MobileMath: the Phone, the Game and the Math

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Abstract: Computer games appear to be able to engage students in meaningful learning, inside as well as outside of school. Mobile games, especially location-based games played on mobile phones with GPS, integrate the player's position into the game-play and thus support situative learning. This type of games can augment the reality by adding 'virtual elements' to it. In this paper we discuss the results of a pilot study on MobileMath, a location-based mobile game that integrates concepts from mathematics and geography.

MobileMath is played on a mobile phone with a GPS receiver. It is designed to investigate how a modern, social type of game can contribute to students engagement in learning mathematics. Teams compete on the playing field by gaining points by covering as much area as possible. They do this by constructing squares, rectangles or parallelograms by physically walking to and clicking on each vertex (point). The shapes they construct are virtual elements added to the real world. As the game proceeds the free playing space gets smaller. It is possible to 'hinder' other teams and to deconstruct the shapes they made, points are gained by this also. During the game, in real-time the locations of all teams and all finished quadrilaterals are visible on each mobile phone. The game data are stored online and can be viewed back and discussed later.

In this pilot study the usability of MobileMath was tested with three different secondary schools. Four one-hour games, each with seven or eight teams of two students (n=60), were played around the schools. Data were gathered by means of (participatory) observation, analysis of the games played, a survey and interviews with students and teachers.

The results show highly motivated students, who enjoyed playing the game. Students indicated they learned to use the GPS, to read a map and how to construct quadrilaterals.

Keywords: game-based learning, mobile games, GPS, mathematics education

1. Introduction: Game-based learning with location-based mobile games

Computer games appear to be able to engage students in meaningful learning, inside as well as outside of school (Gee 2003; Shaffer 2006; DeVane 2008). They fit in the digital lifestyle of the new generation and have great motivational power. According to Egenfeldt-Nielsen (2005) computer games facilitate learning environments with peer-collaboration, constructions of knowledge, new teacher roles and a changed student role. In order to be effective the games need to be embedded in other learning activities. This fits the view that learning is more effective when it is situated (Lave & Wenger 1991). Other factors associated with effective learning are that learning should be realistic or authentic and collaborative (O'Donnell 2005).

Mobile devices make it possible to integrate these characteristics of effective learning. In the definition of O'Malley (2003) mobile learning is any sort of learning that happens when the learner is not at a fixed, predetermined location, or that happens when the learner takes advantage of learning opportunities offered by mobile technologies. A key characteristic of mobile learning is that it enables knowledge building and constructing understanding by learners in different contexts (Winters 2007). Consequently it is a small step from mobile learning to mobile gaming. Mobile gaming is a general term that covers a large range including playing casual games on a mobile phone as well as using highly interactive location-based games on mobile devices, where real and virtual world are mixed. Recent research has shown that the use of mobile location-aware games can contribute to engagement and meaningful learning on several school and academic subjects such as history (Admiraal et al 2007) and science (Squire & Klopfer 2007; Squire 2008).

Mathematics is traditionally seen by a lot of secondary school students as a boring, difficult subject with not much personal involvement or social aspects. What is true for effective learning in general can also be applied to the learning of mathematics: in order to be effective the mathematics should be meaningful to the students. The theory of Realistic Mathematics Education (RME) (Gravemeijer 1994) stresses that problem situations presented in learning activities should be 'experientially' real to students. Other important tenets of RME are that students own productions and constructions should be used and that social interaction is a necessary condition for learning mathematics. With the design With the design and evaluation of the game MobileMath (Demeyer et al 2008) which we discuss in this paper, we have tried to effectuate a combination of principles of RME with principles of mobile game-based learning. The game MobileMath is a location-based game that can be played on a mobile phone with a GPS receiver. MobileMath integrates the players position into the game-play and thus supports situative, authentic and collaborative learning of mathematics. This type of games augments the reality by adding 'virtual elements' to it. A term that stresses the combination of reality and virtual elements is 'hybrid reality game'. 'Hybrid reality games (HRGs) employ mobile technologies and GPS devices as tools for transforming physical spaces into interactive game boards' (De Souza e Silva & Delacruz 2006 p. 231). MobileMath is in this respect a Hybrid Reality Game. The players are immersed in a mixed reality game environment. This type of exciting mixed reality experience can contribute a lot to the fun and engagement (Schwabe & Göth 2005).

2. Objectives

The central question of the pilot study this paper reports about is:

> Can the design and use of a social mobile game, based on the geographical reality, the virtual representation of it (map) and location-sensitive technologies lead to engaging and meaningful mathematics learning for students in grades 7 and 8 (aged 12-14)?

The following aspects of the central question were addressed in a pilot study at three schools:

- The phone, i.e. technology
  Can we make a technical environment that is flexible enough to be used in an actual (educational) playing setting?
- The game
  Is the game appreciated by the students? Are they engaged? Is it fun? Do they appreciate the mixed reality experience? Can the game be fruitfully embedded into education?
- The math
  Which concepts from mathematics (commonly taught in grades 7and 8) can be integrated into game? Do students recognize the math and do they feel they learned something?

Before the pilot and its results are discussed, we describe the design and the game-play of MobileMath.

3. MobileMath

3.1 The design and technical specifications

MobileMath is designed to make mathematics more playful, engaging and real, by having students experience mathematical concepts in the physical world. The idea for its design was born when Mobile phones with GPS receivers became more and more common. In the summer of 2007 the definitive version of MobileMath was developed in several meetings. The first meetings were used to define the design criteria by a team specialised in math education and educational mobile applications. The team formulated four criteria for MobileMath:

- The game should focus more on the game experience than on the educational effects. Playing MobileMath should give students the feeling of playing a game, hence experiencing another way of doing mathematics. Geometry was seen as a suitable mathematical topic to address in a location-based game.
- From previous projects it was known that it is challenging to make a game that online players and street players play at the same time. Therefore it was decided that the game could only be played outside and not online. In this way all players would have the same starting point and goal within the game. It was expected that this would result in more on site dynamics and interaction. A positive side effect was that operating Mobile Math would be independent from the digital facilities at schools.
- The game should not be based on one specific location. We wanted the game to be played anywhere in the Netherlands and not just in for example Amsterdam. In this way every school could play the game in their own direct environment and would not be excluded as had happened in the past with other mobile game applications.
- The necessary preparation time of the teacher should be reduced to a minimum.

Based on these four design criteria, MobileMath was developed. The aim of mobile math is for a team to gain points by creating virtually constructed mathematical shapes (squares, rectangles or parallelograms). They do so by walking to and virtually connecting the vertices of a quadrilateral. When finished the quadrilateral is visible on the map on screen. Deconstructing quadrilaterals of other teams is part of the game-play of MobileMath. Deconstruction is realised by first walking to and clicking on one of the vertices of the quadrilateral that is to be deconstructed and next clicking the midpoint of one of the four non-constructed, thus imaginary, similarly shaped neighbouring quadrilaterals (see figure 1). Determining the location of a deconstruction point thus requires a mathematical construction.

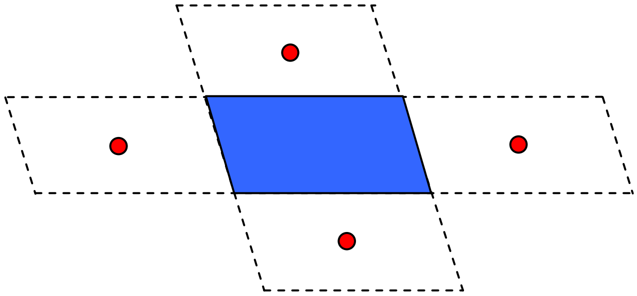
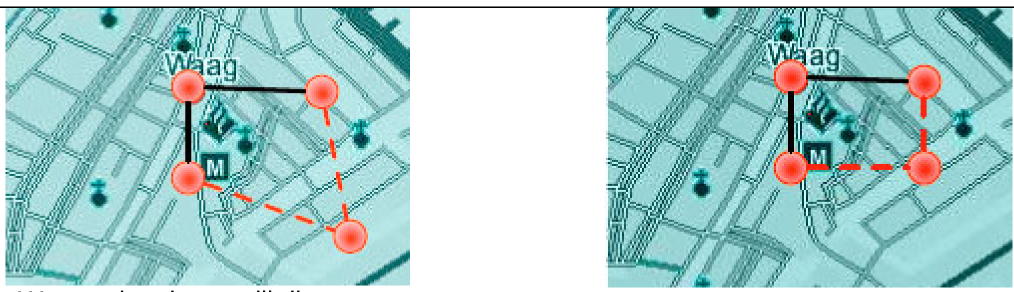


Figure 1: The four deconstruction points of the parallelogram in the centre.

To support the process of constructing and deconstructing quadrilaterals auxiliary lines are visible on screen. A game website was build on which a game can be followed in real time online and on which the game data are stored and can be viewed back later. These data include the tracks of all teams, which are not visible during game-play on the phones, as well as the quadrilaterals that remain at the end of the game.
A pilot with the designers and researchers led to some adjustments in the technical design. The inaccuracy of the GPS readings while clicking vertices caused some frustration. This led to the idea of using an invisible underlying grid in the programme to which vertices would snap. A fixed 'margin' was build in the programme to be used when checking whether the quadrilaterals or the locations of the deconstruction points were indeed correct. Finally the possibility to restrict the size of the playing field was build in the programme. This was done to stimulate the interaction between the teams and to prevent teams from constructing an endless number of quadrilaterals, without ever encountering the other teams.

3.2 The game-play
Up to eight teams compete on the playing field - which can be defined anywhere. Each team is equipped with a mobile phone with GPS-functionality, the playing field is visible as a circle on the map on the screen. Each team is given a colour and each team can choose their own team name. During the game all teams see themselves and the others moving in real-time in the playing field on the underlying map.
The objective of the game is to score as much points as possible within the space and time set for the game. Points are gained by covering area by constructing squares, rectangles or parallelograms on the playing field. This is done by physically walking to and clicking on the location for each vertex (point). During the construction process walking back and forth in the physical world may be required to find the proper location for a vertex or for a deconstruction point. Zooming, in the virtual world on the map on screen, may be needed, either to see more detail (is this edge indeed perpendicular to that one?) or to see the whole shape (is this edge parallel to the one opposite?). If the fourth vertex finishes a shape correctly, it appears on the playing field in the colour of the team, otherwise the shape will disappear. (see figure 2)



Wrong: the shape will disappear | Right: the shape will become opaque

Figure 2: Finding the proper location of the fourth vertex

The score is proportional to the area covered and the ratio is determined by the type of shape (squares are hardest to construct, parallelograms are easiest). The constructed shapes are virtual elements added to the real world as a kind of 'overlay' (see figure 3): the physical world has thus become an interactive game board.

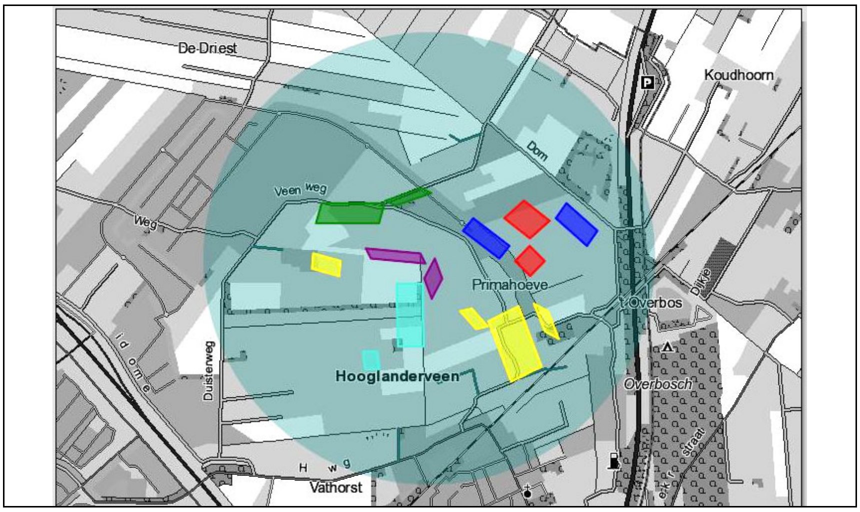


Figure 3: View of a finished MobileMath game showing the quadrilaterals and the playing field.

As the game proceeds teams occupy territory and thus the free playing space gets smaller, which provokes interaction between competing teams. Since the shapes cannot overlap it is possible to 'hinder' a team by trying to construct a shape within a shape under construction. Deconstruction of shapes clears space and the deconstructing team 'steals' half the points connected to that shape from the team that constructed it. The game ends after a set duration, the team with the highest score is the winner.

4. Methods

To answer the research questions a sequence of pilots was set up. A first pilot was held with the teachers, followed by three pilots with students at three different schools. In all pilots researchers observed the team activities during the game and debriefed the teams afterwards. Observation notes were made and the game data were stored online. After they played the game all players completed a questionnaire.

4.1 Pilot with teachers

The pilot with five teachers, one geography, three mathematics and one IT teacher, was held in January 2008. It had three objectives: to test the game-play with a group of 'new' players, to prepare for the pilots with students and to discuss and co-design how to embed the game-play in the educational setting.

4.1.1 results

The test outside with the teachers, each coupled with one of the researchers to form a team, worked well. Game-play was engaging, the technology worked well and the rules and goals were clear. The discussion afterwards in which the tracks were viewed and the strategies of the teams were discussed provided excellent opportunities for reflecting and making connections between game-strategies and aspects of mathematics (geometry and navigation and orientation) and geography (map skills).
Based on the observations, a small questionnaire and the discussion afterwards it was decided that some elements needed extra attention in the introduction to the game, these included: the mathematics involved in finding the deconstruction points, the inaccuracy of the GPS and the working of the grid and the use of the map, which is not a conventional street map.
The educational embedding was designed in the form of materials for a whole class introduction focusing on the mathematics, the geography, the phone and the game play, supported with worksheets. Additionally an online evaluation survey for the students was designed.

4.2 Pilots with students

In March 2008 MobileMath was piloted at three schools with a total of 60 students, 54 of which filled in a questionnaire afterwards (see table 1). All pilots were observed by at least three researchers.

Table 1: Overview of the pilots

	#students	grade	age	male	female	voluntary?	accompanied?
School 1	28	7	13	17	11	no	yes
School 2	12	8	14	4	8	no	no
School 3	16	8	14	11	5	yes	no

4.2.1 organisation

The pilots consisted of a whole class introduction, one round of game-play of 1 hour and a debriefing. Whole class introductions focused on map skills, characteristics of quadrilaterals, the game rules and the technology of the phone. In schools 1 and 2 both a math teacher and a geography teacher were involved. In school 3 the introduction was done by a mathematic teacher the day before the game was played. The technology part of the introduction was done by a designer-researcher.

After the introduction the students, in teams of two, played the game. The playing filed was set to have a radius of 1 kilometre, the duration of the game was set to be 1 hour. Because of the large number of students in the pilot in school 1 two games were played, each with a duration of 1 hour. Half of the students played the game outside, while the other half watched the game-play online in the computer room at school and kept a log of what (they thought) was happening.

At school 1, for safety reasons, all outside teams were accompanied by a teacher or researcher. At the other schools the teams went on their own and the teachers and researchers followed the game online. After the round of game-play a debriefing session was held, using the stored game data and the observation notes, to reflect on the game-play. Notes were taken of the debriefingl. Two forms of debriefing were used: a debriefing session with each team upon its arrival back at school and a whole class debriefing session. At schools 1 and 2 both forms were used, at school 3 there was not enough time for a whole class debriefing.

5. Results

In this section we present results based on the observations, the stored game data and the questions from the questionnaire that relate to research questions discussed in this paper.

5.1 Fun

Students easily engaged in playing MobileMath and on the questionnaire rated it as ‘good fun’ (see table 2).

Table 2: results on the question: 'did you enjoy playing the game?'.

	1 not at all	2 no	3 neutral	4 yes	5 yes a lot	'average'
School 1	-	-	2	10	16	4.5
School 2	-	-	3	6	3	4.0
School 3	-	-	-	9	5	4.4
Total	-	-	5	25	24	4.4

The bad weather during the pilot at school 2 had a negative effect on the score for fun, this was indicated in the questionnaire and during debriefing. On the open question 'give reasons for your answer', a lot of different aspects were mentioned. Some students listed several reasons why they did or did not enjoy the game. These are summarized in table 3.

Table 3: results on question: 'was the game fun?'.

answers	#mentioned
just fun	10
constructing or deconstructing (digital) shapes	11
scoring points	3
use GPS	3
learn something	3
walking and being outside	3
fun, but tiring/bad weather/guided	8
no reason	4

Sample student response: "You learn to use GPS and you learn to construct different shapes quadrilaterals, rectangles, etcetera and at the same time you play a game".

5.2 Game-play

Most students easily understood the goal and the rules of MobileMath. The students in school 1 who played the game in the second round and had seen the game being played by their classmates, did better than the students who played in the first round. In the first round the average score per team was 32 points, whereas in the second round this was 93 points. Observations revealed that the teams in this second round were more aware of each others locations, they were checking these more often and tried to imagine what the strategies of the other teams were.

On the open question 'how was the collaboration within your team?' all students answered positively. They indicated that the collaboration went well: they helped and supported each other, discussed strategies and took turns in controlling the phone.

Not all students were aware of the importance of accuracy for the game-play. In two of the games there were teams that did not succeed in constructing of deconstructing a shape, as a consequence they scored no points. Six of the 32 teams that played MobileMath scored no points at all.

5.3 The phone

The students had no problems using the phone. Observations showed that most students easily interacted within the mixed reality environment. One team, for example, placed the edge they just made on screen, parallel to the street to decide whether to go left or right. Some students however were seen to have problems reading and interpreting the map on screen. These students had difficulty orienting and combining the information from the physical world with the information from the map.

The technical features 'zooming' and 'checking the scores' were used by most students (see table 4).

Table 4: results on the questions 'did you zoom?' and 'did you check the scores?'.

	yes	no
Did you zoom in or out?	44	10
Did you check the scores when playing?	50	4

Almost all students checked the scores frequently. Students who used the zoom-function mentioned several reasons for doing so. They indicated to use zooming-in during the (de)construction process to check the accuracy. Zooming-out is used to get an overview; to see the location of all teams, and the shapes that have been constructed. It is also used to see their own location and plan the route.

The inaccuracy of the GPS-readings, combined with the margins set and the snapping to the grid proved to be frustrating for some of the teams. One team of school 2 tried to make a rectangle around the sports field. They were led by the lay-out in the physical world and their knowledge that the sports field is a rectangle. Due to a greater effect of the inaccuracy margin on larger shapes and students' limited use of the map for deciding on the accuracy of their shape under construction, they didn't succeed in making a correct shape even though they tried three times. They reasoned in the real instead of in the virtual world, which proved to be unsuccessful.

5.4 The construction process

The stored game data, especially the tracks of all teams, show that for the construction of shapes different strategies were employed. One strategy is based on the (virtual) reality of the map. Students use elements from the map - like rectangular street patterns - to construct their quadrilaterals. Another strategy is to use knowledge of the location around school - students know for example where a rectangular playground is located. The third observed strategy is to make use of the visible elements in the physical world. Often students combine their experience in the physical world (the playing field), with the virtual world (on the map) and their knowledge about the environment. Some students constructed their quadrilaterals as free standing shapes, only focussing on the mathematical properties.

5.5 Learning

The questionnaire had three questions related to learning and school subjects:

- Did you learn something? Illustrate.
- Is this game related to geography? Is so, in what way?

- Is this game related to mathematics? Is so, in what way?

Most students answered they had learned something and indicated what this was. The results are summarized in table 5.

Table 5: results on the questions 'did you learn something?'

	#mentioned
no	11
using the GPS	13
constructing shapes	11
collaborating	5
strategic thinking	3
reading a map	3
being accurate	2
playing the game	2

The large majority saw the relation to geography in the use of the map or the GPS. Eight students saw no relation to geography. Three students saw no relation to mathematics. Most students specify the relation they see: shapes are mentioned by 31 students; 7 mention other geometrical terms like area, angles and measurements; calculating (in general) is mentioned 4 times and 4 times the calculation of scores is mentioned.

6. Conclusions and discussion

The pilots made clear that MobileMath can is an engaging game that can be played in an ordinary school setting. The focus has been on the playing of the game. Some work is still needed to fully exploit the potential of MobileMath for learning. The introduction and the debriefing session need to get more attention. The debriefings sessions in the pilot were very short, but we could glimpse the possibilities these sessions have for reflecting on the game-play as well as on the math involved. In this section we discuss the three aspects of the central research question: the phone (i.e. the technology), the game and the math.

6.1 The phone

We can conclude that the technical environment of MobileMath is user-friendly and flexible enough to be used in an actual (educational) playing setting. As expected students easily used the functionality of the phones. The inaccuracy of the GPS-readings sometimes interfered with and frustrated the game-play. For example: what looked like a parallelogram on screen was identified by the game as being a rectangle or a seemingly correctly placed vertex was evaluated to be wrong. Schwabe (2005) in his research on a mobile game discussed this type of effects of (in)accuracy and concluded that for tasks that ask for finding very specific locations the inaccuracy can cause frustration and loss of interest in the game task. Other more 'accurate' location technologies may be preferred in that case. For MobileMath we need to reconsider the margins and the grid size build into the software.

6.2 The game

The results from the pilots proved that MobileMath was highly appreciated by the students. The game-play engaged and motivated students. Two girls even leaped over a ditch to overcome the physical barriers of the location to finish their shape. Students enjoyed playing the game and would have liked to play it again. From the fact that students mention different aspects that contributed to the fun, we can conclude that with the design of Mobile Math we succeeded in creating a rich and interesting gaming and learning environment.

One of the design decisions was to have no online players in the game. This seems to be a good decision: in the game all teams are equal. On the other hand we saw that the game played by students who had first watched a round of game-play online, was much faster, more exciting and interactive. Watching the game obviously helped future players to get a clearer idea about what strategy to follow. This result may be used to better integrate the game in the educational setting.

The deconstruction option had the teams interact with one another which made the game even more exciting. This interaction mainly took place in the virtual reality. The teams spotted each other more easily on screen, than in the physical reality. The mix between the physical and the virtual reality is an important aspect of MobileMath. It has a different character than in most enhanced reality simulations. In MobileMath the virtual reality is added to the game only when teams construct the quadrilaterals. This virtual reality remains available in the stored game data. When reviewed later, the virtual reality of the quadrilaterals and the tracks on the map, can become the reality of the educational setting. In the next phase of the research on MobileMath we plan to focus more on the effects of the use of mixed reality on interaction and learning.

6.3 The math

With the design of MobileMath we have demonstrated that we can successfully integrate mathematics into an engaging mobile location-aware game. We designed the math to be an integral part of the game-play. Students engage in the math when they (de)construct quadrilaterals. Math skills are also needed when a team studies the map and decides on a strategy related to their position: which distances can be covered walking; where can a correct shape fit; can each vertex be reached? how long will the construction process take? Although students report they learned something and can name aspects of the math involved we cannot yet support the claim that MobileMath has a learning effect. The fact that in MobileMath students experience mathematics to be engaging may in itself be seen as a positive result. We end with a statement made by one of the students that reflects how the math has become experientially real by playing the game: "Yes, the game relates to math; with these shapes it is funny, it is like you are the ruler yourself". For this student MobileMath has proven its value.

Acknowledgements

We would like to express our thanks to:

- the teachers of the pilot schools;
- their students who enthusiastically played MobileMath;
- our colleagues of the design team.

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