Fostering joyful practice with digital educational games: the Function Dungeon Game

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ICTMT in the Era of Societal and Digital Transformations

Department of Secondary Education, School of Philosophy,
National & Kapodistrian University of Athens
Athens, Greece
June 7–10, 2023
Editors
Dimitris Diamantidis
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FOSTERING JOYFUL PRACTICE WITH DIGITAL EDUCATIONAL GAMES: THE FUNCTION DUNGEON GAME

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In this paper we present an educational digital game, Function Dungeon, that we developed for learning about functions in a playful way. Results from a pilot conducted with fourteen 13-year-old students in a school in the Netherlands show that the game can foster 'joyful practice'. That is, students experience fun and sense of control while practicing mathematics. Findings from this study contribute to the development of knowledge about digital educational games and its potential to transform traditional practices in education.

Keywords: game-based learning, digital games, mathematics, linear functions

INTRODUCTION

One central concept in mathematics is the concept of function. It enters the curriculum from the beginning of secondary school, and it is needed to understand many topics (e.g. derivatives, equations, modeling). It is also a complex concept for students and not easy to understand for some. A wide range of research on the learning of functions provides directions to design tasks that are suitable to support the understanding of functions (Günster-Weigand, 2020; Janvier, 1987; Oehrtman et al, 2008; Schoenfeld et al., 1993). However, it remains a problem to engage students in thinking about and solving these tasks. Digital games have the potential to engage learners in several dimensions of academic domains such as cognitive, emotional, behavioral, motivational, and social dimensions (Boyle et al., 2016; de Frietas, 2018). A well-designed game can exercise higher-order skills, reasoning, problem solving and collaboration in ways that traditional pedagogy often does not (Gee, 2005; Van Eck, 2006). Digital game-based learning (DGBL) connects better with the way students learn in informal settings in daily life. Instead of learning through explicit linear instruction (e.g., by reading a manual first), many children are used to solving problems through trial and error, recursively collecting evidence which they test through experimentation (Prensky, 2012). In particular, digital games have the potential to enthusiasm students towards playing, while encouraging the development of specific mathematical knowledge and skills (Jensen and Hanghøj, 2020).

In our research we examined the potential of a prototype version of the Function Dungeon game to motivate students 12 to 16 in learning functions in an enjoyable way. The game was developed within Erasmus+ project GAMMA (GAMe-based learning in MAthematics) as a collaborative initiative in which researchers, educators and teachers teamed up with one game developer to develop games for upper secondary education. In this paper we report the results of a pilot in which we investigated how the first two levels of the game enacted students' learning experience. The insights from this study are relevant to understand in a broader sense the usefulness of digital educational games for learning mathematics.

THE FUNCTION DUNGEON GAME

In Function Dungeon the player is an explorer trying to find a way through the dungeon. In order to accomplish this game goal, the player has to traverse through a labyrinth of different rooms. Many rooms are originally locked so it is up to the players to find a way to open them. The players can achieve this by interacting with different objects in the rooms. This will allow them to find function-related problems hidden throughout the rooms. Solving these problems will in turn open the way to other rooms. The main educational goal of the game is to provide students with an opportunity to practice with and learn about linear functions in an appealing and engaging gaming environment. The game is designed to help students strengthen their understanding of the (fundamental) characteristics of linear functions in different representations: textual, numerical, graphical, and analytical.

The game (see Figure 1 for some screenshots) can be played online using the following link: https://play.unity.com/mg/other/function-dungeon.

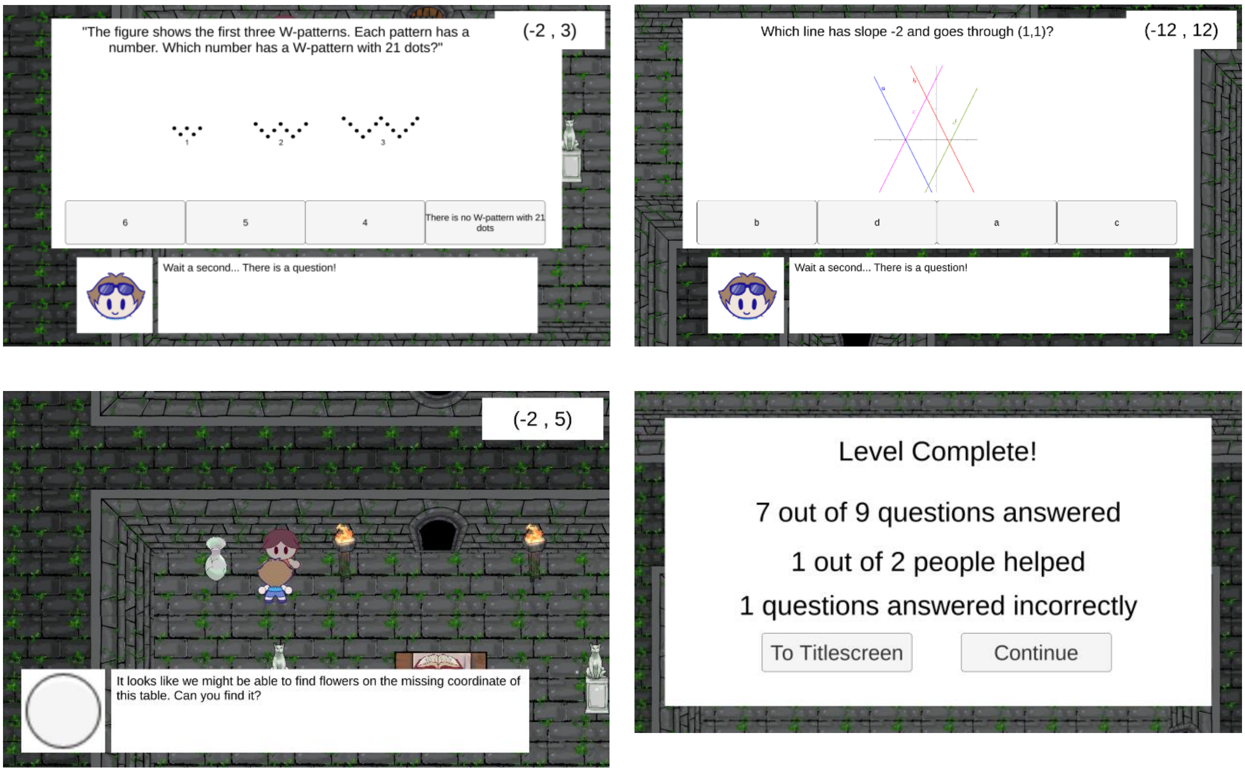

Figure 1. Screenshots of the Function Dungeon game

CONCEPTUAL FRAMEWORK

Literature review on DGBL and learning functions

Several studies report the effectiveness of digital games in mathematics education (e,g. Byun & Joung, 2018; de Freitas et al., 2018; Kangas et al., 2016). In a meta-analysis Byun & Joung (2018) points that games can improve student's motivation, positive attitudes and students' development of specific mathematical skills. Digital games can foster students' interest; motivate them to develop clear goals, and encourage persistence through goal-pursuing activities. In addition, when learning with digital games the student can experience control of his or her learning and consequently remain motivated to solve tasks as part of the game context. Digital games can also provide opportunities for students to make critical decisions in order to solve problems, which can lead to the emergence of problem-solving strategies. Digital games have also the potential to support learning in terms of process skills such as imagination and creativity. However, Byun & Joung (2018) also points that most of the games used in DGBL studies were related to procedural fluency only and few DGBL research had investigated other aspects of mathematical proficiency such as conceptual understanding, strategic competence, adaptive reasoning and productive disposition.

Research on the learning of functions distinguischs between different views on the object function: an action or assignment view, covariational view and object oriented view (Günster-Weigand, 2020). All three views are valuable and depending on the task one view is more adequated than other. An action view involves understanding of the functional notation as an input/output process which helps to organize and to carry out a calculation process. A covariational view is based on causal and dependency relationships between input-output pairs while co-variational understanding. Covariation reasoning is needed e.g. to coordinate an image of two varying quantities and how they change in relation to each other (Oehrtman et al., 2008). An object- oriented view involves awareness of local and global properties and ability to analyze functions by identifying the presence or absence of growth properties. The development of conceptual understanding of function is thus reflected in the capacity of the student to integrate different views of function and coordinate adequately the different representations of the same concept. Examples of learning activities creating opportunities for learning linear function, in particular, involve creating opportunities for students to apply concepts of slope, y-intercept, identify and connect different representations of the same function and reflect on the properties of linear functions (Günster-Weigand, 2020; Janvier, 1987; Schoenfeld et al., 1993).

Framework for the design of an educational game

To design the game, we used a design model developed by Aleven et al. (2010). The method distinguishes three main components in the design process: *educational objectives, game-design framework* and *principles of instructional design*. We framed the development of the game Function Dungeon using this method. In the following paragraphs we describe each component and explain how we applied it in the design of Function Dungeon. Although the process is explained in a sequential way and in well-defined steps, in reality the process was iterative, cyclic and often messy with the designers and teachers jumping between different components. . Table 1 provides and overview of the design elements of the game in relation with the educational objectives.

Specification of educational objectives

Specifying the educational objectives helps the designers ensure that the game they create actually meets an intended and coherent set of educational goals. It involves (a) providing a written specification of the prior knowledge and skills; (b) providing examples of tasks by which a student/player will improve the given knowledge and skills and (c) reflecting about the potential transfer (What knowledge and skills might they learn that go beyond what they encountered in the game?). The main goal of the Function Dungeon is to provide students with an opportunity to practice with and learn about linear functions in an appealing and engaging gaming environment. The prior knowledge needed to play Function Dungeon involves a basic understanding of linear functions, and the notion of a function as a mathematical object with different but equivalent representations (see conceptual framework). In the first level of the game, the players strengthen their understanding of the fundamental characteristics of linear functions: constant rate of change, y-intercept, sign, and magnitude of the slope. An example of a multiple-choice question that requires reasoning with the concept of constant rate of change is depicted in Figure 1 (top-left). In the second level, players enhance their ability to connect representations of linear functions: verbal, table, graph, and formula, An example is shown in Figure 1 (top-right). Reflecting on the potential transfer of the game we expect that the reasoning skills practiced in the game (e.g. analysing the function object; relating different representations) are also applicable to other types of mathematical functions.

Applying a game-design specific framework (the MDA-framework)

In the second step, the MDA framework (Hunicke et al., 2004) was used to support the game design. The Mechanics (M) of a game refer to the basic components out of which the game is made, which are the materials, rules, explicit goals, basic moves, and control options available to the players. The Dynamics (D) of the game refer to the behaviors that result when applying the game's mechanics with player input during game play. The Aesthetics (A) of a game refer to the subjective experience of the player such as emotions and pleasure and it comprises the items: sensation, fantasy, narrative, challenge, fellowship, discovery, expression, and submission. When a game is played, the game's mechanics give rise to its dynamics, which in turn evoke a certain aesthetic. In the design of the game, the three levels will not be considered just in this order. In fact, the designer has only control over the mechanics while the player's experience of a game is at the aesthetics level. The MDA framework allows a designer to articulate aesthetic goals (e.g., challenge), consider possible dynamics that may give rise to this aesthetic (e.g., time pressure), and try out different mechanics that may give rise to this dynamic (e.g., use of a timer, or of parallel play by multiple players with bonus points for whoever finishes their move first) (Aleven et al., 2010).

In the Function Dungeon the *aesthetic experience* is centered around discovery and challenge. The *dynamics* of the game is slow-paced; there is no time pressure in the game. The players can take as much time as they need to explore the rooms, solve the tasks, and think about the feedback. Many rooms are originally locked so it is up to the players to find a way to open them. The players can achieve this by interacting with different objects in a room. This will allow them to find function-related problems hidden throughout the rooms. Solving these problems will in turn open the way to other rooms. While exploring the players can make friends with Non-Playable Characters (NPC: a character in a computer game that is not controlled by someone playing the game) - see Figure 1 (bottom-left). Besides moving the character and interacting with objects, the core game *mechanics* in Function Dungeon include answering multiple-choice questions. By answering correctly, a door is opened. When answering incorrectly, a player is thrown in the vault where a book with explanations can be consulted. The player can also find hidden objects in the dungeon. When a hidden object is returned to a NPC, a power-up is collected: the player can phone the NPC to ask for help answering a multiple-choice question (two wrong answers are identified by the NPC). At the end of the game, statistics are shown to the player: number of questions answered, number of NPCs helped, and number of questions answered incorrectly (see Figure 1, bottom-right).

Applying principles for instructional design and mathematical learning

The Function Dungeon game has been developed along with constructivist perspectives, which emphasize that meanings and understandings grow out of interaction with the learning environment and in the presence of adequate feedback. The player is triggered by the tasks in the game to recall and apply concepts of slope, y-intercept, identify and connect different representations The game environment provides immediate feedback on task (e.g. the doors go open if the answer is correct); reflective feedback (explanation when consulting the book) and social-support (the player can ask help from a NPC). In addition, we applied the suggestions for learning activities from the literature review on the learning of functions.

Knowledge and skills	**Gameplay**
• recognize, remember, and connect function-related concepts • relate different representations of a function • problem solving & recognizing patterns • perseverance, enjoyment and motivation • effort to improve wrong answers	• explore and complete tasks at slow pace • obstacles that force the player to employ their skills to reach mastery level • virtual characters to motivate immersion in the game • narrative motivates to explore and complete the mission • appropriate feedback and scaffolding • control and choice

Table 1. Design elements of the game in relation with educational objectives

METHOD

The game was tested with students and teachers several times during its development. In this paper we use data collected in a pilot (Nov. 2022) conducted in a classroom with fourteen students (13-14 years old, 8th grade) in general education in The Netherlands (Figure 2). The students had previous knowledge on linear functions, which is a topic usually introduced in the 7th grade). The first author assisted with the lesson. The teacher explained briefly the goal of the game, that the game was still being developed and that they could consult the game menu "how to play" in case they needed. The students could choose the level themselves and most of the students (12 students) played both levels; sometimes more than once. The teacher walked around in the classroom, assisting students when they had questions or got stuck in the game. The lesson took about 50 min. At the end of the lesson the students were asked to fill in an online survey to evaluate the pilot.

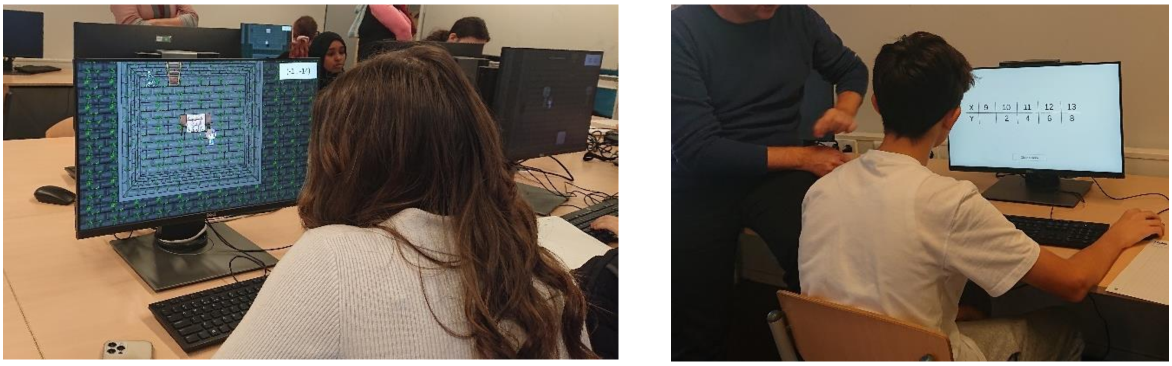

Figure 2. Students play the Function Dungeon game in the classroom

The online questionnaire included open- and closed-ended questions. By using open-ended questions and qualitative analysis procedures, our intent is to develop an in-depth understanding of the way that the Function Dungeon game can foster mathematical knowledge and skills (Tabel 1) from the perspective of the students. In the first questions (Q1-Q3), participants were asked to provide information on aspects related with their learning experience with the game (*What level did you play? What can a player learn with this game? Explain; What did you think of the game? Explain*). Fourth and fifth questions (Q4-Q5) focused on aspects of the game environment (*Was it clear how to play the game? Does the player, in your opinion, get enough feedback to improve his or her answer?*). The last two questions (Q6-Q7) were meant to collect suggestions to improve the game and any other information that students would like to share *(Do you have any suggestions for improving the game? Which one?Do you want to add something else*?). The data collected was analyzed subjected to thematic coding analysis (Gibbs, 2018). According to this method text passages that express equal or similar meaning are identified and combined into categories.

RESULTS

The four categories that emerged from our data were: mathematics learning, fun, agency and other skills (Table 2). The categories mathematics learning, fun and other skills concern *students'mathematical learning* (Q1-Q3) while the category agency concern *students'experience of the game environment* (Q5-4-Q5). In the following of this section we present both results.

Table 2. Learning experience enacted by the game environment according to the students

Categories	Aspects referred and their frequency (N=14 students)
Mathematical learning	Formulas, graphs, functions (5 students)
	Mathematics (5 students);
	Mathematics in a better or different way (3 students);

	Learning (1 student)
Other skills	Looking closely to own work (1 student)
Fun	It is fun (6 students) It is fun and you learn from it (4 students) It is fun but unnecessary to learn (1 student) No opinion about (3 students)
It was clear how to play the game (agency)	Clear (6 students) Clear because of in-game explanation (3 students) Clear but needed help at first (3 students) No opinion (2 students); Unclear (1 student)
Enough feedback to improve the answers themselves (agency)	Enough feedback in-game (8 students) Enough feedback but it can be better (6 students) No opinion (1 student)/Not enough feedback (3 students)

Regarding *students' mathematical learning*, all students considered that players learn mathematics from the game (second row). Some students stated that with the game they learn better or in a different way than in the regular lesson. For example one student considered that he "solved sums faster" with the game. Some students referred to have learned about different function representations: "practicing with formulas and graphs", which was one of the learning objectives of the game (see Table 1). Most students found the game fun (Table 2, third row). One of the students stated: "It makes mathematics fun through fun questions and a beautiful design. You learn something from it and that is very useful". Some students were also critical about the usefulness of the game as learning tool: "It's a lot of hassle to make a few questions because you have to look for them. I'd rather just have the questions directly. I do like that we then work online instead of in the book." Another student was critical about the tasks in the game: "on the one hand nice on the other hand boring because you get the same things". One student mentioned to have learned other kind of skills. Namely "looking more closely at your answers".

With relation to the *game environment*, most students found clear how to play the game (Table 2, fourth row). They valued the 'how to play' option, explanations in the game and the book in the room. Few students needed help from the teacher or classmates: "At first I didn't know what to do, but through help I was able to do it". Some students faced some difficulty at first but they solved it themselves: " Yes, when I pressed how to play I got it a bit but with those coordinates [it] was [quite] difficult". Students found the feedback (Table 2, fifth row) enough to improve their wrong answers but they pointed that the explanation could be better: "If a question is wrong, you will not get an explanation why it is wrong".

DISCUSSION AND CONCLUSION

Digital game-based learning environments have potential to foster broader and specific mathematical skills. However, most of the games used in DGBL studies are related to procedural fluency only and few DGBL research has investigated other aspects of mathematical proficiency such as conceptual understanding, strategic competence, adaptive reasoning and productive disposition (Byun & Joung, 2018). The Function Dungeon game has been developed with the objective to foster a broader range of mathematical skills with regard to the concept of function. In this study we examined the kind of (mathematical) learning experience enacted by the game according to the students.

The first main result is that students feel that they learn mathematics in a fun, better or in a different way with the game. The game environment enact students experience of agency (a sense of control on their actions) when solving the mathematical tasks in the game. The players have fun in the Function Dungeon. The story and the graphics are nice and appealing. Students find it fun because it encourages them to exercise knowledge on linear functions. The player needs to master basic concepts of linear functions to engage with the game and have fun. In addition, function dungeon is a game in which the player has the possibility to make some decisions and therefore experience, in a certain way, control over their own learning. The players can decide which level they play; they can go through the game at their own pace; the game can be played at home; the players can decide if they get help from the NPC or not. The players have access to feedback in case they fail to answer a question correctly, while consulting the feedback being not mandatory. The character falls into a room with a book containing more information on what was done wrong, but it is possible to get out of the room without looking in the book. Although it is possible to finish the level without solving all the tasks, the player must solve most of them to open the doors and move forward.

The second main result is that the game environment fostered several kinds of mathematical fluency. Most students succeed in playing both levels of the game and more than once, which means that they succeed in remember function-related concepts, relate different representations and recognizing patterns. These are activities that foster conceptual understanding (Günster-Weigand, 2020; Janvier, 1987; Schoenfeld et al., 1993). Students also showed perseverance and made effort to improve wrong answers, which are aspects of productive fluency and strategic competence (Byun & Joung, 2018).

The game version that we used in this study is still in development. The coordinates task- see Figure 1 (bottom-left) is so far the only game mechanics that directly involve the player in the mathematics. The main mechanics in the game (solving math questions) do not differ much from the traditional practice (answering questions from the book or teacher). This explains also the criticism of few students that found the game fun but not really necessary to learn. Also, the feedback provided to students in case they fail to answer the question correctly should be more elaborated. In the next design- iteration we will focus on the implementation of in-game mathematical-mechanics and improving the feedback. Future research should also investigate the game as integral element of the learning process and not only as a stand-alone activity. The teacher is essential for the success of learning through games and play (Kangas et al., 2016) and teaching experiments are an effective way to develop examples and practical knowledge that can inspire and motivate teachers to use DGBL.

Finally, digital games are examples of digital media for mathematics education that can be transformative (Bray & Tangney, 2017; Kebritchi et al., 2010). Fostering transformational practices in the classroom involves empowering students with knowledge, attitude and skills that prepare them to be successful in their lives and to contribute in a productive way to our society. This implies many more aspects than we can reach with a single digital game. However, digital games such as Function Dungeon, that create a learning environment in which students enjoy learning and practicing mathematics contributes to empowering students as learners. This is an important step towards transformational mathematical practices.

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