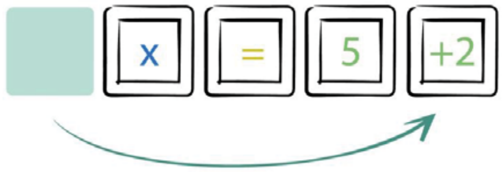

Figure 2: Sketch of concept - solving the equation

In the beginning the user has a lot of helping tools such as color indication which shows the affiliations among the different elements, automatic sign change and automatic calculation when elements are merged. To merge the different elements, you have to put two cubes together and then tilt one of them. The more equations solved, the harder it gets. This means that in the end the student has to do all the work. First of all, the helping colors are removed, and when moving an element past the equals sign the student now has to do a sign change by pushing down the cube's screen. Furthermore, the student has to do the calculation when merging two elements together. This calculation takes place on the computer screen where the right result is to be typed. If the typed number is correct it will show up on the cube, and the student can continue solving the equation. For every badge the student takes, the harder it gets, which should result in an easier return to the equations on paper.

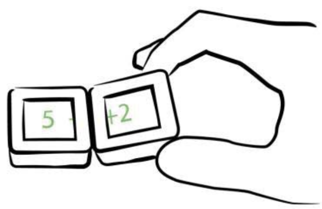

Figure 3: Concept sketch, merging elements using tilt function

The aspect of gamification is included in this paper as an attempt to alleviate the issue of psychological influences in the learning process. It is examined whether the students will benefit from the element of gamification when it comes to confidence and motivation. The lack of these is addressed problems in the mathematical learning process. In the coming sections they will be further discussed.

3.4 Motivating the students and heightening self confidence

A series of design considerations have been made when it comes to gamification. For each equation solved the student receives points. When the student has collected a certain amount of points he or she receives a badge as a reward. The badges represent the accomplishment of a level. This level can for example cover the category of addition in equations, multiplication or equations with more than one x.

Figure 9: Achievement of the "Multi x" badge

These elements are included to increase the motivation of watching your own progress and thereby define your goal for further personal development. These rewards are essential, but it is also important to give the students small successes, so they are rewarded every time they do something correct. This is for example implemented when two numbers are merged onto one cube, where the remaining empty cube will present praising words.

A video of the product in use can be seen by following the link in the Video Prototype section.

4. EVALUATION

After finishing the prototype with all the relevant features, a plan of returning to the case class took shape. An evaluation of the product should be performed in order to answer the research question. Before making an interview guide and deciding how the product should be tested, it was important to examine the best ways of testing prototypes involving children.[10]

The evaluation plan had three main goals; could the interaction form give better understanding of equations, how would the students react to the product and its features, and would the use of these cubes affect their individual learning curve over at short period of time?

The test and follow-up interviews were conducted in the students' own settings, in their school library. The school board and the class teacher at Frisholm Elementary School allowed for three of the case class students to separately come into the library. Each session with a student took approximately 40 minutes. After the three sessions an interview with the teacher was conducted. When the student entered, he or she was presented for the following tasks:

1. Solving of a number of equations with pen and paper
2. Working with equations on the Sifteo cubes
   - Including four steps:
     a. With all helping aids
     b. Without color help
     c. Neither color nor sign-change help
     d. No help (also do the calculations themselves)
3. Once again solving of equations with pen and paper
4. Short interview

The reason behind this order of tasks was to test whether the cubes helped the students in the understanding of the concept of equations. The first task gives insights on what the student's current level is, and how he or she normally deals with an equa-tion problem. In the second part the student was let through a fast scenario where he or she starts out on the simplest level of equations. Gradually the student makes him- or herself familiar with the basics and rules of equations, and in the end hopefully becomes able to solve an equation as difficult as the hardest one they tried on paper. Another part of this second step was the actual testing of the product. Here it was important not to explain too much to the student of how the product worked, so it was possible to see whether it was intuitive for them and whether they at all times knew what their next move should be. The third step was the student's return to the paper and new equations. It was here possible to see whether the student had changed his or her approach to solving the equations; does he or she think in the same way as when using the cubes, are the equations solved faster than before and is it easier for the student to recognize mistakes, move on and not be stuck. The fourth and last step was the interview where the students were asked how they experienced the product and what they thought of it. They were also asked about the different levels of the scenario and which effect they had on them. Another example of a question asked was what differences they encountered between using pen and paper and the cubes. The entire session was documented on video. This was done to make it possible to look over the events and take out some interesting points. Afterwards, an analysis of these points has been performed.

5. CONCLUSION

The main goal of this study was to find out whether 7th-10th graders with tangible interaction could enhance their mathematical understanding of equations. This has been examined through interviews, evaluations and testing of a tangible product. The results from the study tell that there is a significant connection between learning math and tangible representations. The product gave the students an understanding of how equations work and what rules apply in the equation space. They were able to bring the methods with them and use the cube-thinking metaphor when they encountered equations on paper after using the cubes. A great value of the cubes proved to be the exploration and inspection possibilities. This helped the students become familiar with the equation universe on the Sifteos, because they were able to experiment with and control the environment in order to satisfy their curiosity. Ultimately this curiosity can help the students' progress faster when it comes to learning math.

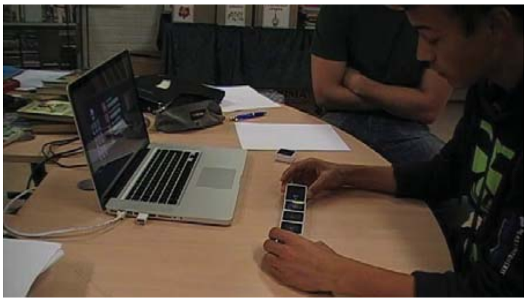

Figure 4: Final prototype is being tested by student

It can also be concluded, that the colors on the cubes had an effect on how the students understood the equations. The colors helped them connect the different parts of the equation, and especially for one student the colors were crucial in order to maximize the gains of the exercises. There was also an evaluation of the gamification and differentiation aspect, where you are moving from the level with colors to more advanced levels while receiving proper ongoing rewards. The result from this was that the students were motivated by the reward and it made them want to sustain their efforts. However, they were afraid that the cubes might feel more like a game than an actual learning device. It was essential to move away from the "mechanical" aspect of just using the cubes to do all the work for you.

A great focus in this study has been to examine the effects of psychology in math. What are the reasons for students getting stuck in an equation task, and how can it be prevented. One suggestion has now been presented, because the cubes give the ongoing possibility of changing the looks of the equation. If you are stuck, you can always try to move things around, and try to find a better starting point for your next move. Nevertheless this can still be difficult for some students, so the problem of getting stuck will occasionally present itself, but the value of the cubes in this area remains significant.

The final conclusion and perhaps the most relevant for the overall theme and the research question is whether there is a value of creating a "physical" equation through Tangible User Interaction. Can students benefit from picking up each link in an equation, moving and manipulating them? According to the research presented about children's learning combined with the testing done in this project, they can. The test students felt almost like they were "inside" the equation when they used the cubes and thereby it was easier for them to know what to do. At the same time being active in doing the exercises, and using their hands, made them feel like they could easier accomplish.

Finally, in the answering of the research question of how tangible user interaction can enhance the understanding of equations among 7th-10th graders, it can be concluded that one way of doing it is by giving the students a possibility of experimenting with the equation and make sure that the concept fits different ability levels. This should be combined with acknowledgements of student achievements, giving them confidence for further learning and making sure that they will not be stuck. Moreover it is essential to make a design that does not prevent the children from doing the math and thereby make sure not to automatize all the processes. Furthermore it is also beneficial to use physical elements, so the students come closer to and become more familiar with the equation.

6. VIDEO PROTOTYPE

6.1 Video of final product in use:

http://www.youtube.com/watch?v=2A0-xj-3fNA&feature=youtu.be

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