Mathematics teachers experiencing a hackathon to design a digital game

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This paper presents a hackathon-style experience in which fifteen secondary mathematics teachers have been involved in designing a digital game. The experience is part of a project aiming at identifying guidelines for designing and using digital games in mathematics education. The main assumption of the project is that the collaboration among teachers, software developers, and researchers could contribute to designing a mathematical digital game for educational purposes. This paper will focus on the teachers' reflection on the design by comparing their work during the hackathon with the five elements of software developers' design principles: interactivity, immersiveness, adaptive problem solving, feedback, and freedom of exploration. Results provide valuable insights into the design of digital games for learning and mathematics teachers' professional development concerning their use.

Keywords: Digital game based learning, hackathon, teachers' professional development.

Introduction

In the new learning framework "The Future of Education and Skills 2030" (OECD-PISA, 2018), increasing importance is given to critical thinking, creativity, enterprise, problem solving, risk evaluation, decision making, and constructive management of feelings. With this respect, teachers' professional development becomes fundamental, particularly when it can activate reflexive modes, with the help of experts. To promote the acquisition of key citizenship skills in the logic-mathematics area, teachers need to use new technologies and implement new methodologies, particularly those involving an informal and inclusive approach. One of the teaching strategies that are becoming increasingly important, Digital Game Based Learning (DGBL), has been extensively discussed in the literature (Hussein et al., 2022; Wang et al., 2022). These studies particularly demonstrate the effectiveness of game-based learning platforms, which promote learners' engagement. The design of a digital game, which generally requires several stages and the developers' involvement of different skills ranging from game design to publishing, to storytelling, results to be particularly important for DGBL. Kucher (2021) considers five principles derived from a successful implementation of digital gaming elements in learning, which provide suggestions and strategies for the incorporation of these elements based on real-life examples: Interactivity, Immersiveness, Adaptive problem solving, Feedback, Freedom of exploration. Full communication between the designer and the developer (if they are different people) about all aspects (e.g., goals, actions, objects, aesthetics, etc.) is essential and should be ensured (Clemens & Battista, 2000). However, for digital games to be used in education we claim that teachers' experience and involvement in the design process are also fundamental.

In a first pilot study, we investigated how prepared mathematics teachers feel for using digital games in their classrooms and how they consider themselves possible contributors to the design of mathematical digital games. Results showed that teachers felt the need to acquire new technological

and pedagogical knowledge; furthermore, they thought they could actively contribute to the design of a mathematical digital game by bringing their experience in terms of pedagogical content knowledge and focusing on some unthought scenarios (Barbieri et al., 2021; Capone & Faggiano, 2022a). Moreover, teachers' beliefs about their potential role in the collaborative design of a digital mathematical serious game to experiment with in their classes are in tune with our hypothesis concerning the importance of the direct involvement of teachers in the design process. We believe, indeed, that to activate reflexive mode in their professional development, teachers can be engaged in designing a mathematical digital game for educational purposes through their direct participation in a collaborative process involving teachers, researchers, and software developers (Capone & Faggiano, 2022b).

This paper focuses on the direct involvement of teachers in the design of a digital game, attempting to analyse how teachers can contribute to the design of a game that could be effectively used in mathematics teaching and learning. In particular, we aim to investigate which elements of game design are focused on by the mathematics teacher for implementing a digital game in the classroom. For this purpose, we involved five small groups of secondary school mathematics teachers in an immersive experience by proposing they participate in a hackathon[1]. We collected data through video, observation, and materials produced during the hackathon by the teachers. From the analysis of dialogues between the teachers, we point out that not all the principles considered important to design a digital game by the software developers were taken into account by the teachers. However, their reflections also focused on some other aspects that could reveal valuable points on which the design of a mathematical digital game can be based.

Theoretical framework

Digital games make learning more effective and meaningful for at least five different reasons[2]: they promote motivation by giving real-time recognition and rewards through fun; they give the possibility to create engaging scenarios, which the more they simulate reality, the more effective they are in terms of meaningful learning; they are based on educational purposes that can be customised and modulated, after a clear and correct analysis of learners' needs; they allow for better and more effective assessment and self-assessment. For this reason, there is the need to identify principles for successful DGBL design. To frame this research, we refer to Kucher (2021) and her five principles: Interactivity, Immersiveness, Adaptive problem solving, Feedback, and Freedom of exploration.

Interactivity - The software developer plans the game, offering learners an appropriate level of meaningful interactivity. This interactivity is needed between a player and the game content and among players. Moreover, the game should provide an elaborate and engaging storyline.

Immersiveness - In an effective DGBL environment, students are immersed in the game through the multisensory representation of the storyline and by being assigned a specific identity or role.

[1] The term Hackathon, derived from the combination of the words 'Hack' and 'Marathon', denotes the holding of a challenge, or competition, to be held within a time limit, during which teams compete in finding innovative solutions to a given problem.

[2] See, for instance: https://elearningindustry.com/5-advantages-games-for-learning

Multisensory integration of gaming components is often achieved through the inclusion of different effects in the game, such as music, sound effects, the narrator's speaking voice, photos, videos, animations, 2D or 3D graphics, and other media elements that help create a vivid scenario and an enjoyable learning context. As underlined by Maraffi and colleagues (2017), this also seems to improve their learning.

Adaptive problem-solving - Engaging students in solving real-world problems positively affects their learning gains, and we could expect that they need to continue solving these problems until they have learned how to do it (Gee, 2005). Bereiter and Scardamalia (1993) also claimed that "new mastery is consolidated through repetition (with variation), only to be challenged again" (p. 318). For this reason, an effective DGBL environment should present learners with a set of challenging problems and offer skill-level adjustments to the problems to ensure gradual learning for all students (Wilson et al., 2009) and create motivational tension (Driskell & Dwyer, 1984). In this sense, the game design could be, for example, based on four stages of problem-solving procedures introduced by Polya (1988): (1) identifying the problem, (2) devising a course of action to solve the problem, (3) applying the plan to solve the problem, and (4) interpreting the solution and checking to see if all the available information was used to solve the problem.

Feedback - Effective feedback should provide timely and relevant information on students' progress toward their learning goals. Indeed, as in any form of learning, quality feedback helps students evaluate their progress, recognize their strengths, and identify areas that need improvement (Charles et al., 2009). By providing students with appropriate feedback, educational games can improve their performance and increase their motivation and engagement in the learning process. For example, Burgers and colleagues (2015) distinguish three forms of positive and negative feedback: 1. Descriptive (e.g., "You achieved the goal" or "You did not achieve the goal); 2. Comparative (e.g., "You completed the game in a time below the average" or "You completed the game in a time above the average"), and 3. Evaluative (e.g., "Well done! Keep it up!" or "Poorly done! Try to be faster!").

Freedom of exploration - When educational games are designed to reduce the severity of consequences for making mistakes, it can create a more engaging and less stressful learning environment for students. By allowing students to play again and change their gaming behavior to succeed, educational games can foster a growth mindset in students, where they view mistakes as opportunities for growth and learning rather than as failures. When students are not afraid of making errors, they are more likely to take risks, try new approaches, and explore alternative solutions to problems (Gee, 2005). This can help them to develop their critical thinking skills and problem-solving abilities.

Research question

The aim of our research is to study how the possible contribution of mathematics teachers in the design of a digital game can engage teachers to explore the potential of these resources and help us in identifying elements for the suggestions of teachers' professional development guidelines. In this pilot analysis of the hackathon, we attempt to answer the following research questions: how can the mathematics teachers' discussion topics during the design process of a mathematical digital game be

categorized according to Kucher's five principles? What are, if any, the aspects that are not considered by Kucher?

Methods

To understand the design process performed by the teachers, we adopted the qualitative research method, using an interpretative perspective to analyse the data through a deductive approach. Fifteen high school mathematics teachers in total experimented with an immersive experience by participating in a hackathon in which they were asked to design a digital game to be used with their students. The hackathon is a competition aimed at highlighting the ideas of mathematics teachers on the design of a game to actively involve teachers in understanding the benefits of a game for teaching and, consequently, to stimulate innovation in mathematics teaching. The teachers who took part in the experimentation came from different parts of Italy. They were informed about the possibility to participate due to their previous involvement in other research projects and then spontaneously decided to be engaged in the hackathon. Each of the five groups was composed of three teachers who know each other, because they work in the same school or because they already collaborated in previous research. At least one between the first and the second authors was present at the hackathon as an observer and to conduct a final discussion on the process and the product. Each session of the hackathon, which lasted two hours and was entirely video recorded, was introduced by one of the researchers who explained that the aim at the end of the two hours was to obtain a draft of the structure of a mathematical digital game to be used in their classroom. The hackathon was designed in such to induce reflective processes in sharing and discussing with peers and with the final support of an expert. This provided us with a "grounded image" to mediate an understanding of teachers' points of view on effective mathematical digital game design. The recorded discussions were transcribed and translated into English. From the video analyses, the dialogues between the teachers were categorized considering the five Kucher's principles derived from the successful implementation of digital gaming elements in learning. Further elements that do not fit into this categorization were taken into account to be discussed.

Results and discussion

In this section, we present and discuss the results of our analysis aimed at comparing the aspects on which teachers focused their attention during the hackathon with Kucher's five principles. One of the first elements we noticed when we analysed how the teachers approached the design of a game is that they focus on some details that the developer misses, while the developer focuses attention on some elements that the teachers leave out. Moreover, other elements are considered by both the teachers and the developer but sometimes with different meanings. The following table schematizes the views of teachers and developers regarding the five elements analysed in the Theoretical Framework.

Table 1. The principles for designing effective digital games

	Software developers	Teachers
Interactivity	Y	Y but in a different point of view
Immersiveness	Y	N
Adaptive problem solving	Y	Y
Feedback	Y	Y but in a different point of view

Freedom of exploration	Y	Y

Interactivity – The idea of interactivity in the teachers' opinion, is different from the interactivity as the software developers see it. Rather than considering the interactivity between the player and the game content or among the players, teachers mainly spoke about interactivity while discussing how students can learn while using the game. The teachers mostly saw the interactivity as interaction among the students using the game. The excerpt below, for instance, shows how they were interested in delving into how games can foster peer learning and how students can learn collaboratively:

[1] We need to think of a phase where they can collaborate and a more individual phase, indeed, think of a reward for those who help others as well. The student who fails requests help, and the other players can send her the hint. To the one who gives the correct suggestion [we can] also give a reward in the score.

[2] Using a game in the classroom to engage even the most listless students can be a good way to interact better with the whole class. Think, for example, of a game about fractions that engages students so much that they play it at home. Sooner or later, they learn fractions.

Their idea of interactivity moved their discussion towards the instructional content to be included into the game to engage students:

[3] The interesting thing is that they cooperate with each other […] We need to think of something interactive. For example, a scale to solve equations, a game like *Memory*.

The following observation comes a little closer to the idea of interactivity found in Krucher because it links interactivity to an underlying story that the game must follow.

[4] We can think of a game in which students have to pursue a goal. It could be to build a city and then acquire a role within that city based on the score achieved. That is, you create a story that, in my opinion, also gives the game a logical meaning.

Immersiveness - None of the groups of teachers explicitly focused on techniques that can be used to make the player feel more like the character they are playing. The idea to incorporate in the game factors including sound effects, graphics, sensory and body experiences that also involve augmented reality and virtual reality, seems far away from their reflections. However, some of them spoke about the possibility of creating a game that carries the player into a virtual world, such as the teacher in [4] who thought of a city under construction, similar to "*Farmville*". The following observation is the only one that comes marginally close to the idea of immersiveness that emerged in Krucher.

[5] It is important to create gaming that grabs their attention, including through a setting that engages them and is close to their world.

Adaptive problem solving - In the teacher's opinion, strategies for solving problems play a role in all stages of problem-solving, including understanding problems, solving problems, reflecting on answers, and solutions.

[6] In my opinion, in the game, students should be able to choose between various paths to achieve the game's goal. They should be faced with a real-life problem situation in accordance with the game's storyline, where they have to work out which is the way forward.

[7] Yes, we should alternate between solving calculations and problems in real situations where they have to be able to work out a strategy and apply it to move

forward. For example, going back to building a city, they have to understand which things they have to build before others for a city to function effectively.

The excerpts above show that in the teachers' imagination, the game itself and its setting should create a problem situation from which the player must escape by implementing problem solving strategies. In utterances [6] and [7], it seems that the student/player should be an adaptive problem solver in Polya's sense. However, as shown in [8], in thinking how to design a game, rather than propose problems, the teachers dwell more on calculations related to the various mathematics topics.

[8] Imagine making a map on various topics: for example, fractions, divisions between polynomials and equations. For example, I have prepared a card game in which you have to make matches based on fractions.

Feedback - It assumes a different meaning in the teachers' opinion and developers' opinion. It is worth noting that, as [9] shows, the teacher believes gaming does not directly impact the improvement of mathematical skills, but mainly influences motivation, participation, and engagement.

[9] It's not that it directly improves math skills, but if students feel like studying more, feel motivated and involved, it's almost automatic that they improve a little bit.

As a consequence, increased motivation, in their view, is linked to a better learning style and thus to student performance, as well as an improved disposition to study mathematics. Moreover, teachers ask themselves how to assess the student and if a digital game can be an assessment tool:

[11] […] Otherwise, what didactic fallout does the game have and how do I evaluate it?

[12] It is very important for us that students learn while gaming in a peer-to-peer mode. I would have them gaming in teams by having mixed teams with someone better who can motivate other teammates as well.

[13] […] If we include a score in the gaming, we could associate the scores achieved with an assessment of how well students know a topic.

[14] I don't really agree with that. I think gaming has other purposes but not assessing the student's mathematical skills [...] At most you can assess soft skills, how much a student participates with others, whether he helps his classmates, whether he can behave properly while gaming […]

Teachers claim that getting feedback from using a game in the classroom is important. However, they use the term feedback with a slightly different meaning than in Krucher. For teachers, feedback is a reaction of the student, a response to a stimulus. The game, in their view, generates situations to which the player reacts. In their imagining of the game design, they envisage that there are rewards and punishments, e.g., the acquisition or loss of coins to build new parts of the city. But their focus shifts to the idea of feedback in terms of mathematical skills. Some also question whether it is correct to associate the score achieved in the game with a way of evaluating the student in terms of mathematical competence. Not everyone agrees on this. They see the game as a medium that returns feedback in terms of motivation, engagement, and participation.

Freedom of exploration - The teachers think that in the game everyone should be given a chance to move forward. They think students should be encouraged to explore, take risks, and try new things. As it is also for developers, in a game, failure is a good thing because when faced with a challenge, players use initial failures as ways to recognize patterns and gain feedback about the progress being made.

[15] All students should be able to move forward in gaming [...] We should create a way for even those who cannot solve complex problem situations to move forward.

[16] We could insert a tutorial. For example, if a student fails to pass the level that involves solving grade II equations, we could include a tutorial entry that prompts them to click on the tutorial where there is a brief explanation and so the student can try again and move on.

[17] Usually games are implemented so that everyone can play and achieve scores. This aspect is very inclusive.

These final excerpts show that on this fifth aspect, the teachers' ideas seem to be quite in line with those reported in Kucher, although for different reasons. The developers are interested in gaming being spread as widely as possible; the teachers emphasise the inclusive aspect.

Conclusions

This paper focuses on mathematics teachers' engagement and reflections on the design of a digital game, collected while teachers were involved in an immersive experience by participating in a hackathon. The hackathon involved five groups of mathematics teachers, each composed of three participants of mixed gender from different geographical locations. The hackathon-style experience revealed to be an opportunity to collaboratively work as members of a professional community. Analysing the video-recordings we have seen how teachers tackled a problematic situation, sharing ideas, experiences, and strategies. In particular, we analysed the video seeking to categorise teachers' dialogues according to Kucher's (2021) five principles of designing digital game-based learning.

Our findings reveal some differences in the elements of teachers' discussion topics when engaged in the design of a mathematical digital game: they did not take into account all the principles considered by Kucher, but their reflections also focused on other valuable points. This allows us to conclude that mathematics teachers' reflections can provide valuable insights into the design of digital games for learning. The feedback and suggestions from teachers can help game designers to create games that are more effective, engaging, and relevant to the needs of students. On the other hand, the hackathon experience showed that the contribution of mathematics teachers in the design engaged teachers to explore the potential of digital games. Moreover, the analysis of results can give us some indications to identify elements for the suggestions of teachers' professional development guidelines.

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