Studying the User Experience of a Tablet Based Math Game

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ABSTRACT

This paper presents the first findings from Math Elements user experience (UX) studies. Math Elements is a game that makes the whole Finnish maths K-2 curriculum (kindergarten and primary school grades 1 and 2) available for players all over the world. The game is based on teachable agent approach, which means that in the game players can teach math skills to their game characters. Research focused on evaluating the implementation of the game, exploring players' opinions about the game, and studying how the game fits to classroom usage. The participants were Finnish (N = 111) and Irish (N = 42) primary school pupils. In both cases interviews, game log data and observation methods were used to evaluate the UX. The Finnish study was conducted in two phases. First, one first grade class (N = 23) participated in a focus group study in which they played the Math Elements game in small groups and finally eight of the pupils participated in an eye tracking study. Second, the class introduced the game in their school and after that all first and second graders of the school played the game daily during a three weeks period. The Irish case study was different from Finnish study and the results are not directly comparable. The Irish pupils (fourth and fifth graders) played the game for 50 minutes as a part of their regular schoolwork. In general, Math Elements was experienced as an engaging learning game in all studied age groups and it was found to fit well into classroom usage in certain contexts. The paper presents the details of the conducted UX studies and discusses the meaning of UX in educational games.

Keywords: *Eye Tracking, Game, Learning, Tablet Personal Computer (PC), Teachable Agent, Usability Test, User Experience*

INTRODUCTION

The evaluation of the subjective playing experience is a crucial part of the game development process. The aim of game designers is to create appealing experiences for all players. Thus, games can be seen as artifacts that arouse experiences (Schell, 2008). According to Dewey (1938/1997) experience can be described as a continuous interaction between human beings and their environment. Dewey states that the experience is a result of interplay between the present situation and prior experiences. Consequently, players do not have identical playing

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experiences but each player's experience is totally unique. Game designers cannot design the subjective experience directly; only the context from which the experience arises may be designed. Thus, the development of games that please as many players as possible and are still educationally effective is a big challenge.

Several models of user experience have been proposed (e.g. Buxton, 2007; Forlizzi & Battarbee, 2004; Forlizzi & Ford, 2000, Garret, 2003). The user experience is often paralleled with usability (Nielsen, 1993), although usability does not consider users' subjective views or the emotional side of product use deeply enough. In fact, the user experience approach extends usability techniques (Lew, Olsina, & Zhang, 2010) that are aimed more at the removal of obstacles from a technical perspective than facilitating engaging and rewarding experiences. User experience is focused on the interactions between people and products, and the experience that results in certain contexts of use. The characteristics of the users, such as emotions, values and prior experience, determine how users perceive a game and the related learning goals. In general, user experience should be considered exhaustively from physical, sensual, cognitive, emotional, and aesthetic perspectives (Forlizzi & Battarbee, 2004). Thus, we argue that plain ease of use does not guarantee good user experience and engagement.

According to Fredricks, Blumenfeld and Paris (2004) engagement is seen as a multifaceted phenomenon that consists of three dimensions: behavioural engagement (involvement with activities), emotional engagement (positive and negative reactions to activities and actors), and cognitive engagement (investment). Within these dimensions engagement can vary in intensity and duration. Thus, engaged users show sustained behavioral and cognitive involvement in activities accompanied by a positive emotional tone. In general, it is crucial to understand that engagement with the educational game must be established before effective learning can be achieved (Whitton, 2011). The positive relationship between cognitive and motivational themes for example in mathematics learning has been widely studied (e.g. Rao, Moely & Sasch 2000; Lapointe, Legault & Batiste 2005; Mason & Scrivani 2004). However, there is no absolute understanding that increased motivation also automatically increases the learning outcomes. In the authors' previous studies the positive learning outcome, as well as the high motivation towards game play have been shown (e.g. Ketamo & Suominen 2010).

The basic elements that comprise every game are mechanics, story, aesthetics, and technology. These are all essential and none of the elements is more important than the others (Schell, 2008). In the case of educational games, the learning objective is also included, which makes the design of the user experience even more challenging. As Quinn (2005) has argued, educational games have to be designed properly in order to incorporate engagement that integrates with educational effectiveness. Because there is no certain recipe that guarantees the success, user studies need to be conducted during the development process.

In this paper we report the results from two user experience (UX) studies in which a mathematics game called Math Elements was evaluated. Math Elements is a game that makes the whole Finnish primary school's math curriculum available for players all over the world. In this study several research methods were used including observation, interview, and eye tracking. Because eye tracking is rarely used in educational game research we start by briefly describing the possibilities that it provides for researchers and game designers. After that the Math Elements game is presented and finally the results from the UX studies made in Finland and Ireland are presented.

EYE TRACKING IN GAME BASED LEARNING RESEARCH

Observing users' eye movements has a long tradition in the field of usability as well as in psychology. In recent years, the adoption of eye tracking in various research fields has increased. Eye tracking is based on identifying fixations (processing of attended information with stationary eyes) and saccades (quick eye movements occurring between fixations without information processing). Fixations usually last approximately 200-500 milliseconds depending on the task. Thus, when a person interacts with a visual environment, he or she makes a sequence of fixations separated with saccades. In the eye tracking method fixations and saccades are used to index mental processes that are on-going when a person interacts with a visual environment. Research relies on the assumption that a person attends to and processes information he or she is currently looking at. Hyönä (2010) reminds us that this assumption holds only if the visual information is relevant to the task at hand. Furthermore, although eye tracking can reveal what a person perceives, it does not tell us whether or not the person comprehends the information that he or she was looking at. Thus, eye tracking should be complemented with offline measures such as retrospective comprehension testing or retrospective think aloud methods.

According to Hyönä (2010) eye tracking has quite a long history in reading research and recently it has been applied also to multimedia learning (e.g. Mayer, 2010; Boucheix & Lowe, 2010; Meyer, Rasch & Schnotz, 2010). For multimedia learning research, eye tracking has provided more detailed information about established multimedia principles and the ways in which different people process certain materials. So far, the use of eye tracking methods in game based learning research and educational game design has been minor (Kiili & Ketamo, 2010). However, for example Kickmeier-Rust, Hillemann, and Albert (2011) have shown that eye tracking can be successfully applied to measure the quality of serious games. Based on eye tracking results Law, Mattheiss, Kickmeier-Rust and Albert (2010) have argued that the layout of the game plays a bigger role than the content in capturing user attention. In general, for game based learning research, eye tracking can provide new knowledge about how learning happens in games, what game elements can be used to enhance learning, how to focus player's attention to important game elements, how to avoid evaluation gulfs and how feedback is perceived and how graphical implementation is perceived (Kiili & Ketamo, 2010). Such knowledge can help educational game designers to develop higher quality educational games.

One important analysis tool in eye tracking is Areas of Interests (AOI). AOIs are areas of a display or visual environment that is of interest to the researcher and thus predefined by them. AOI analysis is used to quantify gazed data within a defined region of the visual stimulus. The number of fixations on such particular display element indicates the importance of that element. Consequently more important display elements will be fixed on more frequently and for longer. Regarding the evaluation of educational games, such information is crucially important since it provides very clear indications of which elements on the screen are attended (sufficiently) and, which elements may be missed during playing.

THE DESCRIPTION OF THE MATH ELEMENTS GAME

The development of the Math Elements game has a long research history. The basic idea of the game, teaching a game character, is based on the AnimalClass game (e.g. Ketamo & Kiili, 2010; Ketamo & Suominen 2010) and the Teachable Agent approach (e.g. Ketamo 2009; Ketamo 2011; Biswas, Leelawong, Schwartz & Vye, 2005). From an educational outcome point of view, AnimalClass was a successful game, but it never made a worldwide breakthrough in everyday classroom use. AnimalClass did not appeal to teachers enough, because the idea of the game was too difficult to understand and AnimalClass was only a collection of separated themes. The Math Elements game tries to solve these two major challenges. That is to say, gameplay is continuously developed based on user feedback and the game makes the whole Finnish K-2 mathematics curriculum (kindergarten and primary school grades 1 and 2) available for players all over the world.

A background story is used to engage young users and facilitate the protégé effect (Chase, Chin, Oppezzo & Schwartz, 2009). According to the story, mice can get cheese only by getting through mathematics labyrinths faster than cats can. Initially, cats are cleverer in mathematics than mice and thus the cheese-loving mice need players' help in learning mathematics. The player's task is to teach necessary skills to his or her pet, that is, to a mouse. The game includes several mice that the player can choose from, which facilitates the bond between the player and his or her pet. When a player has taught enough skills to the pet, the player can send it to the labyrinth to survive on it's own against the cats. In general, the gameplay can be divided into two main functions:1) teaching the agent behavior (i.e. mathematics skills to the pet) and 2) running (reproducing) the agent behaviors (i.e. running a labyrinth simulation that is based on knowledge that mice have been taught).

Teaching the Agent Behavior

The framework for teaching behaviors to teachable agents and reproducing the behavior is based on the authors' previous work both from a cognitive science point of view (Ketamo & Kiili, 2010; Ketamo & Suominen, 2010; Kiili & Ketamo, 2007) and from a technological point of view (Ketamo, 2013; Ketamo, 2011). The AI behind the framework emulates the human way to learn: According to the cognitive psychology of learning, our thinking is based on conceptual representations of our experiences and the complex relations between these concepts and experiences. The phenomenon occurring when the mental structures change is called learning.

In Math Elements' teaching area, the player helps his or her pet (teachable agent) with different tasks. In Figure 1 the Owl asks about multiplication tables and the pet should answer the Owl's question (e.g. what is 3*10?), but because the mouse does not know the answer, it asks the player's help. The player should point out the answer to the pet. The pet learns inductively – case by case. So, in terms of pet's brain the answer is not either correct or incorrect, and each pointed answer builds a new "is equal" connection between concepts "3*10" and the answered concept, let's say as in this case "30". Furthermore, the concept of "3*10" is connected to concepts of "1*3" and "3" with "is not equal" connection. After the teaching of several concepts, the AI has learned a semantic understanding of what is equal and

Figure 1. Screenshot from teaching area of math elements

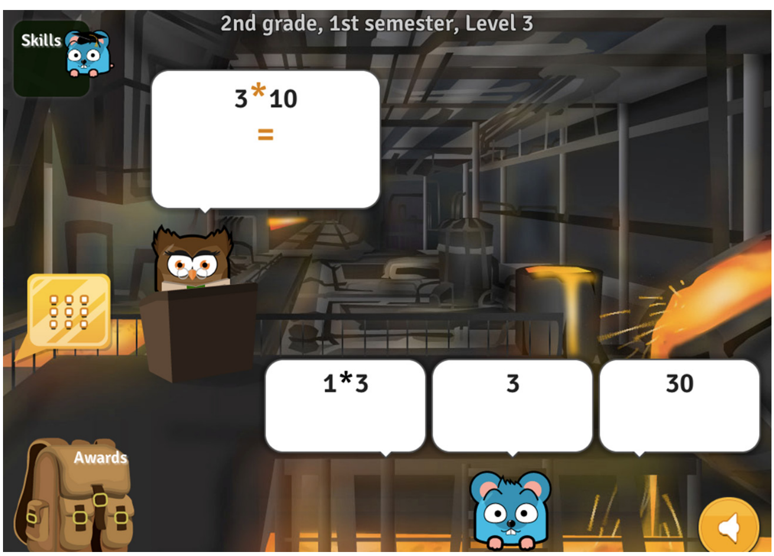


Figure 2. Screenshot from competition area

what is not. All in all, the AI learns exactly how it is taught and the semantic network in game character's AI evolves. The game AI has also "perfect brains" that enables character performance analyses. Finally, when the player has taught enough conceptual relations for his/her pet, a challenge icon appears on the screen. By clicking the icon, player sends his or her pet into the labyrinth to compete against the cat.

It is worth noting that the pet can also be taught wrongly. However, the pet that has been taught wrongly does not perform well in the labyrinth race against cats and thus new levels are not opened for the player. Nevertheless, teaching wrongly on purpose is mentally the same operation as teaching correctly, only in reverse. In other words, it requires same or higher skills than teaching correctly. Furthermore, in our previous studies we have found indicators on a positive relationship between teaching wrongly on purpose and good learning outcomes (Ketamo & Suominen 2010). However, the possibility to teach cats wrongly was excluded from the game version that was used in the studies of this paper. This was done to make the gameplay easier to understand in the beginning.

Reproducing the Agent Behaviors

When the mouse has enough knowledge about the theme of the level, the player can send it to compete against a cat in the mathematical labyrinth (Figure 2). In the competition the player's pet is on it's own and all the performance is based on previous teaching. Both characters proceed in the labyrinth by picking doors according to their taught behavior (knowledge). If the player has taught enough to his or her pet, the mouse will win the race and catch the cheese. In general, a player can compete against any other non-player character or character taught by other players. Furthermore, a player can challenge characters whenever he wants to, no matter if the human player is online or not, because all the taught behavior is always available online. While observing their own pet's behavior and progress in the labyrinth, a player can also revise the content of the game, can find strengths and weaknesses of his or her pet and can thus develop his or her understanding of the theme of the game.

User Experience Principles Applied in the Design of Math Elements

The Math Elements game is not designed according to single UX framework but several principles that relate to UX are taken in to account. Flow experience (Csikszentmihalyi, 1991) in particular has been applied in the design. The game provides clear and easily perceived *goals* for the player. The player can determine sub-goals during play that facilitates the experience: unlock labyrinth, win a cat, achieve three stars from the level, pass the first grade, and teach perfect mouse. The *feedback* that the game provides is designed in the way that the player can evaluate whether he is on track toward his goals or not and this also helps in monitoring playing performance. The gestures of the owl and the mouse give immediate feedback to player about the performance. The gestures are implemented in the way that player cannot miss them and aim to stimulate the player to reflect on his activities. In other words, the feedback focuses the player's attention on information that is relevant for learning objectives. The game is designed to provide *challenges* that are balanced with a player's skill level. The idea behind adaptation is based on the author's previous work (e.g. Ketamo & Multisilta 2003; Ketamo 2003). In brief, the adaptation mechanism is measuring the speed of interaction and the relative number of mistakes. When the speed of interaction is fast enough and the relative number of mistakes is small, the probability of good enough skills is high (goal of the level). On the other hand slow interaction with a high number of errors refers to difficult content and the player is not ready to manage the next level yet. Learning is most effective somewhere between these two extremes. From a flow optimization point of view, when there is not enough challenge, the goal of the current level is received and access for more challenging levels will be opened. The adaptation of game content facilitates the *sense of control*. The feeling of being in control frees the player from thoughts of failure and thus the player is encouraged to perform more exploratively. Furthermore, the labyrinth race and included learning analytics visualizations facilitate the sense of control. On the other hand, the teachable agent approach supports the *loss of self-consciousness,* which means that the player can ignore what others think of him or her during playing. We have noticed that players engage the game more when they can blame their pet about possible failures – "I am not bad in mathematics, my pet is!" This enhances players' self-esteem that is very important in mathematics learning. Finally, we have invested a lot in optimizing the *learnability* of the user interface. The user interface is designed to be intuitive to control and signalling effects and short story-based comic strips are used to ensure the rapid adoption of the game.

Technical Description of Math Elements

Technically Math Elements is an online game with client-server architecture. The Client side is written in HTML5, which turned out to be a relatively powerful and cost-effective way to produce user interfaces. Game mechanics run on the server side, and are built in Google AppEngine. The mechanics used enable game characters to compete against any other character at any time, no matter if the opponent is actually online or not, because all behavior is always available online. Google AppEngine, as well as other big clouds such as EC2 and Azure, provides global access for millions of users. Some years ago the bottleneck for intelligent server-side game AIs' was computational power. Nowadays the bottleneck occurs only in the case of millions of users, unlike with traditional servers or small clouds are also limited by network bandwidth. One of the big differences between building the backend into a global cloud and traditional server is in terms of data storage. In a small cloud, usually employing a dedicated server (or cluster) data can be stored and accessed in one unique place, usually an SQL server. In global clouds, with millions of users, the data should be stored in distributed storages.

MATH ELEMENTS STUDIES

Math Elements in a Finnish School

The aim of this study is to evaluate the implementation of the game, explore players' opinions about the game, and study how the game fits to classroom usage. The study consists of three sub-studies each having a certain focus: 1) The focus group study focuses on learnability, first impression and general use of the game, 2) The eye tracking study focuses on visual implementation and feedback mechanism of the game, and 3) The field study focuses on classroom usage and persistence of engagement during a longer playing period.

Focus Group Study

Participants and procedure. The Finnish focus group study was conducted in May 2012 involving 23 first class pupils. The research procedure was as follows: The participating class was divided into 2-4 pupils groups and each group received 1-2 iPads. Pupils started to play the game with minimum instructions. Playing time was approximately 90 minutes. Researchers observed pupils playing and focused especially on the following themes: how fast pupils understood the idea of the game, what was difficult, what was too easy or boring and what kind of social activities occurred. Researchers were allowed to assist pupils during the game play only in verbal way. No identities or other notes that might make recognizing the pupil possible were written down. During the playing session researchers interviewed pupils and discussed with them in groups. Interviews and discussions focused on following themes: what was their first impression of the game, what was good and interesting, what should be changed in order to improve the UX, how many would like to continue playing the game, and how many would like to invite their friends to play the game. After the playing session pupils received a URL for the game to allow them to continue the gameplay at home, if they want to.

Results. Starting the gameplay in groups went well: during the playing session pupils discussed about game and mathematics. The correct answers were the most discussed theme. In general, the first impression was positive: tablets were easy to use, the game, story and the game characters were good enough to encourage pupils to learn mathematics, even though some of the pupils said that they hate mathematics. Many pupils liked to play the game in groups but if enabled relatively many played the game on their own with great concentration.

The labyrinth challenge was experienced as fun and exciting. Almost all players felt they were successful in the labyrinth and that motivated them to do even more work for their game characters. Players felt that they were responsible for their game characters' performance in labyrinth competitions and they tended to empathize with their game characters' successes and failures. Although pupils played only a limited time the Protégé effect could be recognized. The Protégé effect describes learners' tendencies to work harder for their teachable agents than for themselves (Chase et al., n.d.).

Although the experiment went well in general and the game was liked, several development issues came up. One of the most important was related to starting the game. The devices (iPads) were easy to use but sometimes the touchscreen did not react to the finger movements in the way that pupils expected, which confused players; players started to think whether they did something incorrect or not and after that they tended to just press something irrelevant. For some pupils it was difficult to notice which interactions related to questions and which related to answering. This issue will be fixed by applying appropriate delays in the discourse and by strengthening the facial feedback expressions of the characters.

Furthermore, when starting the game, pupils expected to see a demo or animation about the gameplay. Also the speed of instructions was not optimal for all pupils. Buttons or icons to skip the instructions and to get back to instructions were needed. These issues occurred only when players started the game first time and after few minutes of gameplay there were no misunderstandings or need for further instructions. However, the fist impression is very important and thus the beginning of the game has to be intuitive. Several changes to the user interface were made after the study and the current version now has most of the functionalities that players demanded.

Another major problem was the appearance of the go-to-labyrinth icon on the upper right corner of the screen. Some of the players did not notice it and they felt that teaching their pet required far too much time. After this study changes to the appearance of the icon were made and visual signalling and sound effects were added.

From a mathematics point of view the concept of a number line was felt as being difficult. Maybe this was not completely because of the game; it seems that children are not familiar enough with different ways to express numbers and their order. However, the concept of a number line is an important theme in mathematics and it should be presented in the game so that pupils understand it and learn to apply it.

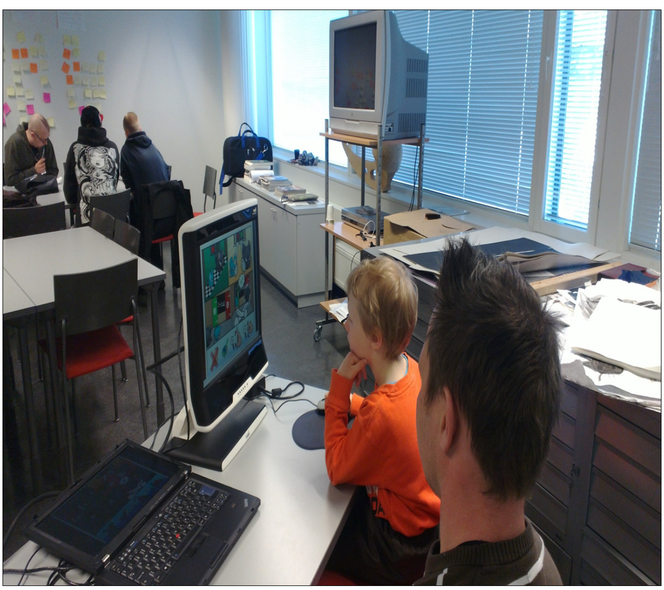
Finally, more than 90% of the pupils told that they will continue the game at home and they will introduce the game to their friends. According to log data, there were spikes in traffic after all playing sessions, which indicates that pupils really did so.

Eye Tracking Study

Participants. Eight pupils from the focus group participants were randomly selected for the eye tracking study (6 boys and 2 girls). The aim was to deepen the results gathered from the focus group study and to investigate the visual implementation and feedback mechanism of the Math Elements game.

Eye tracking device. A Tobii T60 eye-tracker with a 17 inch display was used to record players' eye movements (Figure 3). Large freedom of head movement allows players to behave naturally during the playing session. Furthermore, the Tobii T60 has no visible or moving "tracking devices" that might affect the subject. The Tobii analysis software was used to record the eye movements, operate the calibration process, and replay the recordings of participants' eye movements.

Figure 3. Recording participant's gaze plots with Tobii T60 eye-tracker



Eye tracking measures. Eye tracking was used to explore three research questions. 1) Does the player notice the gestures of the game characters (gestures are used to give feedback on player's performance) presented in the teaching area. In order to study the gestures two areas of interest (AOIs) were formed: The gestures of the owl (teacher in the classroom) and the gestures of the mouse (player's pet) were monitored (see Figure 4). In practice, AOI analysis was used to quantify the eye movement data related to the owl and the mouse. In this study we made the AOI analysis based on the fixation counts and fixation lengths. In order to deepen the analysis the gaze sequences were qualitatively analyzed. 2) Does the player notice and try to solve the math tasks when racing against the cat in the labyrinth. The gaze data of the race was analysed qualitatively, because the dynamic nature of the race did not enable AOI analysis.

Eye tracking procedure. The participants were tested one by one and they were already familiar with the game. First, the eye-tracker was introduced to participants. Second, the eye-tracker was calibrated. Third, the participant answered some background questions and after that they started playing the game. Participant played the game for approximately 5 minutes and finally they competed against the cat in the labyrinth. After the playing phase a retrospective interview phase followed. In practice the researcher and the participant watched a replay of the recorded racing session with gaze plots. The meaning of the gaze plots was explained to the participant. The researcher stopped the recording in crucial places and asked questions from the participant. For example, did you notice the tasks on the black boards or what does the colors of the doors mean?

Results. During the eye tracking session players taught approximately 15 questions to their mouse. In the teaching area players could concentrate on presented tasks and their game characters as the hot spot map shows (Figure 5). Table 1 shows that players paid much more attention to their mouse character rather than to the owl (teacher). As we can see the fixation count varies a lot between players. Furthermore,

Figure 4. Areas of interest that was monitored (owl: pink, mouse: orange)

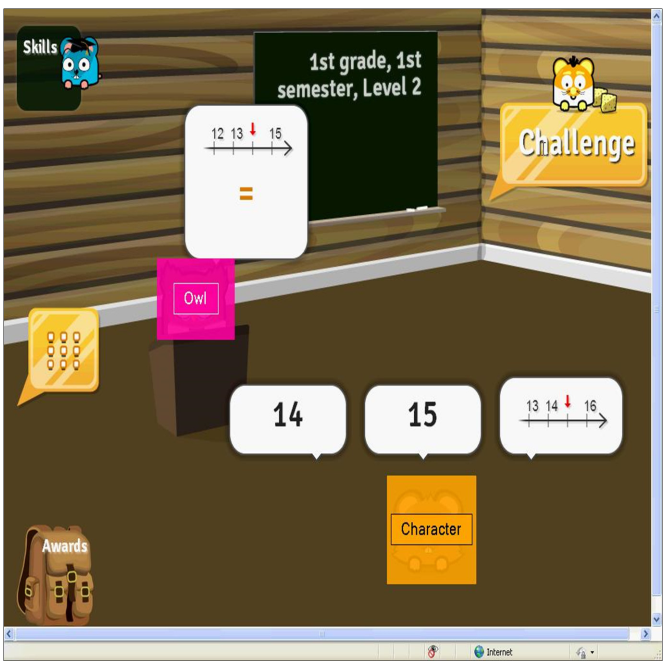


Figure 5. Hot spot map from participants' fixations in the classroom scene

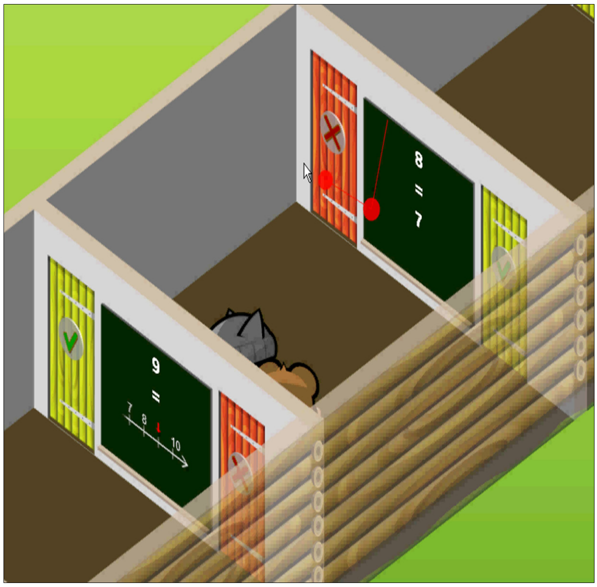
Table 1. Fixation counts on the owl and the mouse

	N	Min	Max	M	SD
Mouse	8	1	17	11.5	3.25
Owl	8	1	5	3.0	1.0

the fixations on the mouse were longer (M = 0.408) than on the owl (M = 0.261). However, when interpreting the hot spot maps and fixation counts on AOIs, we have to remember they give only superficial results about the game's user interface. The investigation of fixation patterns is crucial in dynamic games. The gaze replays indicated that most of the players' fixations were made when the owl or the mouse provided cognitive feedback to the player. On the other hand, the retrospective interview revealed that although some of the players fixated on the owl they did not notice its gestures. Probably the timing of the gestures have affected this – the owl's and the mouse character's gestures are shown at the same time and it is natural that the player is more interested in his or her own virtual character rather than in other game characters. All the players were aware of the mouse's gestures and knew what they meant. Because the meaning of the mouse's and owl's gestures are parallel, there is no need to strengthen the gestures of the owl.

The analysis of labyrinth races revealed that players tend to pay attention either to their mouse or to the tasks that are presented on labyrinth's black boards. Half of the tested players concentrated on the tasks and tried to solve the tasks during the race. After solving a task these players tended to fixate on the door that they thought to be the right answer as seen in Figure 6. For these players the race was a reflection tool that helped them to figure out what their mouse knows and what it does not

Figure 6. Fixation on the door that a player thinks to be the right answer in the labyrinth race (red dots are fixations and red lines saccades)



know. Thus, in the case of these players the race facilitated the reinforcement of learning of the content. On the other hand, half of the tested players followed only the race between their mouse and the cat and totally ignored the tasks. Such behavior is not effective from a learning point of view. However, in this study the participants played the game for only so short a period that the attraction of the thrilling race may disappear later and players' can concentrate also on presented tasks. Nevertheless, the retrospective interviews revealed that two of the eight players did not at all understand that the classroom activities affect the race. They were very disappointed when their mouse lost the race, but they did not understand the possibility to correct the situation in the teaching area.

Field Study

Participants and procedure. The aim of the field study was to investigate how the Math Elements game fits to daily school practices and how the pupils experience the game when it is played for a longer period of time. The field study was a continuum to the focus group and eye tracking studies and the sample consisted of the focus group participants and other first and second grade pupils of the same school. Altogether 111 pupils participated in the study. The focus group students and their teacher introduced the game to the next class that started to use the game in daily practices.

The pupils (each class) played the game for three weeks as a part of their regular schoolwork. On average pupils played the game approximately 30 minutes per day in 3-10 minutes sprints, five days per week. The total playing time was approximately 8 hours on average. After the three-week playing period they then taught the next class to use the tablets and play the game. Teachers (n=6) made observations and interviews in their class in order to anonymize the data and in order to remain good ecological validity (natural test environment) while conducting the study.

Results. Pupils learned the game very fast and the deployment to school was successful. The changes that were made after the focus group session facilitated the adoption process.

In the beginning all the pupils were highly motivated and enthusiastic but for many pupils the eagerness decreased after two weeks. Especially girls get bored after two weeks. They felt that the game is all the same and does not provide enough possibilities. However, many boys, especially the impulsive ones, were engaged in game playing during the whole 3 weeks period.

Most of the pupils of the class who first used the game felt that they were taking care of their characters when they taught them in the beginning. However, because each class used the same tablet devices the following classes got already taught characters. This lowered the engagement because pupils didn't feel that they were teaching their own characters and they did not form as strong a bond with their characters as the first experiment class. They just continued with somebody else's game and that decreased motivation. Furthermore, most of the pupils changed the characters once in a while, and they were not focused only on one character – we assume that the shared game devices influenced on this.

In general, the motivation towards mathematics and numeracy increased during the experiment period. In particular, group discussions on mathematics stayed in better focus because of the game play. There were no bottlenecks in the game play, no downsides on learning or fear of failure. Teachers felt that the game was good for revising and assessing already taught themes. They also expected more detailed reports on children's learning activities. However, where we don't have one device per child -setting at school, this can remarkably decrease 1) teachers' possibilities to receive reliable data about pupils' performance in the game - if the game can be played by any pupil, the analytics won't tell teacher too much and 2) children's motivation towards the game as discussed above.

Math Elements in an Irish School

Participants and procedure. In March and November 2012 the game was studied in a primary school in Dundalk, Ireland (n=42) involving fourth and fifth graders (aged from 9 to 11 years old). The class sizes were 20 and 22 pupils, which are fairly typical for the Irish education primary school sector and consisted of an almost equal mix of boys and girls, with children from different socio-economic, cultural and ethnic backgrounds. Also, the class group contained a mixed ability range from higher achievers, normal achievers and also a number of children who were under achieving (particularly in mathematics) and receiving additional support teaching in this area.

The main research objective was to observe:

1. How easily would the Math Elements game fit i.e. to a typical Irish primary school fourth class given the minimum of introduction to teachers and pupils, preparation or technical infrastructure setup?
2. Even in such a limited initial live trial, how would the outliers i.e. those pupils who had been identified as underachieving in mathematics in particular, respond to the game as compared to their normal learning experience?
3. What impact might using the game have on a live classroom environment, with a realistic mathematics learning assignment, in terms of group interaction and group dynamics between learners and also between learners and their teacher?

After a brief introduction to the game and the learning task (which involved a range of fraction based arithmetic problems and questions e.g. comparing fractions, adding, subtracting and multiplying fractions, using percentages) the class was split up by the teacher into 4 mixed groups of between 4 to 6 pupils in each. Each group was given their own tablet PC. Furthermore, each group was split into two sub-groups of 2-3 pupils each, the first being active participants and the second being passive observers. It should be noted that there was little ICT support or infrastructure available for the trial. The wireless network proved unresponsive and very unreliable and so a network connection was temporarily constructed via a standard mobile smartphone using 3G and providing a WiFi hub to the 4 tablet PC devices. This solution proved stable and was favourably received by the teachers involved.

Pupils were then asked to begin to play the game, including completing the initial tutorial, training their mouse character and then challenging the clever cat. They were asked to see how many game levels they could solve. Each gameplay session lasted about 25 minutes and was carefully observed and assisted by the teacher, the resource teacher (who provides the specialist learning support to underachieving pupils) and also by the research team. The sub-group roles were then reversed allowing each pupil the opportunity to be both active and passive in gameplay and interaction. Finally, after the two gameplay sessions, the teacher facilitated a lengthy question and answer session between the pupils and the research team, where reaction to the game was gauged as well as comments and feedback given on all aspects of the games functionality, playability and user interface / interaction.

Results. During both gameplay sessions observers noted a high degree of positive engagement, interaction and active participation from all of the pupils. Pupils were focused, generally quiet as well as being cooperative and well behaved. There was a rapid uptake, with very few questions or indications that anyone was stuck or overly confused. Both the classroom teacher and the specialist resource teacher commented on the high degree of discussion and interaction within the sub-groups and also between the 4 large groups. Children also moved between groups, formed standing groups and used support materials (e.g. fraction charts on the classroom walls) for reference. In particular, the class teacher was very impressed by how the multiple instances of gameplay actively facilitated good group interaction. Likewise, in the second session of gameplay, where active and observer roles were reversed, the more passive observers still maintained a high degree of interest and input into the task. Their group dynamics had a degree of competitiveness, especially between groups when a mouse was playing against a cat, and groups actually waited and also observed other groups between levels, as the other groups attempted to complete each level.

Two of the groups (with mixed abilities in each) completed all the levels provided in the study and all groups got through at least 7 levels. In particular, it was noted by both the class teacher and the resource teacher that underachieving pupils in particular had engaged and succeeded to a very noticeable degree. Although it was not possible to provide objective quantification for this in such a limited scope trial, this behavior and feedback was particularly encouraging. Furthermore, the decision to limit the number of tablet PC devices to just 4 (giving a ratio of between 4 to 6 pupils to each game instance) was felt to be a good decision as it greatly encouraged sub-group and inter-group discussion and interaction.

There was no opportunity to consider using the learning analytics of the game in this trial. Furthermore, more substantial trials are being planned, which will allow for this aspect of the game to be integrated and evaluated and for a detailed comparison study to be completed. Generally the feedback and comments received were extremely positive. There were one or two issues relating to differences in the Finnish and Irish mathematics curriculums (e.g. how percentages are described) but even these issues did not hold pupils back. Overall the trial proved to be successful, effective and a very positive, engaging and fun experience for the pupils.

DISCUSSION AND CONCLUSION

The aim of this paper was to summarize the user experience studies of tablet based Math Elements game conducted in Finland and Ireland. In general, the results indicated that the Math Elements is an engaging game and can be deployed also into classroom usage. Based on the achieved results we argue that the introduction process of the game is crucial to its success in the school settings. Both pupils and teachers should perceive the idea of the gameplay very fast. In the first focus group studies it took approximately two minutes to learn to play Math Elements game. It is not much but still the players were expecting to learn the gameplay even faster. It seems that the learning curve of the game (i.e. the time it takes to learn how to play and what is the goal of the game) is expected to be extremely short nowadays, especially when the game is targeted to children and played with tablet devices. However, the use of tablet devices caused most of the variation in adoption time. The results revealed that pointing and swiping the surface without previous experience on such a device can take some time to learn: if pointing is too weak, the device does not respond, which may cause an experience of wrong action and lead to unintentional interactions like selecting randomly the next icon to point at. This kind of unintentional behavior can be minimized with appropriate feedback provided by the game. Based on these findings the user interface and gameplay of Math Elements were improved and the results of the followed field study showed that pupils learned to play the game much faster than before (it took approximately 30 seconds to understand the game mechanics and the goal of the game).

The teachable agent approach used in Math Elements seems to be the key factor in engaging players. The results clearly demonstrated how important the game characters are to players and how the emotional bond between the player and his or her game character facilitates player's performance and involvement. Game character customization possibilities tend to strengthen the bond even more. That is why the player can select his or her game character in the beginning of the Math Elements game. In fact, the player can choose his or her favorite character from 12 mice and 12 cats. All characters have different personalities and thus every player can find an ideal character that strengthens the relationship. As always, some of the characters are more popular than others. Figure 7 presents three most popular mouse and cat characters that were identified based on interviews during the Finnish studies. From a game development point

Figure 7. Popular characters and their description

of view, in future, there will be 10 mice and 10 cats waiting for introduction to the game. When there is enough data about character selection preferences, the least selected characters will be replaced with new ones and this cycle will be repeated three – four times per year. As a result of this iterative character development we can not only keep game updated all the time, but also get very accurate user feedback on character design.

In terms of engagement the character development seems to be a crucial factor. The results of the field study showed that if players do not have a total control of the game and their characters it decreases the engagement. In this study players who got already taught characters did not engage with the game as deeply as players who could start the game from the very beginning. This problem could be avoided by providing the possibility to reset the game or by using user accounts. However, both of these solutions have negative consequences. First, the user accounts make the starting of the game harder for young children and resetting the game does not support the long-term usage of the game (for example continuing to playing with the same character when a new school year begins). Against this background, we suggest that in order to maximize the engagement in games like Math Elements each pupil should have a personal tablet device. This would also support the use of learning analytics tools that are included in the game. In fact, the teachers demanded more detailed reports about pupils learning outcomes.

In the studies reported in this paper we did not measure the real learning gains and thus the usefulness of Math Elements cannot be considered in light of learning outcomes. However, the learning analytics that are embedded into the game produce continuously important information about players' math skills and playing performance. For example, when grouping and summarizing the individual game achievements, the schools and the national level policy makers can receive analysis about competences and skills in general level in order to develop their teaching or formal curriculum. The analytics received from game data are sufficiently detailed that we can point out general bottlenecks in education: for example in Finland there is an interesting bottleneck related to fraction numbers with odd nominators that we have revealed from playing behavior (Ketamo & Kiili, 2010; Ketamo, 2010). These numbers mediate or connect nearly all difficulties related to converting numbers between decimal numbers, fraction numbers and percent numbers. The difficulties with odd nominated fraction numbers are not a worldwide challenge. For example, in Ireland such phenomena cannot be found from game data at this point. However, we can not say the phenomena does not exist in Ireland, because the current data from Irish players is relatively small compared to Finnish data and we know that in all countries, the game is first used by more advanced teachers, which might also affect the data. Nevertheless, we can certainly say that in Finland we should pay attention on how to teach odd nominated fraction numbers.

Moreover, the use of eye tracking measures as a part of Finnish case study turned out to be very useful. It seems that eye tracking can provide important information from the visual design of games, the usefulness of feedback provided as well as the whole game based learning process. Although the basic eye tracking measures seems to provide new and important information about the learning process, it needs to be complemented with other methods. If the analysis relays only for example on fixation counts or on hot spot maps, there is a great risk to interpret the results wrongly. Based on only fixation counts and fixation lengths we cannot determine whether the user has understood the game elements that he has fixated on or not. Furthermore, the timing of fixations is also very important in dynamic games and timing should be considered when interpreting the eye tracking data. In this study, we used retrospective interview and gaze replays as complementary methods that both turned out to be very useful and provided much deeper and useful information about player's behavior and understanding than the basic quantitative eye tracking measures. Based on these findings and experiences we suggest that game designers should include eye tracking into their toolbox and utilize the possibilities that it provides. Traditional observation studies and eye tracking provides complimentary information for developers: when traditional studies can provide information how to develop storytelling, dialogue and mechanics, eye tracking can provide very deep information about interaction design and layout.

Taken together, the conducted studies raised several interesting aspects about designing tablet-based games for classroom usage. However, we did not measure the learning effect of the game and more controlled trials should be conducted to evaluate the usefulness of the game. Another limitation of the paper is that the studies in Finland and Ireland were different and the results are not comparable. Nevertheless, all conducted studies provided important information about the studied phenomenon because they explored the use of Math Elements game from different perspectives. In future, we will conduct larger and controlled cross-cultural studies.

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