Th!nklets for mathematics education. Re-using computer games characteristics in educational software

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Abstract: Computer games are engaging activities for a growing number of children. Technology, especially computers and the internet, have rapidly become more widely available in educational settings as well as at home. Mathematics, not always an engaging subject for elementary and middle schools students, can be made more engaging by designing challenging tasks that are meaningful for children in which they actively participate. Also, using computers in math education contributes to students' motivation and engagement. This paper reports on a study focused on the contribution of playing so-called "Th!nklets" on doing and learning mathematics. "Th!nklets" are interactive computer activities that involve mathematical thinking and problem solving. Some findings from the analysis of the online use of the Th!nklet 'Share Money' by 600 Dutch children age 10-12 are presented.

Objectives

Computer games nowadays are omnipresent and very popular. Not only young people play them, but the target group is expanding for example with respect to gender and age. Computer games are very diverse: on the one end of the spectrum we see large open virtual worlds like Habbo Hotel, World of Warcraft or Second Life, on the other end we see small puzzle like games like Bejeweld, Brain Training and Add like Mad.

Children aged 8-12 are a growing audience for commercial game-sites like www.addictinggames.com and educational game-sites, like www.thinklets.nl for mathematical games, and of course the growing mobile possibilities of Sony PSP, Nintendo DS and the mobile (smart) phone. On those sites (and on those mobile devices) children play a variety of mostly small puzzle like games. Prensky (2005) refers to these as mini-games. Playing together this kind of mini-games (educational or not), talking about which games they like, how good they are etc. is part of the culture of children (Gee, 2003).

It is beyond doubt that playing games is a motivating and engaging activity. Most educators and designers agree that playing games can also support learning in general, and contribute to specific skills and subjects in particular. A number of game studies have examined the relationship between games and education (Squire, 2003; Squires & Preece, 1999; Kirriemuir & McFarlane, 2004; Sanford & Williamson, 2005). It is a challenge to find out and understand how to use and/or design games that are engaging for kids and at the same time offer challenging, valuable learning opportunities.

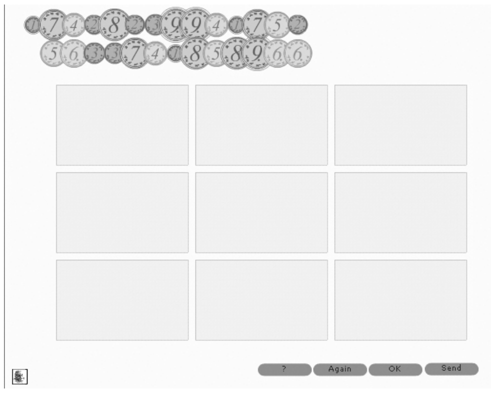
Some studies have specifically focused on mathematics education (Terc 1998; Hoyles & Noss 2003; Jonker & van Galen 2004; Alexopoulou 2006; Wijers & Jonker 2005). For mathematics education a central question is: Can playing games contribute to the learning of mathematics?

This paper reports on a research study that aims to answer this question focused on the use of Th!nklets, online mathematical mini-games, by kids aged 8-12, both in unsupervised settings (at home, at school) as well as in supervised (math at school) settings. Sub questions are:

- Which characteristics of Th!nklets motivate and engage kids to play?
- Which characteristics contribute to a learning-gain?
- How can the learning experiences with Th!nklets be successfully exploited in math education?

The start of the research focuses on the first two subquestions: what characteristics make Th!nklets engaging and how can we assess what students learn from playing Th!nklets in informal unsupervised sessions, without interfering in the free-play setting? In this paper we will focus on the Th!nklet 'Share Money', a mini-game that is part of the Th!nklet collection (that currently comprises around 70 mathematical games for age group 10-12).

Task 2 of 'Share Money' with Euro coins



Task 4 of 'Share Money' with Fantasy coins

Figure 1. Interface of the Th!nklet 'Share Money' with two examples of coin-sets ('Euro' and 'Fantasy').

This Th!nklet 'Share Money' (Figure 1) is designed to support money math (basic skills like counting, addition, subtraction, multiplication and division). The coins at the top must be dragged to one of nine 'boxes' in the middle and the task is to distribute the coins in a 'fair way'. This means that in the end each box has an equal amount of money, not an equal number of coins, a mistake that is made by some children. Four different tasks are presented in the course of one month- every week a new task -. For each task a different sets of coins is used. The final task (task 4) differs from the first three, because instead of the Euro coins with known values a set of 'non-Euro' coins are used with subsequent values from 1 tot 9. When a task is finished, the player clicks 'OK' and if the solution is correct a 9-letter word will appear. This word is the 'solution' that can be sent to the Th!nklets website. Children that send in four correct solutions can win the prize of that month.

Theoretical framework

The first part of the theoretical framework is based on research into design principles and characteristics of 'good' games. In recent years, researchers have begun looking at the educational value of computer games, conducting research, for example, on the ways in which computer games can expand learning opportunities both in and out of school. An important aspect of the educational value of games is motivation, which depends for a large part on the 'flow' the player experiences in the game (Csikszentmihalyi, 1990; Overmars, 2003). The research has also contributed to our understanding of learning and design principles of good games (Gee, 2003, 2004; Squire, 2003). A difficult aspect of gaming is that the learning often stays invisible and is implicit (Leemkuil & de Hoog, 2005). One of the challenges in this research is to find ways to make the learning visible and explicit.

The second component of the theoretical framework consists of domain-specific theory on the learning and teaching of mathematics. In Realistic Mathematics Education - RME - it is important that children actively participate in the learning process (Freudenthal 1973, Gravemeijer, 1994). Other RME principles are interaction and making use of students own productions and constructions. The Th!nklets website, that offers informal mathematical challenges with game-like features, reflects the didactical principles of realistic mathematics education (Jonker & van Galen, 2004). In general Th!nklets are designed to support children in developing mathematical understanding (Drijvers & Gravemeijer, 2004; Jonker & Van Galen, 2004). Th!nklets provide an interactive environment in which children can work actively on their own level and can construct and produce ideas that raise their level of mathematical understanding.

These two theoretical perspectives both stress the importance and influence of specific characteristics of learning environments and of tasks in order to make learning possible.

Methodology

The research as a whole can be seen as a cyclic design study (or design experiment) with several phases. One of the main characteristics of this type of developmental research is the strong and constant interaction between theory and practice (Gravemeijer, 2004). Generating theoretical knowledge, for example on design principles for Th!nklets and on how students learn using Th!nklets in informal settings, and developing practical materials such as Th!nklets and a tracking system for research and educational use, are both ingredients of this type of research.

The objective of the research is to understand both the motivational aspects as well as the aspects of mathematical learning involved when playing Th!nklets. We aim to find out what children like and don't like about the design, interface and 'content', what keeps them engaged, and finally what they actually do when playing Th!nklets. Three instruments are used to gather data:

1. Statistics of the online-behavior. How long do children stay on the website of Th!nklets? At what time do they come to the website (during school time, during after school club time, prior to going to bed, etc.).
2. Online survey connected to the Th!nklet 'Share Money' with questions like:
   a. Did you play the game at home? At other locations?
   b. With whom did you play?
   c. Did you like the game? why/why not?

Previous research on the use of Th!nklets (Jonker and Van Galen 2004) learns that children do like to fill in an online survey after finishing a task. It takes only 1 or 2 minutes to answer the questions. Answers are registered automatically.

3. A tracking system to record what children actually do when playing with the Th!nklet 'Share Money'. This tracking system makes it possible to play back the actual behavior of the child and thus gives insight in the problem solving strategy. The tracking system registers every mouse click of the student with the following parameters (Figure 2):

time stamp	a value in seconds, counted from the start of the session
value of the coin	which coin is clicked and what is the value of the coin
x and y position	position of the coin after being moved by the mouse

Figure 2. The parameters of the subsequent mouse click events as part of the tracking system.

Data analysis is done both in a quantitative way (on the data gathered for all three instruments) and in a qualitative way for a set of data gathered by the tracking system. Conclusions will be drawn from the analysis of data from those three instruments.

Results

1. Statistics on online behavior of users of the Th!nklets website

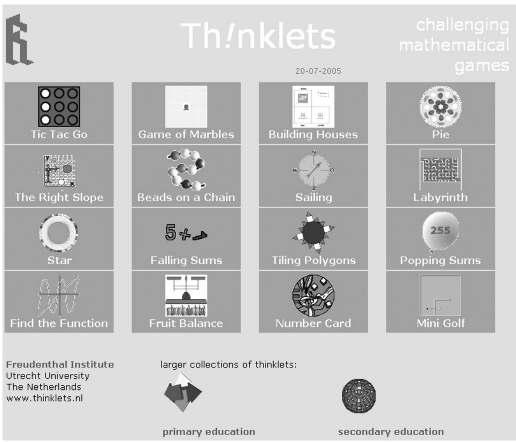


Figure 3. Screenshot Th!nklets online page www.thinklets.nl.

Although Th!nklets (Figure 3) are primarily developed for educational purposes (with an important role for teachers to introduce the software and guide the children while playing and learning), the web statistics log file of the Th!nklets web page make clear that children do play those games at home as well. The bar graph (Figure 4) shows peaks at 4 PM (when children come home from school) and 7 PM (after dinner). Apparently the mini-games are part of their gaming-culture (Kafai, 2002).

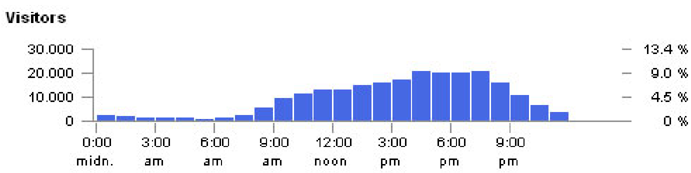


Figure 4. Statistics of the Th!nklets web page (number of visitors each hour of the day) from November 1 to 18, 2007 (1).

2. Online survey

By clicking 'Send' (see Figure 1) the online survey (for collecting facts about the players of the game and the setting in which they play) is presented with the following questions:

1. What is the 9-letter word?
2. I experienced the mini-game to be: (very difficult, difficult, normal, easy, very easy)
3. Did you like to play this mini-game? (yes/no, why)
4. With whom did you play this mini-game (alone/with a friend/with parents/with teacher)
5. Where did you play this game? (at home/ at school / other)
6. You are a (boy/girl). Age.

We will present the outcomes of the survey question by question. The population consisted of 638 children.

Question 1 – What is the 9-letter word?

- On task 1 (with Euro's) 455 out of 638 answers (more than 70%) present the right 9-letter word.
- On task 4 (with fantasy coins) 16 out of 41 answers (39 %) give the right 9-letter word. This task is more complex than all other previous tasks.

Question 2 - I experienced the mini-game to be (very difficult, difficult, normal, easy, very easy).

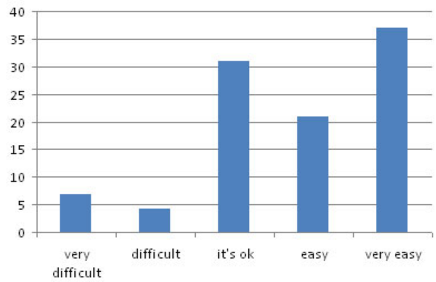


Figure 5. Outcomes on Question 2 for task 1 (the Euro-task) in percentages (n=638).

Question 3 – Did you like to play this mini-games (yes/no)?

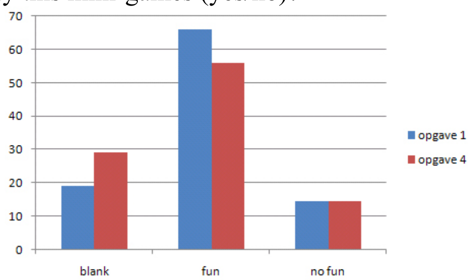


Figure 6. Outcomes on Question 3 for task ('opgave') 1 and 4 in percentages (task 1: n=638; task 4: n=41).

Question 4 – With whom did you play this mini-game (alone/with a friend/with parents/with teacher)

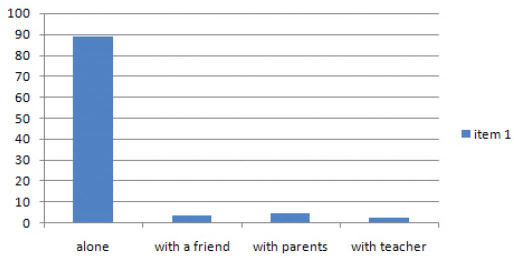


Figure 7. Outcomes on Question 4 for task 1 in percentages (n=638) .

Question 5 - Where did you play this game? (at home/ at school / other)

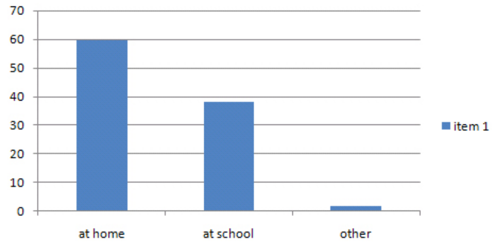


Figure 8. Outcomes on Question 5 for task 1 in percentages (n=638) .

Question 6 – You are a boy/girl. Age.

From task 1 we find an average age of 10.8 years, where 37% is a boy and 62% is a girl. The average age of about 11 years old fits into the Th!nklets web page philosophy. Most mini-games are intentionally meant for grades 5-6 (in the Dutch system 'group' 7 and 8, this equals age group 10-12). The ratio boy-girl is influenced by a greater willingness among girls to fill in the online survey (Jonker and Van Galen, 2004).

3 Analysis of childrens behavior on the Th!nklet 'Share Money'

In order to be able to find out if playing has an effect on learning we want to know in detail what children do. The tracking system recorded the following variables (as stated in the Methodology part): 1) time stamp: a value in seconds, counted from the start of the session; 2) value of the coin: which coin is clicked and what is the value of the coin and 3) x and y position: position of the coin after being moved by the mouse. The data set of the subsequent mouse clicks during one session can be used as input for the 'Share Money Analyzer' where the researcher can replay the played sesson.

Qualitative analysis - task 4

Since it is possible to play back each session a qualitative analysis is possible. We did this for task 4 in the Th!nklet 'Share Money'. This is the most difficult problem for which a straightforward strategy of dividing the coins in order of their value does not work. An extra effort is needed to finally make combinations that will work.

We analysed 41 solutions, 25 of which were incorrect and 16 correct. If we look at the time on task related to the result (correct or incorrect) we see the following pattern.

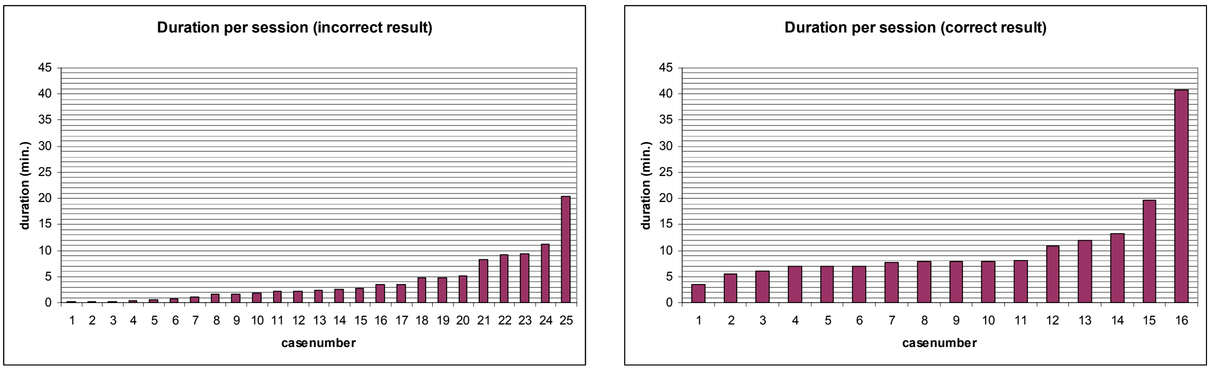


Figure 9. Duration per session on task 4 (n=41).

For incorrect results the duration is shorter: average around 4 minutes, for correct results the average is about 10 minutes, (8 minutes without the online survey part). It is interesting to see what actually happened in the longest session with an incorrect result an the shortest session with a correct result.

Analysis longest - incorrect - solution

When analysing this solution (no.25 in the left graph of Figure 11) step by step, it turned out that in this session after about 5 minutes a correct solution was found. This was not acknowledged by clicking 'OK'. The process of sharing money continues and several times during this process another correct solution is found, but the result is never submitted. There are some long breaks in the process, the longest one lasted for over 3 minutes. In the end all coins are removed from the playing field and are back in their starting position. Only at that time (after about 20 minutes) the anonymous player clicked the button 'OK'. In the online survey the only filled in field showed that the player thought the activity to be 'hard' (5); further we know when it was send: a Saturday morning at 11:15. Since no other information was provided on the form we can only guess what happened: maybe a teacher was preparing the use of the Th!nklet in class by trying out several solution methods, maybe a group of children was playing together taking turns.

Analysis of shortest - correct - solution

The whole solution process of this session took a little over 3 minutes, 49 steps were needed. It was a clear concise process of dividing the coins systematically over the nine field on the playing board. There are no very long breaks in this process, the longest one took 13 seconds the next longest 9. All other actions follow each other mostly within 3 seconds.

Player starts by dividing the three coins with the highest value i.e. 9, and then makes 9 in the other six fields as well (left picture of Figure 10). Then a mistake was made: player starts adding another total of 9 to each field, after two fields the mistake was discovered and the coins were removed. Now a total of 10 is created in each field by moving the coins with values 1 and 2 in the playing board one row up (middle picture of Figure 10). After a break of 13 seconds the last row is filled, by adding the coins with value '3'. Then after a pause of 9 seconds the other coins are distributed: the 6-es are added to the 9-s in the first row and the ones are moved within the playing field to the bottom row, so that finally each filed has a total value of 15 (picture on the right of Figure 10).

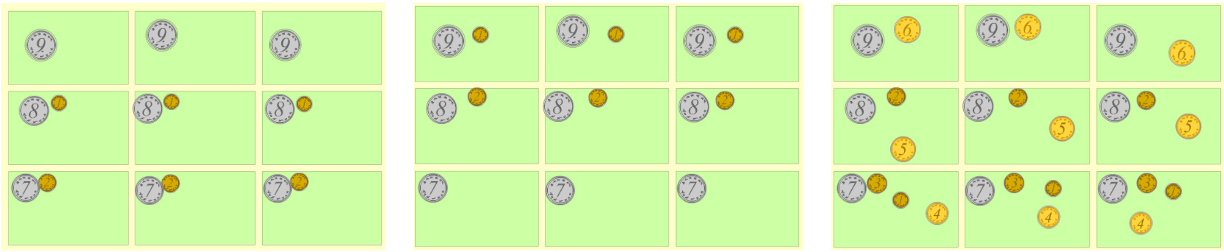
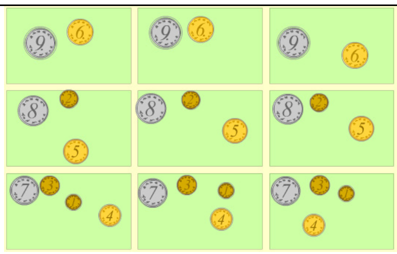


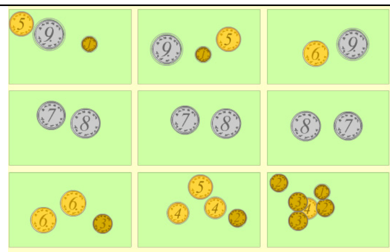
Figure 10. Subsequent situations of the shortest – correct – solution analysed.

Other information: player is a girl aged 11 who is playing alone, she thinks it is fun, scores difficulty medium and writes: it is fun because it is 'not too easy'.

We can conclude from the playback of sessions that we may need to include more variables in a detailed quantitative analysis. For example we could use the time between each two actions to detect pauses. Pauses may be used for thinking or calculating. One example of a thinking pause is found in the solution of a boy of 10 who finds it pretty hard but fun. The boy starts by distributing coins with value 1 and 2, then after some thought he removes the coins (45 seconds have passed). Now for 2 and a half minutes nothing happens. Then in about a minute a fully correct solution is laid out. This solution: found by thinking or calculating differs from solutions found by just moving coins in that it does not show a regular pattern (Figure 11):



solution found by shuffling coins (used mostly)



Solution found with long pause by the 10 year old boy (used rarely)

Figure 11. Two solutions of task 4.

Conclusion

In this research we focussed on the use of the mini-game 'Share Money' that was played by 600 Dutch children age 10-12 years old. We formulated the main research question "Can playing games contribute to the learning of mathematics?" and operationalized this question into three more detailed questions.

1. Which characteristics of Th!nklets motivate and engage kids to play? From our research we can state that:
    - It is important that the game is accessible both from a classroom setting and home setting;
    - Online (free) accessibility of those mathematical games makes it possible to play the games during the whole day, children can choose their own moment of playing;
    - Children do not experience the tasks as mandatory, they play it for fun.
    - Characteristics that make this Thinklet 'fun' for kids can be derived from the answers on the open part of question 3 'why is it fun/no fun', We distinguish three main groups of characteristics that are mentioned:

- Level of difficulty in relation to ability of the player (hard, a challenge, easy, I'm good at it);
  - Characteristics of the game content ('I like money');
  - Characteristics of the activity (I like to puzzle, to calculate, to think, to learn, I like math).
- The average duration of playing one task of the Th!nklet Share Money with a correct result is between 5 and 10 minutes. We hypothezise that this is a duration that is attractive for this age group. To test this hypothesis we will analyse and compare data of other popular and less popular Th!nklets.
- It is important that the task is not too difficult and also not too easy in order to have a right 'flow' (Csikszentmihalyi, 1990).

2. Which characteristics contribute to a learning-gain?
   It is too early to draw hard conclusion. We assume that the fact that children can keep going on, there is no time limit and a coin can always be moved again to another part of the playing field or to the side, and the fact that they are in control, contribute to learning. During the process of solving the task we can see that decisions are being made towards a correct solution or towards a more systematic approach (sometimes all equal coins in the same box). This indicates learning taking place. It is yet unclear if this learning only applies to the task they are doing or whether a strategy is also applied to the next tasks or even to other tasks. In the further research we will look more deeply into this.

3. How can the learning experiences with Th!nklets be successfully exploited in math education?
   - The money context is important for basic skills. We think that using mini-games like 'Share Money' can enrich the mathematics lessons. But:
   - We do miss the involvement of the teacher. This will be the challenge of developers and researchers and on-going research: to explore possibilities that both student and teacher will be involved in playing and using the mini-games.

Importance of the study

Research in the field of computer games and education connects several themes: 1). The growing awareness that children learn both in and out of school; 2). The shift in attention from teaching to learning and from teachers to learners; 3). The view of learning as an enjoyable, social activity; 4). The focus on the role of information technology in collaborative learning; and 5). An understanding of the motivational aspects of learning. These observations apply not only to games and education generally, but also to games and mathematics education specifically.

Technology is changing the traditional setting of a mathematics lesson. Intelligent software (like Th!nklets described above) can take over the hours of practice that nowadays is done by the teacher with a whole class. Children can work on their own level and in their own time (including home). The teacher will get more time to concentrate on reasoning and reflection, on group dynamics and individual support.

The study shows that the development of game-like activities like Th!nklets can enhance the mathematics lesson and make a natural bridge with home learning.

Endnotes

(1) Source: Sawmill (Universal log file analysis & reporting)

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