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 (e.g., Ellis et al., 2016) for exponential growth). 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).

However, to succeed in school practice, digital game-based learning must be well understood by teachers and students and be integrated with classroom activities. Teachers should be assisted in integrating games in the classroom as this is not an easy task (Kangas et al., 2016). Not all teachers (and students) are used to teach (and learn) in a classroom where students work independently, have more responsibility and the content is not structured in a linear way. In fact, teachers' preference to traditional teaching and teachers' stereotypical perceptions about the value of digital games are some of the barriers for the successful use of DGBL in the classroom (Kaimara et al., 2021). Therefore, it is important to communicate about digital games in ways that illustrate their value for transforming education.

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' experience of fun and control, which are aspects closely related with students' motivation for learning (Keller, 1987). 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. While exploring the players can make friends by bringing hidden objects to Non-Playable Characters (NPC: a character in a computer game that is not controlled by someone playing the game).

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.

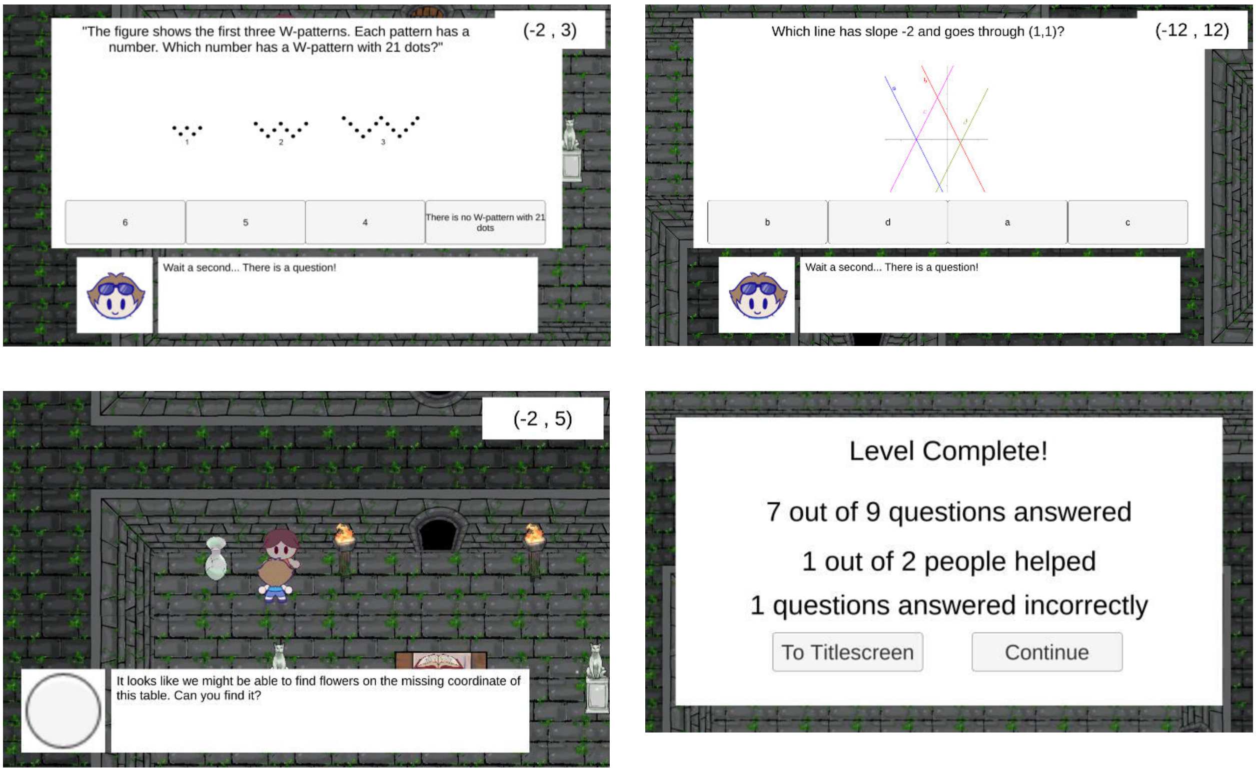

Figure 1. Screenshots of the Function Dungeon game

CONCEPTUAL FRAMEWORK

The Function Dungeon game has been developed along with constructivist perspectives, which emphasise that meanings and understandings grow out of interaction with the learning environment. In Function Dungeon, the players' progress in the game is connected with the players' experience with solving mathematical tasks. The player is triggered to recall, apply, connect, and reflect on mathematical knowledge, and therefore to develop (new) mathematical meaning and understanding. This process occurs in interaction with the the game environment which provides verbal and visual feedback (e.g., the doors go open if the answer is correct), explanation (consulting the book) and support (you can ask help from a NPC).

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. However, the three components were useful to keep the focus and to structure the development process. 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 game 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. The game incorporates theories about learning mathematical functions. In the first level of the Function Dungeon, the players strengthen their understanding of the fundamental characteristics of linear functions: constant rate of change, y-intercept, sign, and magnitude of the slope (Schoenfeld, Smith & Arcavi, 1993). An example of a multiple-choice question related to the fundamental characteristic constant rate of change is depicted in Figure 1 (top-left). This task requires mathematical reasoning, an important mathematical skill. An essential element in understanding linear functions is to understand these functions in different representations, and "be able to translate and form linkages among and between them" (Even, 1990, p.524). Therefore, in the second level, players enhance their ability to connect representations of linear functions: verbal, table, graph, and formula (Janvier, 1987). An example of a multiple-choice question related to connecting different representations is depicted in Figure 1 (top-right). Since the four representations (i.e., verbal, table, graph, and formula) are the main representations to describe functions, the skills practiced in Function Dungeon are also applicable to other types of mathematical functions (e.g., goniometric functions and exponential 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 behaviours 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

In this step we applied the 'Fundamental characteristics of linear functions- schoonfeld (2005) and the function representations of Janvier (1987).

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

Knowledge and abilities	**Gameplay**
• recognize, remember, and connect function-related concepts • Relate different representations of a function • Problem solving & recognizing patterns • Perseverance 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

METHODS

The game was tested with students and teachers several times during its development. In this paper we use data collected in a pilot conducted in a classroom with fourteen students (13-14 years old) in general education in The Netherlands (Figure 2). The first author assisted with the lesson. The students played the game during the mathematical lesson, which was conducted by the teacher of the class. Playing both levels took about 50 min. Twelve students played both levels; sometimes more than once. Two students only played level 1. At the end of the lesson the students were asked to fill in an online survey to evaluate the pilot.

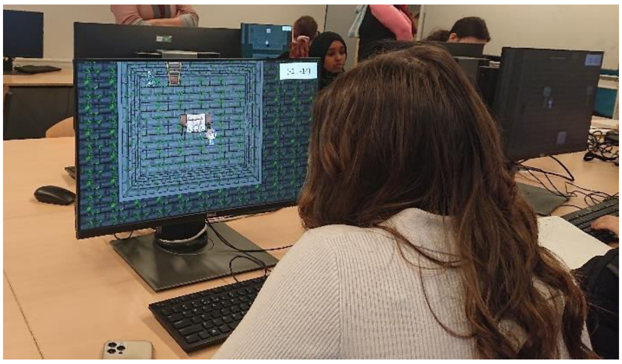

Figure 2. Students play the Function Dungeon game in the classroom

The online questionnaire included open- and closed-ended questions. By using open-ended questions and qualitative analysis procedures, our intent is not to generalize findings to a given population, but to develop an in-depth understanding of a central phenomenon. In this case: the potential of the Function Dungeon game to enact mathematics learning, fun, agency and other skills from the perspective of the students.

In the first three questions, participants were asked to provide information on the learning and fun potential of the game (*Q1. What level did you play? Q2. What can a player learn with this game? Explain; Q3. What did you think of the game? Explain*). The fourth and fifth questions focused on their feeling of agency (*Q4. Was it clear how to play the game? Q5. Does the player, in your opinion, get enough feedback to improve his or her answer?*). In the last two questions they were asked for suggestions to improve the game and if they wanted to add something *(Q6. Do you have any suggestions for improving the game? Which one?; Q7. Do you want to add something else*?). Responses to the seven items were used to determine students' views about the potential of the Function Dungeon game to enact mathematics learning, fun, agency, and other skills.

The data collected through open-ended questions 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. The categories were then clustered within the four themes investigated: mathematics learning, fun, agency and other skills.

RESULTS: STUDENTS' VIEWS OF THE GAME

Results from the analysis of students' answers are summarized in Table 2. Regarding learning, all students considered that players learn from the game. Students referred to mathematical learning in general (9 students). Four of these students considered that with the game they learn better or in a different way than in the regular lesson: "learning mathematics better", "solve sums faster", "math by playing games”. Five students mentioned specific concepts involved, such as formulas, graphs and functions: “how to deal with functions”, “practicing with formulas and graphs”.

Eleven students found the game fun and 3 students didn’t have an opinion. Four students who found the game fun related fun with learning math. 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”. The three students with no opinion were critical about the usefulness of the game to learn. One student stated: “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”. The third student was critical about the mistakes in the second level of the game and the fact that the game got stuck at a certain point.

Students found it clear or very clear how to play the game (11 students). They referred to the 'how to play' option, explanation in the game or to the book in the room:” because it was clear what the intention is. And you get an explanation”; “On the home screen it said how to move”. Three students mentioned that the game was clear but they 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”. Two students had no opinion; they found it clear on one hand but on the other hand they faced some difficulty: " Yes, when I pressed how to play I got it a bit but with those coordinates [it] was [quite] difficult”. One student found it unclear how to play the game: "I always needed help with how it works because there is no clear explanation".

The feedback provided in the game informs the player about their knowledge but also how to proceed with the game. When the player answers correctly a green correction mark is displayed and one of the doors in the room is opened. When players answer a question wrong, they will fall into a room with a book that they can consult. Students found the feedback enough to improve their wrong answers (8 students) but students also found that the explanation could be better (6 students): “If a question is wrong, you will not get an explanation why it is wrong". Only one student mentioned other kind of skills: “mathematics, looking more closely at your answers”

Table 2. Aspects enacted by the game according to the students

Aspects of the game	Categories and 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)
Fun (satisfaction)	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 (control)	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 (control)	Enough feedback in-game (8 students) Enough feedback but it can be better (6 students) No opinion (1 student)/Not enough feedback (3 students)
Other skills	Looking closely to own work (1 student)

DISCUSSION AND CONCLUSION

According to our analysis, Function Dungeon can contribute to improving students' learning about linear functions: (1) students experience fun when solving the mathematical tasks in the game, while feeling a sense of control on their actions; (2) students feel that they can learn mathematics with the game (according to some students in a better or in a different way).

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. Also, the feedback provided to students in case they fail to answer the question correctly is limited because the explanation is very short and task-based.

Students had the feeling that they learn mathematics with the game. A close analysis of the game shows that the main mechanics in the game (solving math questions) do not differ much from the traditional practice (answering questions from the book or teacher). The exception is the coordinates task, which involves secondary mechanics. One way to improve the game is to implement other kinds of mechanics that directly involve the player in the mathematics. Also, aspects of collaboration, problem-solving and social-scientific issues are currently not addressed in the game. In addition, the game should not be presented as a stand-alone activity, but it should be integrated by the teacher with other classroom activities. The teacher is essential for the success of learning through games and play (Kangas et al., 2016). One of the aims of the GAMMA project was to assist teachers in the task of teaching with games. Therefore, teaching scenarios were created for each game developed in the project. The teaching scenarios provide a concrete example about how to use Function Dungeon. The teaching scenarios are text documents that can be easily adapted by teachers while scaffolding teachers' pedagogical activities specific for game-based learning (Bado, 2019; Kangas et al., 2016). Examples of these activities include planning the integration of the game with the topics of the curriculum (pre-game activity), orienting the students to the game and playing the game (in-game activity) and debriefing and reflection (post-game activity).

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.

REFERENCES

Aleven, V., Myers, E., Easterday, M., Ogan, A. (2010). Toward a framework for the analysis and design of educational games. In G. Biswas, D. Carr, Y. S. Chee, & W.Y. Hwang (eds.), *Proceedings of the 3rd IEEE International Conference on Digital Game and Intelligent Toy Enhanced Learning* (pp. 69–76). IEEE Computer Society.

Bado, N. (2022). Game-based learning pedagogy: a review of the literature. *Interactive Learning Environments*, *30*(5), 936-948, https://doi.org/10.1080/10494820.2019.16835

Bray, A., & Tangney, B. (2017). Technology usage in mathematics education research–A systematic review of recent trends. *Computers & Education*, *114*, 255-273.

Byun, J., & Joung, E. (2018). Digital game-based learning for K–12 mathematics education: A meta-analysis. *School Science and Mathematics*, *118*(3-4), 113-126.

de Freitas, S. (2018). Are games effective learning tools? A review of educational games. *Journal of Educational Technology & Society*, *21*(2), 74–84.

Ellis, A. B., Ozgur, Z., Kulow, T., Dogan, M. F., & Amidon, J. (2016). An exponential growth learning trajectory: Students' emerging understanding of exponential growth through covariation. *Mathematical thinking and learning*, *18*(3), 151-181.

Even, R. (1990). Subject matter knowledge for teaching and the case of functions. *Educational studies in mathematics*, *21*(6), 521-544.

Gee, J. P. (2005). Learning by design: Good video games as learning machines. E-learning and Digital Media, 2(1), 5-16.

Hunicke, R., LeBlanc, M., & Zubek, R. (2004, July). MDA: A formal approach to game design and game research. In *Proceedings of the AAAI Workshop on Challenges in Game AI* (Vol. 4, No. 1, p. 1722).

Janvier, C. E. (1987). *Problems of representation in the teaching and learning of mathematics.* Hillsdale, NJ: Lawrence Erlbaum Associates.

Jensen, E. O., & Hanghøj, T. (2020). What's the math in Minecraft? A Design Based Study of Students' Perspectives and Mathematical Experiences Across game and School Domains. *Electronic Journal of e-Learning*, *18*(3), 261-274.

Kangas, M., Koskinen, A., & Krokfors, L. (2016). A qualitative literature review of educational games in the classroom: The teacher's pedagogical activities. *Teachers and Teaching: Theory and Practice*, *23*(4), 451e470.

Kebritchi, M., Hirumi, A., & Bai, H. (2010). The effects of modern mathematics computer games on mathematics achievement and class motivation. *Computers & education*, *55*(2), 427-443.

Schoenfeld, A. H., Smith III, J. P., & Arcavi, A. (2019). Learning: The microgenetic analysis of one student's evolving understanding of a complex subject matter domain. In *Advances in instructional psychology* (pp. 55-175). Routledge.