Game-Based Teaching Scenarios in Upper Secondary Mathematics Teaching – European User Experiences

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Abstract. Research shows that digital games can engage students in mathematics and enhance their performance. While mathematics teachers see "maths games" as useful tools, their lack of knowledge about teaching with such games as well as shortage of appropriate games for teaching upper secondary school mathematics prevents the full potential of game-based teaching. This study presents GeomWiz, a gamified geometry quiz, for learning geometry in upper secondary schools as well as two teaching scenarios for using it in teaching. A student user experience study was carried out in three European countries in which teachers piloted GeomWiz and the teaching scenarios. Based on the results, game-based learning with game contents that matches the learning objectives is suitable for geometry teaching in upper secondary schools. Teaching scenarios assist the inclusion of the game into teaching.

Keywords: Maths Game · Game-based Learning · Implementation · Teaching Scenario · User Experience

1 Introduction

Mathematics is a fundamental educational requirement and continues throughout different levels of teaching. Research shows that digital games can engage students in mathematics and enhance their performance [1–3]. Such "maths games" are not neutral tools but designed around teaching philosophies targeting specific outcomes [1]. Likewise, teachers are not neutral agents in game-based activities. In fact, how teachers support students in use of a maths games affects its usefulness [1, 2]. Thus, training the teachers on the use of maths games and instructional strategies are essen-tial points [2].

Several countries have highlighted the need for integrating technology into mathematics education [4]. There is, however, a major gap in game-based teaching and learning

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in maths: While maths games are used in elementary classes, they are not yet widely implemented in upper secondary school mathematics [3]. Research shows that while mathematics teachers see maths games as useful tools, their lack of knowledge about teaching with such digital games as well as shortage of appropriate games for teaching upper secondary school mathematics prevent them from using maths games for their full potential [3].

This study provides tools for the identified need by developing a gamified geometry quiz (GeomWiz) for learning geometry in upper secondary schools as well as two teaching scenarios for the implementation of the tool. Through these, it is possible for any mathematics teacher to use the GeomWiz tool as part of their teaching. A student user experience study was carried out in three European countries, in Finland, Croatia and Greece, where teachers piloted the GeomWiz with both teaching scenarios. The results of the student experiences are reported in this study.

2 GeomWiz in Game-Based Learning of Geometry

Successful implementation of game-based learning requires development of proper tools as well as processes for their use [5]. These tools and processes need to be developed by multidisciplinary groups consisting of experts in pedagogy, maths, as well as game design and programming [6]. In this paper, GeomWiz gamified geometry quiz and two scenarios for its use is discussed as an example of these.

Geomwiz is a single player gamified geometry quiz, for now on referred as game. GeomWiz is targeted for learning geometry in upper secondary schools. It was implemented as part of an international GAMMA (GAMe-based learning in MAthematics) project funded by Erasmus+. The game has six levels, each of which has its own geometry-related theme (shapes, angles of triangle, right angle, area of triangle, sine rule and cosine rule). The themes were determined by maths teachers according to the maths curriculum. GeomWiz is meant to be played with a mobile device, but it can also be played on PC. It was made with Unity game engine using isometric 2D elements as it makes the game look like 3D.

The game has a wizard character controlled with a virtual joystick. The wizard tries to collect as many points as possible by learning through multiple choice questions and given learning material. The game starts from the main menu from which the player selects a level (theme) to learn. After selecting a level, the game shows material through which the player learns the main points about the geometry topic of the level. The learning material can also be accessed later during the gameplay from an info icon (i).

Figure 1 illustrates the game screen. There is no time limit in the game. Each level consists of a different number of rooms, which the wizard must visit and complete. The difficulty level of the rooms will gradually increase as the game proceeds. Each room has four question boxes with difficulty levels from 1 to 4 concerning the same topic (marked with stars on the box). Each box will show the player one question, which is randomly selected from a question pool (made by maths teachers) from the database. The questions are multiple-choice tasks, in which one answer is correct, and four answers are incorrect.

The player may take all the question boxes (Fig. 1) of the room to earn more points. The number of points earned depends on the difficulty level of the box. This encourages

the player to take also more difficult ones, although only one question from any of the boxes in the room needs to be answered correctly to open the next room. Additionally, if the player selects all boxes in the room but answers incorrectly to all questions, the next room will automatically open to enable the player to continue studying. The player can also take a hint for each question without affecting the points. After answering a question incorrectly for the 1st time, the game will automatically give a hint and a new try. The previous incorrect answer is removed from the answer options. When completing a level, the player earns a trophy and the game shows a summary window with the level statistics, including points, correct answers, incorrect answers and hints taken. There is also an exit button in the game if the player wants to quit playing. That will lead back to the main menu.

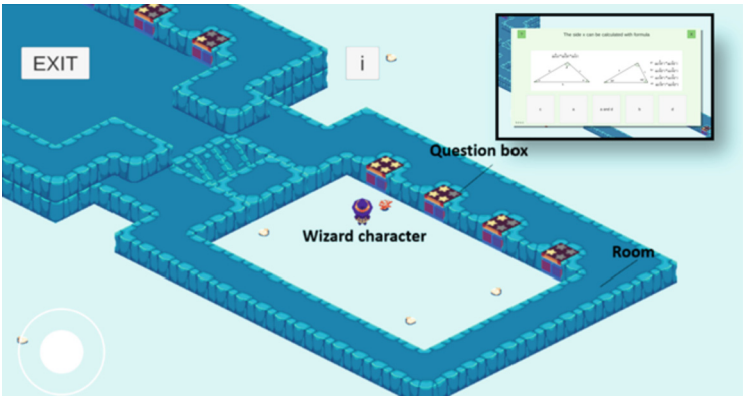

Fig. 1. Game screen of GeomWiz and example of multiple-choice question.

From the main menu, the player can also open a diploma that opens in a web browser, which shows all player's results from all times of playing the game. The statistics can be shared with a teacher by the player sharing a link to the player's statistics webpage. The statistics themselves do not contain any personal information. Thus, only the teacher (or the person to whom the link is shared) knows whose data that is. Sharing the results is a very important feature in the game to allow teachers to see the progress and the gaming activity of each student. Another important feature of the game from the teacher's perspective is the ability to modify the content (questions) in the database without any programming.

2.1 Teaching Scenarios for GeomWiz to Ease the Implementation

For the implementation of all the games of the GAMMA project in the classrooms, teaching scenarios were produced. With the help of the scenarios, it is possible for any mathematics teacher to implement the game as part of their teaching. The teaching scenario template was designed by the Croatian researchers and evaluated and modified by other researchers and teachers of the project. The teaching scenarios contain detailed information on subject, domain, and topic of the game, the learning objectives of the

game, keywords, description & name of the game, summary of the scenario, age range of the students playing the game, prerequisite knowledge for students, prerequisite knowledge for teacher, preparation time, teaching time, needed resources (e.g., devices, paper and pencil, etc.), instructional setting (individual works, small groups, whole glass…), correlation with other subjects and/or cross-curricular topics, instructions for the activities (introduction, preparation, motivation, pregame info, playing the game, formative assessment), students' feedback about GBL, teacher's remarks, activities for students who wish to know more, suggestions for further activities and sources like literature and links to the game. The detailed scenarios are publicly available at http://www.project-gamma.eu/.

GeomWiz geometry game is extensive with its six levels, but the game was piloted for levels 4 (area of triangle) and 6 (cosine rule). The researchers carried out the game design and implementation, while the high school mathematics teachers produced the game's tasks and the teaching scenarios.

3 User Experience Study

In total n = 95 upper secondary students from Finland (n = 60) and Croatia (n = 35) participated in the lesson provided by maths teachers according to teaching scenario for GeomWiz at level 4 (L4). The corresponding number for level 6 (L6) was n = 111, from Finland (n = 18), Croatia (n = 70) and Greece (n = 23). After the scenario-based lessons, the students answered a questionnaire to evaluate the usefulness of the game & the scenario as part of mathematics education, and the attitude towards the game. The questionnaire contained 11 questions, of which 6 were compulsory and 5 optional. All optional questions were open type of questions. There were two Yes/No questions with an additional sub-question for a No answer, as well as a Likert scale question (with 5 sub-questions), where 1 = strongly disagree, 5 = strongly agree.

4 Results and Discussion

The first question students were asked about the game was: Is this digital game different from what you consider a game? 52% of the students who played L4 and 58% of the students who played L6 answered Yes. When asked about the differences, they referred to the educational aspect of the game, the need to think (in their own words "to use brain") and solve mathematical problems. There were some comments that it is more of a quiz than a game, while some pointed out the lack of a storyline.

The next question was about the comparison between regular mathematics lesson and lesson with GBL. The relative frequencies of the answers (1–5, Likert scale) to this question can be found in Fig. 2. A positive impact can be clearly seen in all aspects, with the exception of the aspect of engagement, especially for L6.

When asked about the positive aspects of the game, about 50% of the students said it made learning mathematics more fun. A few mentioned the possibility of answering a question twice and getting hints. Other positive aspects were learning at your own pace, learning through play, something different and more interesting than the usual maths lessons and the motivating aspect. Negative aspects mainly concerned some technical

problems in the game, which were fixed after the pilot phase. Other negative aspects were the lack of storyline, game graphics, not knowing the correct answer when both guesses were wrong and the lack of additional explanations for formulas.

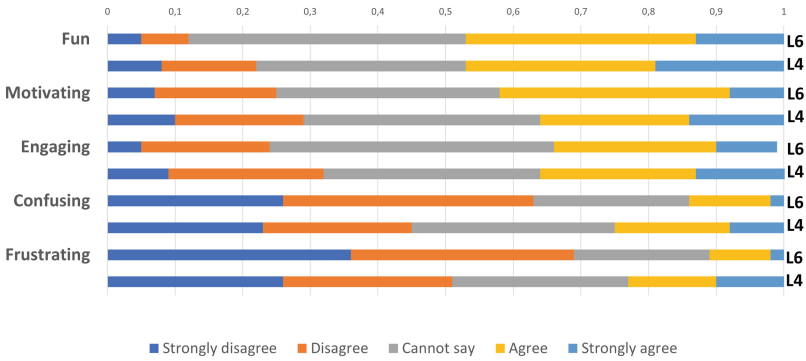

Fig. 2. Experiences of lesson with game compared to a regular mathematics lesson.

About 86% of students who played L4 and 81% who played L6 did not need any additional explanations during the game, but only 54% for both levels indicated in the self-assessment that they learned all or most of the predicted content. Students were mostly successful in perceiving the maths content included in the game and gave more precise answers in L6, while giving more general answers in L4.

The game still needs development especially when it comes to the engagement. As the focus of this paper was on the instructional design and implementation of a digital tool (GeomWiz) in teaching, further game design is required. Well-known MDA framework [7] will be applied in the design process, as the entertainment element will play a crucial role in the next steps for developing a full-scale math game, including evolving avatars, storytelling and reward mechanisms.

From the learning viewpoint it would be necessary to add a feature, which teaches the player the correct answer if the player is incorrectly answering the question after the hint is given. This could be linked to the tutorial material in which the topic is first introduced. The next steps in the game development also include further development of a teacher's dashboard for modifying questions and for analyzing the shared results. There could also be a chat to enhance and motivate and guide learning.

Our future research includes more detailed analysis of the students' and the teachers' feedback in different countries. Further research is also needed from the teachers to study the teaching scenarios & implementation and their thoughts of the long-term role the game would have in teaching. Using the game as a part of the assessment is also a future goal. The versatile tools for formative assessment could support the teacher's assessment work. Another interesting future research topic is to study how games development as such could be used as a tool for maths learning, as the development typically requires understanding of physics and maths.

To summarize the learning outcomes of this study, designing and implementing the game and producing all the tasks in the game was a huge job, even though it was done

in a multidisciplinary team of researchers and teachers. The higher the level of expertise the game aims for, the more in-depth knowledge of the subject is required (in this case teaching and maths). This is why such games for the upper secondary schools are not yet widely available. Cultural aspects were also observed in this study, especially with regard to the production and publication of learning materials. Sharing the best practices between different countries is and will be an important tool in creating and implementing new ways of working in this subject area.

5 Conclusions

This paper presented the design, implementation, and user experiences of GeomWiz gamified geometry quiz and teaching scenarios for learning geometry in upper secondary schools. It can be concluded that game-based learning is suitable for geometry teaching in upper secondary schools. The game contents must match the learning objectives and it is useful to produce a teaching scenario for the help of the teachers. By following the scenario, the inclusion of the game as part of mathematics teaching is smooth. This requires multidisciplinary collaboration between researchers, teachers and game designers. From the teachers' point of view, important features included the player's possibility to share learning analytics with the teacher and that the tasks of the game are in the database, where they can be modified and supplemented without programming the game. Teaching scenarios were seen to be important in that a teacher can actually use the game as part of geometry teaching without much initial effort.

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