Designing a Game-based Social Application for Mathematics Education

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Abstract

Addressing learner avoidance of mathematics is a crucial issue in mathematics education. Researchers claim a discontinuance between mathematical thinking in everyday activities and the overall knowledge learned in math classes. Although previous studies have indicated that using digital-based games may be an effective approach for mathematics education, very few applications bridging such discontinuance exist. This research introduces a design scheme and prototype of a game-based application specifically targeting learners who tend to avoid traditional mathematics education. The educational purpose of this game-based application, *Treasure & Axis,* is to gain knowledge of mathematical vectors and coordinates by navigating a ship toward a treasure on the game map. The playful and interactive activities in the game are based on mathematical knowledge, and the players receive instant feedback that supports their learning during game play. While navigating the ship is the main challenge, it also offers additional learning activities such as math quizzes related to the learner's experience during the game play. The gaming activities and assessment of learning outcomes are coordinated so that the game log data is automatically stored in the database and connected to the learners' profile. This study reports the ongoing formative evaluation of the game prototype and discusses the relevant findings, which may be useful for future researchers interested in studying game-based social media applications for mathematics education.

Keywords: mathematics education, game-based learning, Facebook, social media, serious games

Designing a Game-based Social Application for Mathematics Education

The low achievement levels of students in mathematics have been a major issue in mathematics education (Ministry of Education, Culture, Sports, Science and Technology, 2009). A combination of high anxiety and low interest in math generally forms a tough barrier that prevents students from sufficiently learning mathematics. Students with high math anxiety are most susceptible to turning off their motivation for learning. Learning activities in math classes, such as taking examinations, increases overall anxiety (Richardson & Suinn, 1972), which may contribute to mathematics avoidance and poor performance (Rounds & Hendel, 1980).

To address such issues, interests in applying digital games for mathematics education have been pursued since the beginning of computer-based learning (Malone, 1981). Recent research shows that digital games can be one possible approach that can enhance effectiveness and engage learners that show little interest in mathematics (Kebritchi & Hynes, 2010).

The purpose of this study is to design and evaluate a game-based social media application that teaches mathematics through digital game play. After first discussing the issues in mathematics education and how they can be addressed, we introduce the design features that are implemented in the application and report on the formative evaluation of the prototype.

Issues in mathematics education and digital game-based learning

While two of the challenges in mathematics education are to help students conduct logical thinking in everyday settings and express their thoughts mathematically (National Institute for Educational Policy Research, 2010), students have difficulty applying mathematical knowledge learned in school to everyday mathematical thinking (Devlin, 2011). Lave demonstrated such difficulty in a study on how supermarket customers use mathematical thinking during everyday shopping (Lave, 1988). Her study also indicated that supermarket customers who perform mathematical thinking during shopping tend to have difficulty performing the same mathematical functions in the context of school math classrooms. Although such everyday mathematical thinking cannot be simply compared with the knowledge taught in math classes (since the level of abstraction is different), disconnection between everyday activities and classroom learning can be a major concern. Yoshizawa (2006) classified the cause of students' problems while learning math and argued that students tend to stumble and dislike math because of the lack of clear images on how abstract math concepts actually work. Because it is difficult for novice students to grasp mathematical concepts without connecting concrete examples with such concepts, it may be necessary to provide them with learning opportunities that connect actual examples with mathematical knowledge.

Anchored instruction is a widely known design approach that utilizes highly contextual and familiar experiences to anchored learning (Cognition and Technology Group at Vanderbilt, 1992). This approach emphasizes situating learning opportunities into authentic contexts that engage learners in realistic problem-solving activities. In addition, it provides principles to design learning environments that connect mathematical concepts with concrete examples by introducing stories or challenges to orient learners to the contextualized tasks.

Instead of using video-based stories like the early example of anchored instruction, researchers consider that digital games can be a powerful and alternative tool to build learning environments for mathematical problem solving (Van Eck & Dempsey, 2002; Devlin, 2011; Ke & Grabowski, 2007). Several researchers conducted studies to determine whether game-based learning applications were a possible solution to this issue (Kebritchi & Hynes, 2010). Game-based learning environments incorporate various levels of interaction within the game environment itself and enable designers to flexibly arrange fictional elements in a so-called realistic environment. Unlike traditional instructional environments, learners can participate in playful activities that help them engage in challenging tasks supported by immediate and active feedback from the game system. Once they become motivated in the game activity, learners are more likely to practice the game's functions and build their self-confidence during learning activities.

Design features of the application

Basic premise for game design

In this study, we consider the target users of the game application to be high-school students with little or no interest in mathematics. Instead of being used in classrooms itself, it was offered as a supplemental game-based learning application that could be casually played for a short period of time outside of the classroom.

While any type of game theme can be incorporated, it is crucial to choose a suitable game that can be aligned to the learning contents (Van Eck, 2006). Several possible combinations of games and the learning contents to be taught were planned during the preproduction phase. Marine adventure was chosen as a theme for the game by considering the following two reasons. First, because the theme is relatively familiar to younger audiences in entertainment media, especially in regard to comics and games, it was easy for the target users to become accustomed to the game's context without explaining the background or game elements. Second, the theme offers a variety of fun-filled, problem-solving activities, such as sailing to the destination with limited resources, competing against time to find a hidden treasure, and avoiding the dangers of the open ocean. From the learning viewpoint, various types of mathematical knowledge can be incorporated into this theme ranging from simple arithmetic problem solving to complex integrations. In this study, we chose vector synthesis and coordinate transformation as the main contents of the game.

We then decided to develop the prototype of the game application titled *Treasure & Axis*, which utilized the HTML5 canvas with JavaScript. To take advantage of social-networking connectivity and lower the overall development cost, it was implemented as a *Facebook*

application hosted on the Google Apps server. In addition, both the user and game log data could be stored in a secured database at a minimal cost. These *freemium* Internet services enabled us to develop and implement the application in a very stable environment within a short period of time.

Game mechanics

During development, we considered that game mechanics has to be a key feature to incorporate gaming activity and learning. The primary challenge was to include problem-solving activities in a real world context by using mathematical thinking in an engaging game environment. For the prototype production, we designed an action-style, treasure-hunting game that visualized how vector synthesis works in the context of ship navigation (Figure 1). The learners sail the ship by using the navigation interface on the screen. The goal of the game is to reach the treasure before either running out of time or fuel while avoiding specific dangers, such as rocky banks, pirates, and sharks. The learners can also gain fuel bonuses and coins as rewards on their way to the final goal.

The navigation tool for the ship works as a vector synthesis simulator to describe how the ship's direction is influenced by the force of the wind (Figure 2). The learners have to estimate the influence of the wind and set both the power and direction. The challenge of the game is to successfully guide the ship to hit the treasure icon under the influence of random wind speeds. If the ship sails out of the area or runs out of fuel, the learners have to start all over again. The length that the ship moved and the current coordinates are visualized every time the learners make a movement. By designing the game so that the learners receive instant feedback, they can play and even make mistakes during their quest for the treasure.

Once the learners reach the goal, the final challenge is offered to them in a mathematical quiz format. The quiz challenges the learners with questions on their previous game activity, such as asking for coordinate estimates and calculating the distance of the ship's movement. We constructed different types of quizzes on the basis of the game context (Figure 3). For example, to calculate a target coordinate on a sea chart, the following question is asked: "In order to reach

your destination in the northeast, you must avoid the dangerous zones as seen above. What is the estimated coordinate near the destination that will help you avoid the rocky bank?" While this quiz requires simple arithmetic skill to answer, it also functions as a reflective activity that connects both what they experienced during the play and their mathematical concepts. We made the quiz questions as simple as possible so that the learners could answer them within 15 seconds in order to sustain the game flow active and the learners do not feel like they are working on a math test.

Features for social interaction

There were several additional features that enhanced game engagement aside from just receiving a score and competing against time. First, we added a "*ghost replay*" feature in the game by using play log data. Although the game does not have a multiplayer mode, this feature offers a gaming experience that gives a feel of playing with other players simultaneously. When a learner completes a certain level, the game posts a note with a link on the learner's *Facebook* wall. The note informs the learner's friends (via their timeline) that he/she completed the stage and they can now compete with him/her by clicking on the link. By accessing the game via the link, they can play the game with the replay data, as seen in Figure 4. This feature enhances social interaction although the game is designed for single-player use. We designed this feature because it tends to be more expensive and requires more advanced development skills to build an online multiplayer game that works synchronously and collects play log data even though it is a simple game application. The ghost replay poses as if it works in a real-time multiplayer mode while playing alone. In addition, it enables the learners to either learn from others who are better at the game or compete against themselves to improve their overall performance.

Second, the game application also includes a *stage-map editor* feature that enables instructors to edit the game maps (Figure 5). By assigning items for rewards and dangers, game maps can be generated to adjust to specific learning needs. It can also be used on multiple game maps filled with items in different difficulty levels without technical support. For example, instructors may use the editor function to create a map that includes a problem that teaches the basic concept of graph theory by locating items with certain constraints. This feature also enables learners to create a map and challenge other learners with the map that includes a problem that they created.

The prototype of the game application with these features was developed and evaluated. The remainder of this study examines the initial results of the formative evaluation and discusses how the application worked.

Methods

Data Collection and Analysis

We conducted a formative evaluation to examine the reactions of the target learners. Their feedback was collected through an open-user test that determined the possible problems and addressed how the overall learning experience could be improved. Brief online questionnaires were developed that asked the target learners about how they felt during the game play. The questions were based on their preference in the math class and games, and how they felt about the overall gaming experience.

Participants were recruited publicly through an announcement on the application page and in *Facebook* ads from 19 April to 29 April 2012. By recruiting participants openly from Facebook users, we expected to assess how the target learners use the application in their usual environment. While a total of 32 high-school students installed the application and agreed to participate in the user test, seven learners (six male students and one female student) actually completed the game stage more than once and answered the required postsurvey. The learner-profile data was based on the game log data, and it was automatically stored in a secured database.

Results and Discussion

The summary of the responses by the test users is seen below in Table 1. Six out of seven learners reported that they liked playing the game, while most of them held mixed emotions about learning math. Four learners considered that the game was fun or somewhat fun, whereas two learners considered it as not fun or not really fun. Five learners felt that the activity was not study-like at all or less study-like than usual, whereas two of them felt that it was study-like. Although these results cannot be claimed as conclusive evidence, the reactions by the learners indicate that the experience offers game play that is more playful than study-like.

One learner commented on how the game offered him a positive experience as follows: "It was fun once I got the knack to play it well. It felt good when I got through the narrow path and reached the goal successfully. Since I like vectors, vector synthesis is fun to play (Learner C)." For him, the application seemed to offer an enjoyable experience that is fun and not study-like. As he was already familiar with the mathematical concept of the game, he might find it interesting because of the familiarity to the concept. If a learner did not understand the mathematical concept, it might not be interesting to him/her at all.

Another learner commented on the shortcomings of the game as follows: "The simplicity was good, but it was too simple and I got bored pretty quickly (Learner E)." Because the game contents were not fully implemented, the game might not have offered enough excitement for him to play repeatedly. While game-based learning has its potential to offer playful experiences that traditional instructions do not easily offer, learners might find it study-like by comparing with their favourite entertainment games that learners usually play. So far, we could not collect such learners' subjective perspectives to gain insight of what type of game they compared with when they evaluated this game application.

Conclusion

Although this study did not provide conclusive results, the formative evaluation indicates that the game application may provide learners with a playful experience although it contains substantial amount of mathematical learning materials taught in the math classroom. While it is certain that further research is required to understand in detail the type of gaming experience this game offered to the learners, this early-phase evaluation provided us with crucial information to detect the issues to be addressed for further development.

There are some overall limitations in this research. First, as the data was collected from a limited number of learners, the results did not provide concrete evidence that showed the effectiveness of the game application. Our approach to recruit test learners did not reach the target learners who do not like mathematics. We were able to gather user information regarding how learners used the application outside the classroom environment. However, we could not reach a conclusion whether this application fits the needs of target learners. Second, the learning materials included in the application were still in the formative evaluation process. Simplified measures were also applied to gain user reactions and to determine if the application worked as expected before we conduct further software development. It may be possible that the learners did not repeat the game as we expected because the game content was not adequate and they get bored easily. We have not tested the social functions as noted above. While it is difficult to test the detail functions in the early prototyping phase, it is also true that we expect to gain good evidence to make sure the ideas for design work appropriately. Therefore, to fully claim the effectiveness of the application, it requires substantial measurement and future research on a large scale.

REFERENCES

Cognition and Technology Group at Vanderbilt (1992). The Jasper experiment: An exploration of issues in learning and instructional design. *Educational Technology Research and Development*, *40*(1), 65–80.

Devlin, K. (2011). *Mathematics education for a new era: Video games as a medium for learning*. Natick, MA: AK Peters, Ltd.

Ke, F., & Grabowski, B. (2007). Game playing for math learning: Cooperative or not? *British Journal of Educational Technology*, *38*(2), 249–259.

Kebritchi, M., & Hynes, M. (2010). Games for mathematics education. In A. Hirumi (Ed.), *Playing games in school: Video games and simulations for primary and secondary education* (pp. 119–145). Washington DC: International Society for Technology in Education.

Lave J. (1988). *Cognition in practice: Mind, mathematics and culture in everyday life*. Cambridge, UK: Cambridge University Press.

Malone, T. W. (1981). Toward a theory of intrinsically motivating instruction. *Cognitive Science*, *5*, 333–369.

Ministry of Education, Culture, Sports, Science and Technology. (2009). White Paper on Education, Culture, Sports, Science and Technology. Retrieved from http://www.mext.go.jp/b_menu/hakusho/html/hpab200901/1305844.htm

National Institute for Educational Policy Research (2010). National assessment of academic ability report.

Richardson, F., & Suinn, R. N. (1972). The Mathematics Anxiety Rating Scale: Psychometric data. *Journal of Counseling Psychology*, *19*, 551–554.

Rounds, J. B., & Hendel, D. D. (1980). Measurement and dimensionality of mathematics anxiety. *Journal of Counseling Psychology*, *27*(2), 138–149.

Yoshizawa, M. (2006). Classification of students' stumbles while learning mathematics. *Japan Journal of Mathematics Education*. *88*(3), 24–28.

Table 1.

Summary of the User Test

	Gender	Math Preference	Good at Math	Game Preference	# of Stage Completion	Game was Fun	Game Felt Study-like
A	Male	Somewhat Yes	Somewhat No	Yes	12	Somewhat Yes	No
B	Female	Somewhat Yes	Somewhat No	Somewhat Yes	1	Neither	Somewhat No
C	Male	Somewhat No	Somewhat Yes	Yes	16	Somewhat Yes	No
D	Male	Neither	Somewhat No	Yes	4	Yes	Yes
E	Male	Somewhat No	Somewhat Yes	Yes	4	Somewhat No	No
F	Male	Somewhat Yes	Somewhat Yes	No	1	Yes	Yes
G	Male	Neither	No	Yes	2	No	No

Figure 1. Screenshot of the Game Map

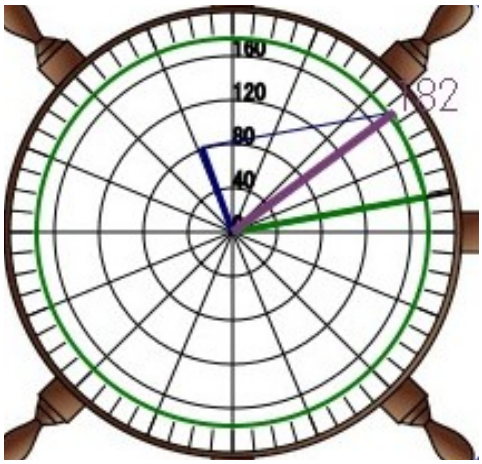

Figure 2. Screenshot of the Navigation Interface

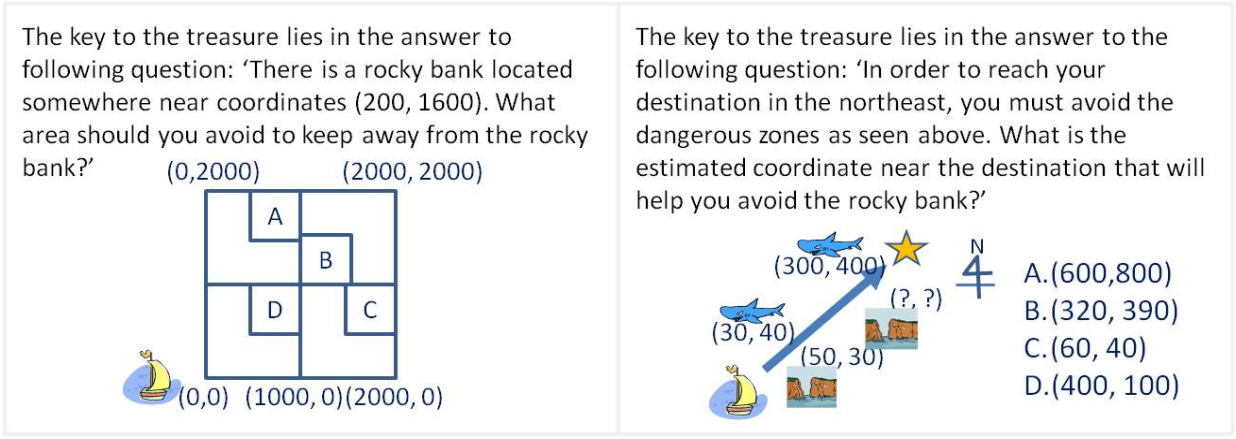

Figure 3. Screenshot of the Mathematical Quizzes

Figure 4. Screenshot of the Ghost Replay Feature

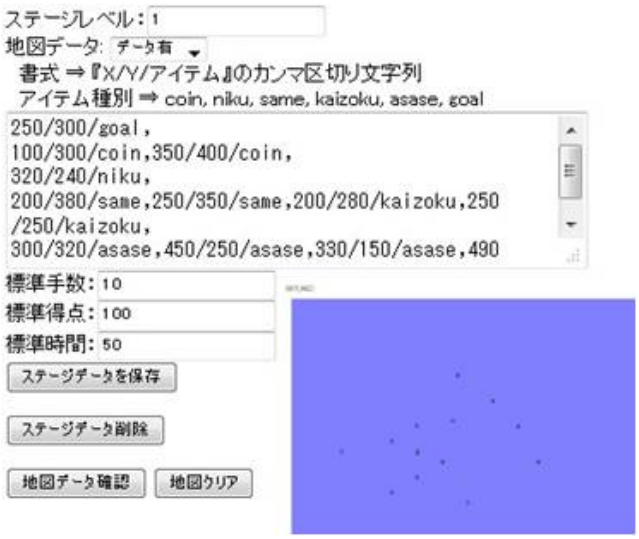

Figure 5. Screenshot of the Stage Editor