Computers & Education 200 (2023) 104806

Contents lists available at ScienceDirect

Computers & Education

journal homepage: www.elsevier.com/locate/compedu

Assessing the benefits of gamification in mathematics for student gameful experience and gaming motivation

Dorit Alt

Tel Hai College, Israel

ARTICLE INFO

Keywords:
Gamification
Mathematics learning
Gameful experience
Gaming motivation

ABSTRACT

This study addresses the question of how to use game design elements to raise students' motivation to engage in mathematics learning activities. Four conditions of mathematics learning activities were designed and assessed: 1. a problem-based digital gamification activity (research group 1); 2. a non-problem-based digital gamification activity (research group 2); 3. face-to-face game-based learning with a problem-based activity (control group 1), and 4. face-to-face game-based learning with a non-problem-based activity (control group 2). The effectiveness of the conditions was assessed in relation to the following dependent variables: (1) Gameful experience, including playfulness, challenge, accomplishment, and immersion; and (2) Gaming motivation, comprised of intrinsic and extrinsic motivation to play. A total of 779 students participated in this study from six Israeli public schools located in urban northern regions with similar socioeconomic profiles. The results mainly showed the superiority of the problem-based gamification activity compared to the other activities, in enhancing students' gameful experience and gaming motivation. The lowest results were obtained for the face-to-face game-based learning with a non-problem-based activity. These results mainly indicate that merely using gamification might not motivate students to actively participate in the learning activity unless it hinges on a sound pedagogical rationale.

1. Introduction

Mathematics is considered one of the most difficult subjects taught in school, and perhaps the most difficult one. It is viewed as a central part of the curriculum in education systems around the world, therefore it has a significant impact on students' success and future (Fadlelmula, 2022). Researchers (Doabler et al., 2022; Finesilver et al., 2022; Rojo et al., 2022) believe that learning mathematics may be fraught with difficulties that may lead to repeated failure experiences, lack of motivation, and even passivity. One of the main challenges in teaching mathematics is to actively involve students in building mathematical knowledge through problem-based activities and deep understanding and to avoid routine learning of procedures that inhibits students' ability to pursue mathematical proficiency (Hendriana et al., 2018; Merritt et al., 2017).

Another challenge deals with the question of how to adapt a unique instructional path to students' needs so as to allow them to progress at their own pace, to consult with their friends via online tools, and at the same time, to enable teachers to receive information concerning students' difficulties and strengths (Christopoulos et al., 2020; Higgins et al., 2019; Kurvinen et al., 2020). To address this challenge, in recent years, schools and educational systems have been required to integrate technologies in teaching in general and in mathematics curricula in particular. In this context, gamification has been suggested to be employed to enhance student motivation

E-mail addresses: altdor@telhai.ac.il, doritalt@014.net.il.

https://doi.org/10.1016/j.compedu.2023.104806
Received 24 September 2022; Received in revised form 22 February 2023; Accepted 6 April 2023
Available online 7 April 2023

and learning outcomes (Legaki et al., 2020).

This study hinges on these two aspects in relation to mathematics learning, the pedagogical and the technological. It unpacks the question of how to apply game design elements in well-structured activities accompanied by a sound pedagogical structure to raise students' motivation to engage in and focus on learning activities. Building on these aspects, this study sought to address the question of which pedagogical approaches, employed in gamified learning environments, may provide a more engaging learning experience. This study attempted to contribute to the literature in this area by investigating the effectiveness of the pedagogical and technological aspects of gamification. In relation to the pedagogical aspect, it explored the differences between problem-based gamification activities utilizing problems in mathematics vs. non-problem-based gamification activities (which are similar to the above digital activities yet lack the element of problem-solving). In addition, to assess the benefit of the technological aspect, these groups were compared to two control groups introduced to a face-to-face game-based learning with a problem-based activity and a face-to-face game-based learning with a non-problem-based activity. The scant research work conducted thus far mostly compared digital to traditional mathematics learning (Hwa, 2018; Kurvinen, 2020; Legaki et al., 2020; Lo & Hew, 2020). In the current research, the objective was to determine which of the four suggested learning environments would be more beneficial to spur students' game experience and motivation to actively participate in the proposed activities. Another objective was to measure the potential effect of players' gameful experience on their gaming motivation to play (Feng et al., 2022; Komala & Rifai, 2021; Nguyen, 2021) in the context of mathematics learning. This might aid in filling the lacuna regarding the appropriate gamified learning environment required for engaging students in mathematics activities.

2. Literature review

2.1. Mathematics instruction and gaming

Mathematics is closely related to the world of programming and computing (Bråting & Kilhamn, 2022). The game is an important resource in teaching mathematics due to the activity, the practice, the feedback, and the enjoyment, and above all, it is a good ground for building new knowledge (Partovi & Razavi, 2019). Several researchers (e.g., Behnamnia et al., 2020) believe that incorporating technology-based games in teaching mathematics may motivate students to learn mathematics, encourage creativity, and promote their enjoyment (de Almeida & dos Santos Machado, 2021). Hence, the main goal of games in teaching mathematics is to increase students' curiosity, motivation, and involvement. To this end, optimal learning programs should include, as much as possible, the following principles: repetition (constant practice), feedback (receiving frequent, immediate, and reliable feedback); adaptation (assignments divided according to difficulty level), conciseness (complex assignments divided into short and specific exercises that encompass the general topic); freedom of choice (regarding the exercises and the order of the solution); and recognition and reward (online prizes and rewards). Students who learned mathematics through games and received immediate personal feedback in addition to the opportunity to practice and repeat the material several times reached a higher level of accuracy in calculations, and significant differences in achievements compared to students who studied using the traditional method (Kurvinen, 2020).

The game aids the student to become an independent learner, it stimulates intuition and allows for all student levels to participate in the lesson (Hwa, 2018). Games provide teachers with a simple way to adapt the teaching to students at different learning levels by having the students develop different calculation strategies while playing (Brezovszky et al., 2019; Deng et al., 2020). For example, Brezovszky et al. (2019) assessed the effects of a digital game-based learning environment (Number Navigation Game [NNG]), in advancing primary school students' arithmetic skills by enriching regular mathematics teaching with gameplay. The results showed the positive effect of the gameplay on students' different types of arithmetic skills and knowledge and provided teachers with a flexible and useful tool to extend their classroom practice. Similarly, Hwa (2018) showed the efficacy of using technology-enabled game-based approaches to motivate primary students' mathematical learning. Digital game-based learning was found more effective than traditional learning in acquiring mathematical knowledge. The authors maintained that games are intrinsically motivating, hence have a positive impact on learning achievements.

Yet, Hu and Shang (2018) argued that digital gamification should not be seen as a universal panacea. Applying gamification in education might be more challenging than in other fields. Integrating game elements into learning content might entail negative results for students such as being distracted by game elements. In their study, the researchers designed and applied gamified math lessons in an elementary school to tackle these problems. Findings indicated that differentiated technology-enabled teaching approaches might facilitate students' perception of the connection between game rules and knowledge points.

Another obstacle is related to the integration of problem-based learning into mathematics learning as underscored by Nurlaily et al. (2019). Problem-based learning is a teaching-learning method based on the idea of using problems as the starting point for the acquisition and integration of new knowledge (Walker et al., 2015). It is considered a constructivist instructional method that provides students with ill-structured problems requiring students to work collaboratively in small groups to resolve the problem. In this process, students increase their knowledge and develop understanding by engaging in self-regulated learning and participating in collaborative discussions (Behlol et al., 2018; Merritt et al., 2017). Problem-based learning has been suggested as an effective approach to the teaching and learning of mathematics (Abdullah et al., 2010). It enhances students' teamwork and collaboration (Schettino, 2016), mathematics problem-solving skills (Amalia et al., 2017; Siagan et al., 2019), and mathematics self-efficacy (Masitoh & Fitriyani, 2018).

Nurlaily et al. (2019) delineated teachers' obstacles in applying a problem-based learning approach to mathematics learning of elementary students. These were related to teachers' time-consuming and challenging endeavors of preparing and determining problems at the onset of learning, and during the learning process, grouping and directing students to problems that need solutions, encouraging students to actively ask questions, and having the teacher's timely feedback. Although the application of digital gamification has gained much attention in recent years, much less is known regarding the ways gamification may be used to advance such constructivist pedagogies in mathematics learning. For example, Lo and Hew (2020) showed the advantages of flipped learning with gamification in enhancing students' cognitive engagement compared with traditional learning, and online independent study with gamification. Yet, the challenges posed by Nurlaily et al. (2019) regarding the integration of problem-based activity in gamification remain ancillary to mathematics education.

2.2. Gameful experience

The game experience is "an ensemble made up of the player's sensations, thoughts, feelings, actions, and meaning-making in a gameplay setting" (Ermi & Mäyrä, 2005; cited in Högberg et al., 2019, p. 623). The game experience is initiated during the game-player interaction and is perceived to be multifaceted, including dimensions that depict this experience (Huotari & Hamari, 2017). The current study is focused on four main facets of gameful experience: playfulness, challenge, accomplishment, and immersion.

2.2.1. Playfulness

Gamification is defined as the use of game-like elements to increase user engagement as they may find gamified activities enjoyable and fun (Deterding et al., 2011). Based on the assumption that millennials were highly engaged for hours playing and enjoying video games, it was theorized that digital game elements like avatars and badges can be used to engage students in enjoyable learning environments and achieve learning outcomes (Gupta & Goyal, 2022; Koivisto & Hamari, 2019).

Playfulness is considered a sub-category of the experience of playing games (Högberg et al., 2019). A comprehensive gamification framework might spur "hedonic outcomes" such as enjoyment, playfulness, and fun (Patrício et al., 2018). With the rapid growth of gamification, researchers (e.g., Codish & Ravid, 2017) raised the importance of using core digital game elements to increase the benefits of playfulness. The core question is which game elements might trigger playfulness. The frequently used game mechanics are points, badges, progress bars, or leaderboards. The use of which might increase the player's perceived playfulness in a digital gamified learning environment (Bevins & Howard, 2018; dos Reis Lívero et al., 2021). Cruaud (2018) echoed this argument following a study that examined a teaching situation where a digital gamified application was used in a Norwegian upper secondary school. The interaction analysis of video data revealed that students were showing expressions of playfulness. Indeed, playfulness might be perceived as a stable personality trait (Codish & Ravid, 2017), however, in the current study perceived playfulness was assessed in the context of a specific situation based on the interaction between an individual player and the situation, and hence can be controlled.

2.2.2. Challenge

Drawing on Högberg et al.'s (2019) study, being challenged is necessary to enhance the player's immersion in the game, hence this experience is considered a dimension of the game experience. This feeling is linked to achievement; therefore, gamers are more likely to choose levels of difficulty in games that challenge their capabilities and enable them to improve their achievements. Hamari et al. (2016) suggested gradually enhancing the challenge experience to spur the players' immersion in the game thereby motivating them to improve their abilities to meet the raised challenge and experience the enjoyable condition of immersion. Hence, the challenge in games is closely linked to the player's feeling of immersion and increases his/her motivation to play.

Moreover, the researchers underscored the importance of engaging students with a gamified problem-based activity instead of confronting topics superficially. By introducing an in-depth problem, students use higher-order thinking skills, realize more connections, become more intrinsically interested, and direct increased attention to the topic. Legaki et al. (2020) measured the effects of challenge-based digital gamification on learning in statistics education, including game mechanics such as points and a leaderboard. The findings showed that challenge-based gamification positively affected student learning compared to traditional teaching methods. According to Gibson et al. (2018), similar to problem-based and project-based learning, challenge-based learning in a gamified learning environment context enabled learners to collaborate in a digital platform and offer solutions to their research questions based on real-world problems. It might be supported by designated applications that can nurture students' abilities such as leadership, creativity, and critical thinking.

2.2.3. Accomplishment

Accomplishment relates to pursuing success and goals (Savvani, 2020). In Högberg et al.'s (2019) study, the participants' feeling of accomplishment was related to goals and completed tasks created by the game mechanics. Moving towards the completion of a task or a goal, tended to encourage the players to progress and improve. Several digital game elements might help increase players' sense of accomplishment. For example, badges, which represent one's accomplishments and status, might encourage the player to strive for more achievements, thus motivating players to obtain rewards that demonstrate their accomplishments (Komala & Rifai, 2021; Suh et al., 2018). Hence, reaching milestones and receiving badges might increase the player's sense of accomplishment. According to Nguyen (2021), a positive perception of accomplishment can be achieved by completing a challenge game-level.

2.2.4. Immersion

The term immersion is often characterized as presence in the gaming world, the player experiences being consumed by all his or her attention and enveloped by a different and engaging reality (Hamari et al., 2016; Högberg et al., 2019). Players who experience immersion tend to focus their attention on the choices that seem meaningful in the game (Goethe, 2019), and become physically or virtually a part of the game experience (Mäyrä & Ermi, 2011). Researchers (Feng et al., 2022; Xi & Hamari, 2019) associated immersion with motivation to play and stated that digital gamification mechanics such as storytelling, avatars, and role-play, might increase the gamer's experience of immersion. Nevertheless, other researchers (e.g., Mäyrä & Ermi, 2011) noted that strong immersion might impair the player's game experience. When players are totally immersed in the game which holds their faculties and imaginations, it might as well block off certain routes of communication often needed in games based on social interactions with other players. Hence in activities that demand social interaction, a less immersive game might be preferred.

2.3. Gaming motivation

While there is considerable literature on gaming and motivation (Demetrovics et al., 2011; Ryan et al., 2006), literature in the area of motivation and digital gamification remains sparse. To fill this void, Lafrenière et al. (2012) have designed a new gaming motivation scale based on the Self-Determination Theory (SDT; Deci & Ryan, 1985; 2000). This macro-theory of human motivation details the origins and outcomes of human agentic action (Adams et al., 2017). SDT demarcates the interplay of individuals' psychological needs, motivation, and well-being and suggests that there are three basic psychological needs sought by humans: autonomy, competence, and relatedness. SDT suggests two general types of motivation: intrinsic and extrinsic, concepts that guide the creation of policies, practices, and environments that further both high-quality performance and wellness (Deci et al., 2017). In the context of gamification, as an important contemporary motivation theory, SDT postulates that increased levels of individuals' self-determined behavior could positively increase their intrinsic motivation (Ryan & Deci, 2002). It follows that when students engage in learning processes and in determining their learning paths, they would tend to be intrinsically motivated to learn (Gupta & Goyal, 2022). To address motivational mechanisms in learning environments, game mechanics should be designed (Mekler et al., 2017) to facilitate motivating and enjoyable learning experiences and consequently achieve desired learning outcomes (Koivisto & Hamari, 2019).

Drawing on intrinsic motivation, Lafrenière et al. (2012) suggested that players chose to play due to their enjoyable exploring experiences when playing, their will to upgrade their skill levels, or due to the thrill and sensation provided by the game mechanics. Extrinsically motivated players do not experience inherent pleasure, instead, their incentive for playing is obtained by in-game awards or admiration from other players. However, Lafrenière et al. undermined the original notion according to which extrinsic motivation is associated with external sources of control and largely relies on the absence of volition. In line with the SDT theory, extrinsic motivation is multifaceted, they argued, and is based on the degree of internalization (Ryan, 1995).

Based on SDT, the cognitive evaluation theory, and the organismic integration theory, in a recent study (Mitchell et al., 2020) the role of extrinsic motivation in digital gamification was explored. The researchers have highlighted the possibility that the behavioral effects of gamification may arise from extrinsic rather than intrinsic motivation, as others have also shown previously (e.g., Mekler et al., 2017). Therefore, they suggested moving beyond the current tendency to center on intrinsic motivation toward evaluating the role of extrinsic motivation in gamification outcomes. In their study, they demonstrated that gamification does not promote intrinsic motivation and concluded that in situations where gamification is mandated, its impact on fulfilling autonomy needs may be limited.

2.4. Gaming motivation and gameful experience

Several studies have linked gaming motivation to gameful experience. Regarding playfulness, game mechanics used in a digital gamified learning environment such as points, avatars, role-play, or leaderboards are considered effective in supporting the learner's motivation to play (Bevins & Howard, 2018; dos Reis Lívero et al., 2021). Similarly, others (Feng et al., 2022; Xi & Hamari, 2019) argued that digital gamification mechanics might spur the gamer's experience of immersion which is positively associated with motivation to play.

Being challenged is also required to nurture the player's motivation to play (Högberg et al., 2019). In relation to accomplishment, Buckley and Doyle (2016) explored how learners' motivation types affect their interaction with a digital gamified learning environment. According to their findings, intrinsic motivation toward accomplishment was not found significantly and positively correlated with participation while certain types of extrinsic motivation were. However, it should be noted that they did not utilize a control group in their study. Hence, it is still not clear what effect digital gamification has on an individual's intrinsic and extrinsic types of motivation to engage in a game (Richter et al., 2015).

2.5. Research questions and hypotheses

Given the scant research comparing digital to traditional gamified learning environments in the context of mathematics, and to assess the technological impact on students' gameful experience and gaming motivation, the current study sought to assess the benefits of mathematics learning activities in relation to two main aspects: pedagogical and technological. More specifically, it aimed to explore the differences among four conditions:

1. A problem-based digital gamification activity utilizing problems in mathematics (research group 1).

2. A similar digital activity that lacks the element of problem-solving and instead includes a series of exercises in mathematics in a certain subject matter (hereinafter: non-problem-based gamification activity; research group 2).
3. A face-to-face game-based learning with a problem-based activity (control group 1)
4. A face-to-face game-based learning with a non-problem-based activity (control group 2).

Based on the literature review, the dependent variables were (1) Gameful experience, including playfulness, challenge, accomplishment, and immersion; and (2) Gaming motivation, comprised of intrinsic and extrinsic motivation to play. An additional objective was to measure the links between the dependent variables, based on the above-surveyed studies. Research questions and hypotheses were formulated as:

(Q1). How effective are problem-based digital gamification activities in terms of supporting players' gameful experience and gaming motivation relative to non-problem-based gamification and face-to-face game-based learning activities? It was expected that students participating in the problem-based digital gamification activities (research group 1) would tend to have increased levels of playfulness, challenge, accomplishment, and immersion (*H1*); and intrinsic and extrinsic motivation to play (*H2*) compared with the other groups of students (research group 2, and control groups 1 and 2).

(Q2). What is the potential effect of players' gameful experience on their gaming motivation to play? Based on the above-surveyed studies (e.g., Komala & Rifai, 2021; Suh et al., 2018), it was hypothesized that the players' gameful experience variables (playfulness, challenge, accomplishment, and immersion) would increase their gaming (intrinsic and extrinsic) motivation to play (*H3*). Based on past studies (Feng et al., 2022; Xi & Hamari, 2019), it was also expected that playfulness and challenge (Hamari et al., 2016) might increase the players' sense of immersion *(H4)*. Lastly, drawing on previous studies (e.g., Nguyen, 2021) it was postulated that the sense of accomplishment would be informed by student perception of challenge *(H5)*.

Background variables of gender, and grade level were addressed to examine and control for their potential effect on the research constructs. Table 1 summarizes the research hypotheses.

3. Method

3.1. Participants

A total of 779 students participated in this study from six Israeli public schools located in urban northern regions with similar socioeconomic profiles. As indicated in Table 2, in each school, two research and two control groups were sampled, both treated by the same teachers. The number of participants from each school ranged from 119 to 139, of whom 384 were 7th-grade students and 395 8th-grade students, 374 male, and 403 female students (in two cases the participants chose not to indicate their gender). The distribution of participants' background variables (school, grade level, and gender) are shown in Table 2. The anonymity of participants was reassured, in accordance with the regulation of the chief scientist office of the Israeli ministry of education which approved this study. The participants were assured that no specific identifying information about them would be processed. The research was approved by the college's Ethics Committee.

3.2. Measurements

Gameful Experience Questionnaire (GAMEFULQUEST). To measure the following variables: *accomplishment, challenge, playfulness,* and *immersion,* four respective sub-scales of the GAMEFULQUEST (Högberg et al., 2019) were used. A 5-point Likert-style format was employed ranging from 1 = *strongly disagree* to 5 = *strongly agree.* Accomplishment was comprised of eight items for example, 'The activity, made me feel that I need to complete things' (α = 0.88). Challenge included nine items for example, 'The activity, made me push my limits' (α = 0.78). Playfulness was measured by using nine items for example, 'The activity, gave me the feeling that I explore things' (α = 0.93). Immersion comprised of nine items, for example, 'The activity gave me the feeling that time passes quickly' (α = 0.90).

Gaming Motivation Scale (GAMS). In this study, three factors were selected from GAMS (Lafrenière et al., 2012): Intrinsic motivation and extrinsic motivation. The participants were asked to indicate on a 5-point Likert-style format (ranging from 1 = *strongly*

Table 1
Summary of research hypotheses.

H1	Students participating in the problem-based digital gamification activities (research group 1) would tend to have increased levels of playfulness, challenge, accomplishment, and immersion compared with the other groups (research group 2, and control groups 1 and 2).
H2	Students participating in the problem-based digital gamification activities (research group 1) would tend to have increased levels of intrinsic and extrinsic motivation to play compared with the other groups (research group 2, and control groups 1 and 2).
H3	Players' gameful experience variables (playfulness, challenge, accomplishment, and immersion) would increase their gaming (intrinsic and extrinsic) motivation to play.
H4	Playfulness and challenge might increase the players' sense of immersion.
H5	The sense of accomplishment would be informed by the perception of challenge.

Table 2
Distribution of participants' background variables.

Variables	Variable description	Participant (%) $N = 779$
Research group 1	Problem-based digital gamification activity	41.1 (320)
Research group 2	Non-problem-based digital gamification activity	26.6 (207)
Control group 1	F2F game-based learning with a problem-based activity	16.4 (128)
Control group 2	F2F game-based learning with a non-problem-based activity	15.9 (124)
School 1	7th grade	15.3
School 2	7th grade	16.3
School 3	8th grade	17.8
School 4	8th grade	16.0
School 5	7th grade	17.7
School 6	8th grade	16.8
Grade	7	49
	8	51
Gender	Male	48
	Female	52

Table 3
Factors and descriptive statistics.

Factor	*M*	*SD*	Skewness		Kurtosis	
			Statistic	*SE*	Statistic	*SE*
Accomplishment	3.82	0.81	−0.61	0.09	−0.31	0.18
Challenge	2.86	0.71	0.18	0.09	0.37	0.18
Playfulness	3.58	1.05	−0.55	0.09	−0.76	0.18
Immersion	3.41	0.94	−0.26	0.09	−0.81	0.18
Extrinsic Motivation	2.80	1.25	0.19	0.09	−1.09	0.18
Intrinsic Motivation	3.92	1.00	−0.94	0.09	0.25	0.18

disagree to 5 = *strongly agree),* their perceived motivation to engage in the game. For example, 'For the feeling of efficacy I experience when I play' (intrinsic motivation, three items $\alpha = 0.87$); 'To gain in-game awards and trophies or character/avatar's levels and experiences points' (extrinsic motivation three items $\alpha = 0.83$). Descriptive statistics of the research factors are provided in Table 3.

3.3. Procedure

Four groups of participants were recruited from each school.

1. Research group 1 (problem-based digital gamification activity).
2. Research group 2 (non-problem-based digital gamification activity).
3. Control group 1 (face-to-face game-based learning with a problem-based activity).
4. Control group 2 (face-to-face game-based learning with a non-problem-based activity).

3.3.1. Research group 1

Research group 1 (problem-based digital gamification activity) was enrolled in a digital problem-based activity where the students were given a problem-based scenario. For example, To-Be Education platform (https://www.to-be-education.com/) was used to help students solve problems related to the usage of linear functions in daily life, or to figure out how to save a herd of elephants that got into trouble in an African reservoir, while calculating time, speed, and distance problems. Each teacher could use a previously designed game or create a new one. Avatars were used to represent different perspectives of the problem. The participants were required to read materials and address mathematical issues that might help them solve the problem. They shared their informed-based opinions about the problem while receiving rewards and feedback from their teacher who monitored the game. The following steps, accompanied by illustrations (Figs. 1 and 2), reflect the procedure of the game from preparation to implementation (the illustrations correspond to a To-Be Education game entitled "Save the elephants: Time, velocity and distance calculations").

Fig. 3. Summary of research procedure.

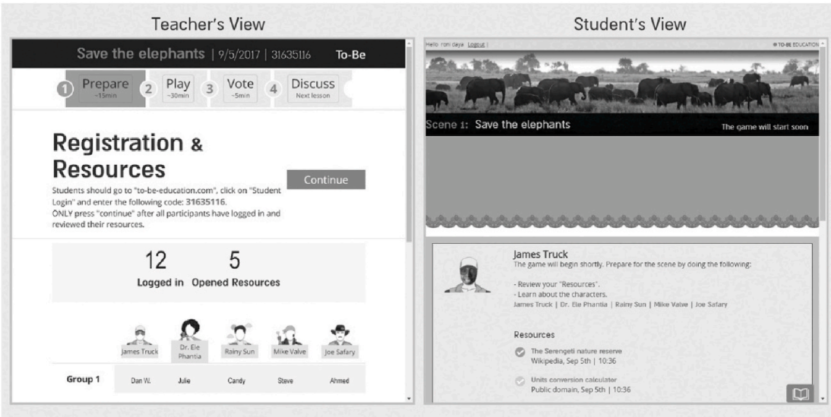

Fig. 4. Mean results of research variables per group.Note: Research group 1 (Problem-based digital gamification activity); Research group 2 (non-problem-based digital gamification activity); Control group 1 (F2F game-based learning with a problem-based activity); Control group 2 (F2F game-based learning with a non-problem-based activity).

3.3.1.1. Preparations.

1. Constructing a story reflecting an ill-structured problem (possible with the students).

2. Creating learning material (resources).

3. Creating avatars – images that represent different perspectives of the story (i.e., solutions to the problem).

3.3.1.2. Implementation.

4. Students are randomly assorted into groups by the platform (in other activities using different e-platforms the teachers randomly assorted the participants into groups), and each group represents an avatar, to enable students to examine and experience a given problem from multiple perspectives. Each learner uses the avatar through which s/he will argue in favor or against a certain option.

5. Students read the material.

6. Students share their informed-based opinions about the problem.

7. Students receive rewards and feedback from their teacher who monitors the game.

3.3.2. Research group 2

Research group 2 (non-problem-based digital gamification activity) was presented with mathematics exercises related to the studied material, without using an overarching problem to be solved. For example, the students were required to solve exercises of linear and non-linear equations, while receiving points for each correct answer. Each correct cohort of answers led to the next game level. For this purpose, the teachers used digital platforms such as Genially or ThingLink to create the game. Students were randomly assorted into groups by the teacher.

3.3.3. Control group 1

Control group 1 (face-to-face game-based learning with a problem-based activity) was introduced to problem-based physical gamified activities in the classroom. The problems were similar to those of the digital platforms, however, this time the teachers prepared a game-based face-to-face activity. Students were randomly assorted into groups by the teacher.

3.3.4. Control group 2

Control group 2 (face-to-face game-based learning with a non-problem-based activity) was presented with exercises similar to those used in the digital platform, only this time the game was in the classroom and included handout materials prepared by the teachers. Each game lasted around an hour, and group work was employed by the teacher who randomly sorted the participants into groups.

In relation to the feedback process, the students who participated in the gamified e-activities (research groups 1 and 2) received immediate online feedback from the teacher or the game elements and could go back and correct their answers. The students of the control groups who learned, for example through a physical board game, were given the same activity as the research groups, however, instead of online activity, the game included, for example, paper cards. The students used the cards by attaching them with scotch tape and placing the answers on the board. A correct answer or a reasonable explanation to an ill-structured problem earned them feedback such as "Excellent!" provided by the teacher.

Fig. 3 summarizes the research procedure.

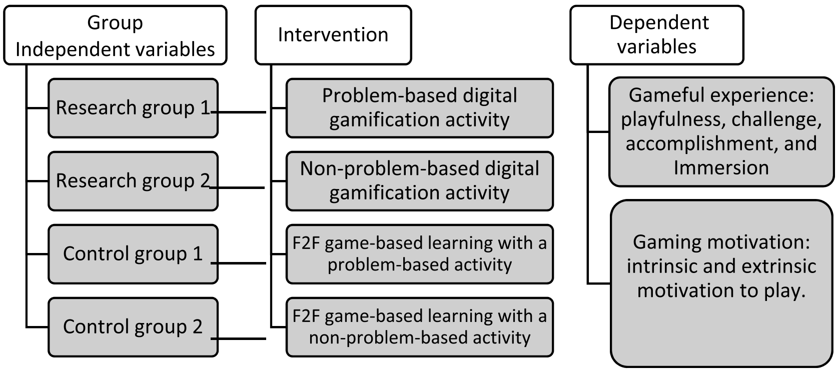

Fig. 5. Model 1. Analysis results of research model by SmartPLS.

Table 4
Mean scores, *SD*, *F* values, and partial Eta-squared statistics (ηp^2) of the research and control groups.

Factor	Research group 1 Problem-based digital xgamification activity		Research group 2 Non-problem-based digital gamification activity		Control group 1 F2F game-based learning with a problem-based activity		Control group 2 F2F game-based learning with a non-problem-based activity			
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*F*	ηp^2
Accomplishment	4.26	0.54	3.80	0.73	3.44	0.92	3.11	0.69	102.68***	0.29
Challenge	3.03	0.64	2.74	0.76	2.70	0.89	2.76	0.46	11.73***	0.04
Playfulness	4.35	0.58	3.57	0.78	2.65	0.93	2.59	0.89	249.68***	0.49
Immersion	4.05	0.66	3.39	0.78	2.71	0.81	2.50	0.60	196.48***	0.43
Extrinsic Motivation	3.56	1.16	2.55	1.14	2.01	0.90	2.09	0.85	103.88***	0.29
Intrinsic Motivation	4.55	0.50	3.91	0.82	3.40	1.03	2.84	0.95	168.85***	0.40

$p < .001$***.

3.4. Data analysis

Data were analyzed by using multivariate analysis of covariance (MANCOVA) and Partial Least Squares - Structural Equation Modeling (PLS-SEM; Hair et al., 2017) with SmartPLS 3 software. MANCOVA is a multivariate analysis of variance (MANOVA) with the addition of covariates, by which a researcher can assess statistical differences between groups on multiple dependent variables while controlling for covariate variables.

4. Results

4.1. First research question and H1

To evaluate the effectiveness of the problem-based digital gamification activity in supporting the participants' gameful experience, a MANCOVA was applied with Wilks' Lambda criterion to allow the characterization of differences between the four groups (research group 1; research group 2; control group 1; control group 2) regarding the linear combination of the four dependent factors of gameful experience: accomplishment, challenge, playfulness, and immersion. Gender and grade level variables were entered as covariate variables to allow controlling their possible confounding effect on the dependent variables. The results showed significant between-group differences regarding the linear combination of the four dependent factors ($F_{[12, 2032]} = 73.47, p < .001, \eta p^2 = 0.27$). As for the covariates, non-significant results were detected between the groups in relation to gender ($F_{[4, 768]} = 1.43, p > .05, \eta p^2 = 0.01$). Regarding the grade level covariate, a significant result was detected between the groups ($F_{[4, 768]} = 6.37, p < .05, \eta p^2 = 0.02$), however with a merely minor effect size result.

Table 4 displays the mean scores, standard deviations, and univariate tests including F values, and Eta-squared statistics of each group. Post-hoc test results showed that regarding immersion and playfulness, research group 1 scored significantly higher results than the other groups. Research group 2 scored higher results than the control groups (1 and 2), and non-significant results were detected between the control groups. In relation to accomplishment, significant differences were shown between the groups. The highest score was associated with research group 1, and the lowest was with control group 2. The results for challenge showed significant differences only between Research group 1 and the other three groups. Non-significant results were detected between these three groups. H1 was confirmed.

4.2. First research question and H2

Another MANCOVA was applied with Wilks' Lambda criterion to allow the characterization of differences between the groups regarding the linear combination of the two dependent factors of gaming motivation: Intrinsic and extrinsic. Similar to the above-described analysis, gender and grade level were entered as covariate variables. The results showed significant between-group differences regarding the linear combination of the two dependent factors ($F_{[6, 1540]} = 96.31, p < .001, \eta p^2 = 0.27$). As for the covariates, non-significant results were detected between the groups concerning gender ($F_{[2, 770]} = 1.28, p > .05, \eta p^2 = 0.00$). Regarding the grade level covariate, a significant result was found between the groups ($F_{[2, 770]} = 11.02, p < .001, \eta p^2 = 0.03$), yet with a merely minor effect size result.

Post-hoc test results showed significant differences between the four groups in intrinsic motivation. Research group 1 scored a

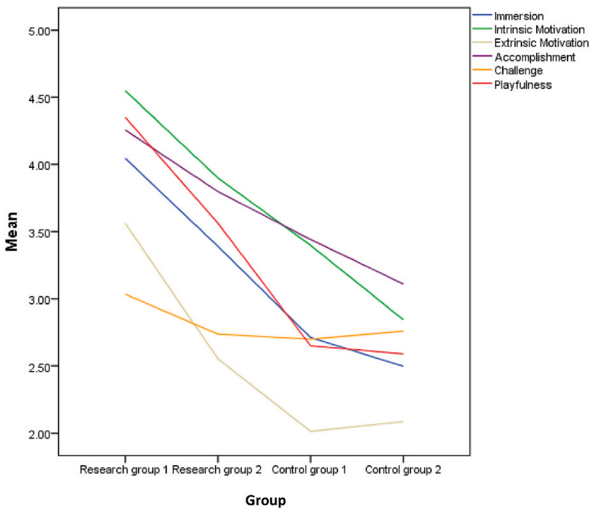

Fig. 1. Screenshot 1. Sample screenshot from the "Save the elephants: Time, velocity and distance calculations" To-BE Education game. Examples of avatars.

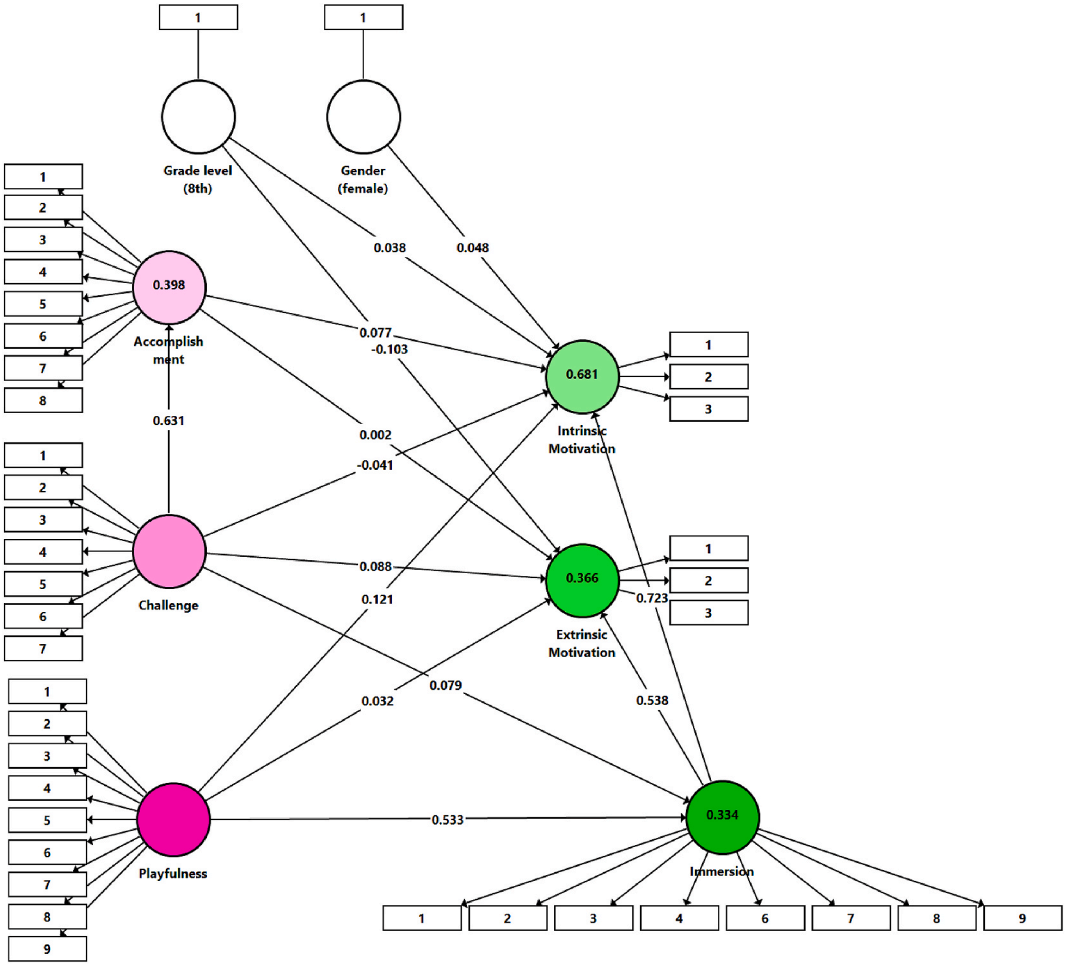

Fig. 2. Screenshot 2. Sample screenshot from the "Save the elephants: Time, velocity and distance calculations" To-BE Education game. The teacher's and the student's views.

significantly higher result than the other groups, followed by research group 2, control group 1, and control group 2. Concerning extrinsic motivation, research group 1 scored a significantly higher result than the other groups, followed by research group 2. However, non-significant results were detected between the two control groups (see Table 4). Fig. 4 summarizes the findings of this study, illustrating a trajectory according to which participants enrolled in the problem-based digital gamification activity have outperformed their counterparts, followed by students who participated in the non-problem-based digital gamification activity. Face-to-face game-based learning with a problem-based activity generally affected the dependent variables more than face-to-face game-based

Table 5
Significance analysis of the direct effects for Model 1.

Paths	Direct Effect	*t* value	*p* value
Accomplishment - > Extrinsic Motivation	0.00	0.04	0.97
Accomplishment - > Intrinsic Motivation	0.08	2.38	0.02
Challenge - > Accomplishment	0.63	30.18	0.00
Challenge - > Extrinsic Motivation	0.09	2.11	0.04
Challenge - > Immersion	0.08	2.25	0.03
Challenge - > Intrinsic Motivation	−0.04	1.55	0.12
Gender (female) - > Intrinsic Motivation	0.05	2.51	0.01
Grade level (8th) - > Extrinsic Motivation	−0.10	3.70	0.00
Immersion - > Extrinsic Motivation	0.54	17.23	0.00
Immersion - > Intrinsic Motivation	0.72	29.77	0.00
Playfulness - > Extrinsic Motivation	0.03	0.76	0.45
Playfulness - > Immersion	0.53	17.03	0.00
Playfulness - > Intrinsic Motivation	0.12	3.88	0.00

learning with a non-problem-based activity. H2 was corroborated.

4.3. Second research question and hypotheses H3 – H5

Model 1 (Fig. 5) was designed to test the impact of players' gameful experience on their gaming motivation and the set of connections between the research constructs as proposed by the theory (see Table 1, hypotheses 3–5). The model includes six latent constructs: accomplishment, challenge, playfulness, immersion, and extrinsic and intrinsic motivation to play. Three indicators were omitted due to low loading results (<0.40), two challenge-related items, and an immersion-related item. Connections between the constructs, as proposed by theory, are shown as arrows. Background variables (gender and grade level) were also entered into the model to control their effect on the latent variables. Note that only significant links are shown in the model in relation to the gender and grade level variables.

A bootstrap routine was used to assess the direct effects (Hair et al., 2017). In H3, it was postulated that the players' gameful experience variables (playfulness, challenge, accomplishment, and immersion) would increase their gaming (intrinsic and extrinsic) motivation to play. As can be learned from Model 1 (Fig. 5), and Table 5, immersion had the highest impact on intrinsic motivation and extrinsic motivation to play with moderate to high coefficient results. The gameful experience variables of playfulness and accomplishment were positively linked to intrinsic motivation, and challenge to extrinsic motivation, however with merely low direct effect size results. Non-significant results were indicated between accomplishment and extrinsic motivation, challenge and intrinsic motivation, and playfulness and extrinsic motivation. H3 was partially corroborated.

In H4 it was hypothesized that playfulness and challenge might increase the players' sense of immersion. Based on the results presented in Table 5, both variables had increased students' immersion thereby confirming H4. However, whereas the playfulness variable was accompanied by a moderate effect size result, the challenge-immersion path was accompanied by a low result. Lastly, in H5 it was postulated that the sense of accomplishment would be informed by the perception of challenge. The path coefficient result indicated a moderate effect. H5 was confirmed.

4.3.1. Model evaluation

For each scale, convergent validity assessment was based on the outer loadings of the indicators (should be > 0.40) and average variance extracted (AVE) values. AVE is defined as the grand mean value of the squared loadings of the indicators connected to the construct and is equivalent to the communality of a construct. An AVE value of 0.50 or higher indicates that, on average, the construct explains more than half of the variance of its related indicators (Hair et al., 2017). As can be learned from Table 6, generally, convergent validity has been established for the research model. Composite reliability was also calculated (should be > 0.70), and as can be learned from Table 6, satisfactory results were shown for the model.

Discriminant validity was assessed by using the heterotrait-monotrait ratio (HTMT) of the correlations (Henseler et al., 2015), defined as the mean of all correlations of indicators across constructs measuring different constructs. The HTMT serves as the basis for a discriminant validity test. An HTMT value above 0.90 suggests a lack of discriminant validity. Moreover, relying on a bootstrapping procedure, a bootstrap confidence interval containing the value 1 indicates a lack of discriminant validity. The evaluation of Model 1 yielded sufficient results, namely, HTMT values were found lower than 0.90 (in one case it was found equal to 0.90) and the confidence interval did not include 1 (Table 7).

Variance Inflation Factor (VIF) values were checked for collinearity. The results of all sets of predictor constructs in the structural model showed that the values of all combinations of endogenous and exogenous constructs are below the threshold of 5 (Hair et al., 2017) ranging from 1.00 to 2.31. The coefficient of determination (R^2) values for the endogenous factors ranged from 0.33 to 0.68, these values can be considered moderate to high (Hair et al., 2017). The change in the R^2 value (f^2 effect size) showed that the highest effect size results were found between immersion and intrinsic motivation ($f^2 = 1.08$) followed by challenge and accomplishment ($f^2 = 0.66$), playfulness and immersion ($f^2 = 0.31$), and immersion and extrinsic motivation ($f^2 = 0.30$). Lastly, the blindfolding procedure was used to assess the predictive relevance (Q^2) of the path model. Values larger than 0 suggest that the model has predictive relevance for a certain endogenous construct (Hair et al., 2017). The Q^2 values ranged from 0.20 to 0.53.

In addition, the potential differences regarding the relationship between gameful experience and gaming motivation in the problem-based digital gamification activity group and the face-to-face game-based learning with a non-problem-based activity group were tested. To this end, a multi-group analysis (MGA) was performed. According to the MGA, significant results were indicated only between challenge and extrinsic motivation to play. However, whereas a non-significant result was found between the variables in the

Table 6
Result summary for the research model.

Latent Variable	Convergent Validity	Composite Reliability
	AVE	
	>0.50	>0.70
Accomplishment	0.55	0.91
Challenge	0.42	0.82
Extrinsic Motivation	0.75	0.90
Immersion	0.61	0.93
Intrinsic Motivation	0.79	0.92
Playfulness	0.65	0.94

Table 7
Discriminant validity assessed by the heterotrait-monotrait ratio (HTMT).

Factor	1	2	3	4	5
1 Accomplishment					
2 Challenge	0.70				
3 Extrinsic Motivation	0.36	0.34			
4 Immersion	0.49	0.39	0.67		
5 Intrinsic Motivation	0.51	0.38	0.58	0.90	
6 Playfulness	0.74	0.58	0.43	0.61	0.62

problem-based digital gamification activity group ($\beta = .01$, $p > .05$), a significant negative coefficient result was found in the face-to-face game-based learning with a non-problem-based activity group ($\beta = -0.27$, $p < .05$). Based on the MGA, the difference between the two paths yielded a significant result ($\beta = 0.28$, $t = 2.11$; $p < .05$).

5. Discussion

The focus of this study was two-fold: the first objective was to measure the potential effect of different game-based learning environments (digital vs. non-digital, and problem-based vs. non-problem-based) on students' perceptions of the game experience and motivation to actively participate in mathematics activities. Hence, it enabled addressing two aspects of the learning environment, the pedagogical and the technological, by measuring the impact of four different instructional activities using game elements in the context of mathematics learning. Another objective was to evaluate the links between players' gameful experience and their gaming motivation. In the succeeding section, each research question and findings will be separately discussed.

5.1. The effectiveness of problem-based gamification activities

The impact of the problem-based digital gamification activity on participants' sense of accomplishment, challenge, playfulness, and immersion was assessed. The analysis showed the superiority of the proposed digital gamified activity which included an overarching problem to be solved compared to the three other groups (including non-problem-based digital gamification activity, and two face-to-face games), in enhancing students' gameful experience and gaming motivation. The second effective group was the non-problem-based digital gamification activity; the least effective group was control group 2 using gamified face-to-face activity without framing it in a wider problem-based context. These findings are consistent with those found in past studies, showing the benefits of digital gamification as more appealing to users as it provides an increased sense of playfulness (Högberg et al., 2019), accomplishment (Komala & Rifai, 2021; Suh et al., 2018), immersion (Goethe, 2019), challenge (Högberg et al., 2019), and motivation to play (Mitchell et al., 2020).

Notably, the findings also undermine previous investigations indicating that in some contexts, gamification may not facilitate motivation to play or even impede it (Mekler et al., 2017). Yet, the contribution of the present study lies in its focus on a specific context of learning (i.e., mathematics), and the comparison of digital gamified problem-based activities to more than a single, vastly used, traditional learning environment (Hwa, 2018; Kurvinen, 2020; Legaki et al., 2020; Lo & Hew, 2020). The findings of which mainly suggest that merely infusing serious digital games with game elements into learning might not necessarily raise student engagement in the activity, as opposed to a view vastly espoused by gamification researchers (Codish & Ravid, 2017).

More specifically this study underscores the importance of centering digital gamification on a sound constructivist pedagogy that enables students to connect mathematics with solving ill-structured problems. By considering the pedagogical and technological aspects of learning activities, this study adds to the corpus of knowledge by stressing the importance of the underlying instructional method to raise student engagement in the activity. A gamification activity based on problem-solving might provide a partial solution to the challenge raised by researchers in the field of mathematics (e.g., Nurlaily et al., 2019) dealing with the integration of problem-based learning into mathematics learning. Teachers might find digital platforms, which enable the use of problem-solving techniques, more efficient in spurring student motivation to actively participate in the activity than those lacking the ability to introduce ill-structured situations.

5.2. The effect of gameful experience on gaming motivation

A PLS-SEM analysis was used to evaluate the links between the research constructs as suggested by theory. The results of which partially coincide with those indicated in previous studies (Högberg et al., 2019). The analysis results corroborated the positive role players' sense of challenge has on their perception of their accomplishment, with a resultant slight increase in their intrinsic motivation to play. According to Hamari et al. (2016), being challenged might be perceived by some students as arduous, yet they suggested that students tend to like challenging activities and value cognitive complexity. However, it bears mentioning that a sense of challenge and accomplishment is not necessarily connected to the design of the activity, it may as well stem from individual differences between students. These differences might be linked, for example, to students' deep rather than surface strategies for learning – variables that were not measured in this study. This may also account for the low intrinsic motivation increased by the accomplishment variable.

Another interesting finding showed, as hypothesized, that challenge was positively linked to extrinsic motivation, accompanied by a low direct effect size result. To delve deeper into this result, a multi-group analysis was conducted, according to which, this significant coefficient result was found merely associated with face-to-face game-based learning with a non-problem-based activity group. The difference between the two paths was found significant. In the latter group, students who perceived the activity as more challenging reported being less extrinsically motivated to play. In line with Högberg et al. (2019), being challenged is essential to increase the player's motivation to play. Yet, as suggested by others (Gibson et al., 2018; Legaki et al., 2020) and by the current research, the pedagogical method that lies at the core of the game alongside the integration of digital game mechanics may affect the player's motivation to continue playing and tackle possible challenges. It may be inferred that superficially introducing topics to students through face-to-face games might discourage their extrinsic motivation to play.

Another finding showed that playfulness mainly enhanced students' sense of immersion which, in turn, had a bearing on both intrinsic and extrinsic motivation to play. Playfulness can be achieved by integrating game mechanics such as points and badges. As previously stated by several researchers (e.g., Hamari et al., 2016), a joyful game can 'envelope' the learner as it creates an emotional experience that prompts a deep engagement with the learning activity. The present study enhances this notion by pointing to intrinsic and extrinsic motivation to play as additional variations of students' increased engagement in the activity, informed by their sense of playfulness. It also warrants mention that the challenge-immersion coefficient path was accompanied by a significant yet low result. This can be explained by the possible association of playfulness and immersion with emotional aspects (Patrício et al., 2018), whereas the challenge variable can be perceived as a cognitive aspect related to students' capabilities to deal with the requirements of a given learning activity and improve their achievements.

5.3. Limitations and recommendations for future research

This study is riddled with several limitations. For example, student perceptions were measured using a self-reporting survey. Future studies may further benefit from additional measurements that center more specifically on observed behaviors. To this end, approaches such as participatory design research might have the potential to substantively elaborate on the current study's findings. In addition, the present investigation was focused on mathematics to isolate the effect of the subject taught in the research and control groups. It is suggested to test the hypotheses presented herein in relation to other subjects to give credence to its findings. Moreover, the research procedure did not include pretests as the participants were asked to relate to their experiences after the intervention. A pretest-posttest design can be proposed to check, for example, attitudes towards gamification, measured before and after the treatment is implemented.

It should also be acknowledged that the effect of using serious games might fade over time. As indicated by several researchers, student engagement and interest in games might decrease over time once the novelty wears off, and at an incredible pace if all the learning contexts are introduced in a gamified format (Faiella & Ricciardi, 2015; Hanus & Fox, 2015; Koivisto & Hamari, 2014; Mavletova, 2015). Therefore, future studies should assess the long-term effect of using gamification (with or without problem-based learning), with the purpose of investigating the novelty effect of this learning environment on the dependent variables.

5.4. Conclusions and implications

The results of the present study mainly indicate that merely using digital gamification might not effectively motivate the student to actively participate in the learning activity unless it hinges on a sound pedagogical rationale. To obtain learning outcomes that coincide with constructivist approaches to mathematics learning, this study proposes to focus instructional efforts on activities where students are given opportunities to actively engage in problem-solving processes. This study adds to previous studies by underscoring the importance of integrating constructive pedagogical methods into gamification. These should be espoused with game elements that prompt students' sense of playfulness, thereby increasing their motivation to engage in the learning activity. Consequently, these suggested activities could lead to several learning-related outcomes, such as cognitive, affective, and behavioral learning outcomes (Nurtanto et al., 2021; Sailer & Homner, 2020); improvement in knowledge-based learning outcomes (Papp & Theresa, 2017); mathematical knowledge (Hwa, 2018); learning in formal educational settings (Huang et al., 2020); interest in math classes (Stoyanova et al., 2017); and calculation or arithmetic skills (Brezovszky et al., 2019; Deng et al., 2020). Collectively, the researchers underscored the importance of ensuring that the design of the gamified learning activities is closely connected to learning outcomes.

This study points to an exciting new venue for further research, the findings of which are likely to have a bearing also on features of teacher education. The field of gamification studies has burgeoned in recent years, offering a multitude of educational platforms teachers can use in different contexts. However, as argued by Salomon (2016) these should not be viewed as "magic wands and wonder tools" (p. 149). Teachers should first consider the learning outcomes in terms of knowledge acquisition and cultivation of skills needed for students, such as problem-solving abilities. This can be followed by choosing an appropriate educational app that might engage students in the proposed activity. Searching for instant solutions, based on the idea that technology can mitigate educational challenges should be reconsidered in light of the present study. It is suggested that in this search for solutions, special consideration should be given to the selection of the game in a way that enables the pedagogical 'dog' to wag the technological 'tail' rather than the other way around.

Credit author statement

Dorit Alt: Conceptualization, Methodology, Data curation, Analyses, Writing- Original draft preparation, Writing- Reviewing, Editing, Revising.

Declaration of competing interest

The author declares that she has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

References

Abdullah, N. I., Tarmizi, R. A., & Abu, R. (2010). The effects of problem-based learning on mathematics performance and affective attributes in learning statistics at form four secondary level. *Procedia-Social and Behavioral Sciences, 8*, 370–376.

Adams, N., Little, T. D., & Ryan, R. M. (2017). Self-determination theory. In M. Wehmeyer, K. Shogren, T. Little, & S. Lopez (Eds.), *Development of self-determination through the life-course* (pp. 47–54). Springer.

de Almeida, J. L. F., & dos Santos Machado, L. (2021). Design requirements for educational serious games with focus on player enjoyment. *Entertainment Computing, 38*. https://doi.org/10.1016/j.entcom.2021.100413

Amalia, E., Surya, E., & Syahputra, E. (2017). The effectiveness of using problem-based learning (PBL) in mathematics problem solving ability for junior high school students. *International Journal of Advance Research and Innovative Ideas in Education, 3*(2), 3402–3406.

Behlol, M. G., Akbar, R. A., & Sehrish, H. (2018). Effectiveness of problem-solving method in teaching mathematics at elementary level. *Bulletin of Education and Research, 40*(1), 231–244.

Behnamnia, N., Kamsin, A., Ismail, M. A. B., & Hayati, A. (2020). The effective components of creativity in digital game-based learning among young children: A case study. *Children and Youth Services Review, 116*. https://doi.org/10.1016/j.childyouth.2020.105227

Bevins, K. L., & Howard, C. D. (2018). Game mechanics and why they are employed: What we know about gamification so far. *Issues and Trends in Learning Technologies, 6*(1). https://doi.org/10.2458/azu_itet_v6i1_bevins

Bråting, K., & Kilhamn, C. (2022). The integration of programming in Swedish school mathematics: Investigating elementary mathematics textbooks. *Scandinavian Journal of Educational Research, 66*(4), 594–609.

Brezovszky, B., McMullen, J., Veermans, K., Hannula-Sormunen, M. M., Rodríguez-Aflecht, G., Pongsakdi, N., … Lehtinen, E. (2019). Effects of a mathematics game-based learning environment on primary school students' adaptive number knowledge. *Computers & Education, 128*, 63–74.

Buckley, P., & Doyle, E. (2016). Gamification and student motivation. *Interactive Learning Environments, 24*(6), 1162–1175.

Christopoulos, A., Kajasilta, H., Salakoski, T., & Laakso, M. J. (2020). Limits and virtues of educational technology in elementary school mathematics. *Journal of Educational Technology Systems, 49*(1), 59–81.

Codish, D., & Ravid, G. (2017). Gender moderation in gamification: Does one size fit all?. In *Proceedings of the 50th Hawaii international conference on system sciences*. http://hdl.handle.net/10125/41398.

Cruaud, C. (2018). The playful frame: Gamification in a French-as-a-foreign-language class. *Innovation in Language Learning and Teaching, 12*(4), 330–343.

Deci, E. L., Olafsen, A. H., & Ryan, R. M. (2017). Self-determination theory in work organizations: The state of a science. *Annual review of organizational psychology and organizational behavior, 4*, 19–43.

Deci, E. L., & Ryan, R. M. (1985). *Intrinsic motivation and self-determination in human behavior*. Plenum.

Deci, E. L., & Ryan, R. M. (2000). The ''what'' and ''why'' of goal pursuit: Human needs and the self-determination of behavior. *Psychological Inquiry, 11*, 227–268.

Demetrovics, Z., Urbán, R., Nagygyörgy, K., Farkas, J., Zilahy, D., Mervó, B., & Harmath, E. (2011). Why do you play? The development of the motives for online gaming questionnaire (MOCQ). *Behavior Research Methods, 43*, 814–825.

Deng, L., Wu, S., Chen, Y., & Peng, Z. (2020). Digital game-based learning in a shanghai primary-school mathematics class: A case study. *Journal of Computer Assisted Learning, 36*(5), 709–717.

Deterding, S., Dixon, D., Khaled, R., & Nacke, L. (2011). From game design elements to gamefulness: Defining" gamification. In *Proceedings of the 15th international academic mindTrek conference: Envisioning future media environments* (pp. 9–15). September.

Doabler, C. T., Clarke, B., Kosty, D., Sutherland, M., Turtura, J. E., Firestone, A. R., … Jungjohann, K. (2022). Promoting understanding of measurement and statistical investigation among second-grade students with mathematics difficulties. *Journal of Educational Psychology, 114*(3), 560–575.

Fadlelmula, F. K. (2022). Enablers and obstacles in teaching and learning of mathematics: A systematic review in lumat journal. *LUMAT: International Journal on Math, Science and Technology Education, 10*(2), 33–55.

Faiella, F., & Ricciardi, M. (2015). Gamification and learning: A review of issues and research. *Journal of e-Learning and Knowledge Society, 11*(3). https://doi.org/10.20368/1971-8829/1072

Feng, Y., Yi, Z., Yang, C., Chen, R., & Feng, Y. (2022). How do gamification mechanics drive solvers' knowledge contribution? A study of collaborative knowledge crowdsourcing. *Technological Forecasting and Social Change, 177*. https://doi.org/10.1016/j.techfore.2022.121520

Finesilver, C., Healy, L., & Bauer, A. (2022). Supporting diverse approaches to meaningful mathematics: From obstacles to opportunities. In Y. P. Xin, R. Tzur, & H. Thouless (Eds.), *Enabling mathematics learning of struggling students* (pp. 157–176). Cham: Springer.

Gibson, D., Irving, L., & Scott, K. (2018). Challenge-based learning in a serious global game. *Encyclopedia of Computer Graphics and Games, 1–4*. https://doi.org/10.1007/978-3-319-08234-9_115-1

Goethe, O. (2019). *Gamification mindset. Human–Computer interaction series*. Springer.

Gupta, P., & Goyal, P. (2022). Is game-based pedagogy just a fad? A self-determination theory approach to gamification in higher education. *International Journal of Educational Management, 36*. https://www.emerald.com/insight/0951-354X.htm.

Hair, J. F., Jr., Hult, G. T. M., Ringle, C. M., & Sarstedt, M. (2017). *A primer on partial least Squares structural equation modeling (PLS-SEM)* (2nd ed.). Sage.

Hamari, J., Shernoff, D. J., Rowe, E., Coller, B., Asbell-Clarke, J., & Edwards, T. (2016). Challenging games help students learn: An empirical study on engagement, flow and immersion in game-based learning. *Computers in Human Behavior, 54*, 170–179.

Hanus, M. D., & Fox, J. (2015). Assessing the effects of gamification in the classroom: A longitudinal study on intrinsic motivation, social comparison, satisfaction, effort, and academic performance. *Computer Education, 80*, 152–161.

Hendriana, H., Johanto, T., & Sumarmo, U. (2018). The role of problem-based learning to improve students' mathematical problem-solving ability and self-confidence. *Journal on Mathematics Education, 9*(2), 291–300.

Higgins, K., Huscroft-D'Angelo, J., & Crawford, L. (2019). Effects of technology in mathematics on achievement, motivation, and attitude: A meta-analysis. *Journal of Educational Computing Research, 57*(2), 283–319.

Högberg, J., Hamari, J., & Wästlund, E. (2019). Gameful experience questionnaire (GAMEFULQUEST): An instrument for measuring the perceived gamefulness of system use. *User Modeling and User-Adapted Interaction, 29*(3), 619–660.

Huang, R., Ritzhaupt, A. D., Sommer, M., Zhu, J., Stephen, A., Valle, N., … Li, J. (2020). The impact of gamification in educational settings on student learning outcomes: A meta-analysis. *Educational Technology Research & Development, 68*(4), 1875–1901.

Huotari, K., & Hamari, J. (2017). A definition for gamification: Anchoring gamification in the service marketing literature. *Electronic Markets, 27*(1), 21–31.

Hu, R., & Shang, J. (2018). Application of gamification to blended learning in elementary math instructional design. In S. K. S. Cheung (Ed.), *Blended learning: Enhancing learning success* (pp. 93–104). Springer International Publishing.

Hwa, S. P. (2018). Pedagogical change in mathematics learning: Harnessing the power of digital game-based learning. *Journal of Educational Technology & Society, 21*(4), 259–276.

Koivisto, J., & Hamari, J. (2014). Demographic differences in perceived benefit from gamification. *Computers in Human Behavior, 35*, 179–188.

Koivisto, J., & Hamari, J. (2019). The rise of motivational information systems: A review of gamification research. *International Journal of Information Management, 45*, 191–210.

Komala, A. S., & Rifai, I. (2021). The impacts of the cherry orchard video game on players' reading comprehension. *Procedia Computer Science, 179*, 368–374.

Kurvinen, E., Kaila, E., Laakso, M. J., & Salakoski, T. (2020). Long term effects on technology enhanced learning: The use of weekly digital lessons in mathematics. *Informatics in Education, 19*, 51–75.

Lafrenière, M. A. K., Verner-Filion, J., & Vallerand, R. J. (2012). Development and validation of the gaming motivation scale (GAMS). *Personality and Individual Differences, 53*(7), 827–831.

Legaki, N. Z., Xi, N., Hamari, J., Karpouzis, K., & Assimakopoulos, V. (2020). The effect of challenge-based gamification on learning: An experiment in the context of statistics education. *International Journal of Human-Computer Studies, 144*. https://doi.org/10.1016/j.ijhcs.2020.102496

Lo, C. K., & Hew, K. F. (2020). A comparison of flipped learning with gamification, traditional learning, and online independent study: The effects on students' mathematics achievement and cognitive engagement. *Interactive Learning Environments, 28*(4), 464–481.

Masitoh, L. F., & Fitriyani, H. (2018). Improving students' mathematics self-efficacy through problem-based learning. *Malikussaleh Journal of Mathematics Learning (MJML), 1*(1), 26–30.

Mavletova, A. (2015). A gamification effect in longitudinal web surveys among children and adolescents. *International Journal of Market Research, 57*(3), 413–438.

Mäyrä, F., & Ermi, L. (2011). Fundamental components of the gameplay experience. *Digarec Series, 6*, 88–115.

Mekler, E. D., Brühlmann, F., Tuch, A. N., & Opwis, K. (2017). Towards understanding the effects of individual gamification elements on intrinsic motivation and performance. *Computers in Human Behavior, 71*, 525–534.

Merritt, J., Lee, M. Y., Rillero, P., & Kinach, B. M. (2017). Problem-based learning in K–8 mathematics and science education: A literature review. *Interdisciplinary Journal of Problem-Based Learning, 11*(2). https://doi.org/10.7771/1541-5015.1674

Mitchell, R., Schuster, L., & Jin, H. S. (2020). Gamification and the impact of extrinsic motivation on needs satisfaction: Making work fun? *Journal of Business Research, 106*, 323–330.

Nguyen, A. (2021). Why do students engage in gamification? An exploratory study using means-end chains. *Journal of Theoretical and Applied Information Technology, 99*, 5783–5793.

Nurlaily, V. A., Soegiyanto, H., & Usodo, B. (2019). Elementary school teachers' obstacles in the implementation of problem-based learning model in mathematics learning. *Journal on Mathematics Education, 10*(2), 229–238.

Nurtanto, M., Kholifah, N., Ahdhianto, E., Samsudin, A., & Isnantyo, F. D. (2021). A review of gamification impact on student behavioral and learning outcomes. *International Journal of Interactive Mobile Technologies, 15*(21). https://orcid.org/0000-0002-6357-7152.

Papp, T. A., & Theresa, A. (2017). Gamification effects on motivation and learning: Application to primary and college students. *International Journal for Cross-Disciplinary Subjects in Education, 8*(3), 3193–3201.

Partovi, T., & Razavi, M. R. (2019). The effect of game-based learning on academic achievement motivation of elementary school students. *Learning and Motivation, 68*. https://doi.org/10.1016/j.lmot.2019.101592

Patrício, R., Moreira, A. C., & Zurlo, F. (2018). Gamification approaches to the early stage of innovation. *Creativity and Innovation Management, 27*(4), 499–511.

dos Reis Lívero, F. A., da Silva, G. R., Amaral, E. C., de Souza, A. N. V., Baretta, I. P., Diegues, M. E. M., … Lovato, E. C. W. (2021). Playfulness in the classroom: Gamification favor the learning of pharmacology. *Education and Information Technologies, 26*(2), 2125–2141.

Richter, G., Raban, D. R., & Rafaeli, S. (2015). Studying gamification: The effect of rewards and incentives on motivation. In T. Reiners, & L. C. Wood (Eds.), *Gamification in education and business* (pp. 21–46). Cham: Springer.

Rojo, M., King, S., Gersib, J., & Bryant, D. P. (2022). Rational number interventions for students with mathematics difficulties: A meta-analysis. *Remedial and Special Education*. https://doi.org/10.1177/07419325221105520

Ryan, R. M. (1995). Psychological needs and the facilitation of integrative processes. *Journal of Personality, 63*, 397–427.

Ryan, R. M., & Deci, E. L. (2002). Overview of self-determination theory: An organismic dialectical perspective. *Handbook of self-determination research, 2*, 3–33.

Ryan, R. M., Rigby, C. S., & Przybylski, A. (2006). The motivational pull of video games: A self-determination theory approach. *Motivation and Emotion, 30*(4), 344–360.

Sailer, M., & Homner, L. (2020). The gamification of learning: A meta-analysis. *Educational Psychology Review, 32*(1), 77–112.

Salomon, G. (2016). It's not just the tool but the educational rationale that counts. In E. Elstad (Ed.), *Educational technology and polycontextual bridging* (pp. 147–161). Brill.

Savvani, S. (2020). Emotions and challenges during game creation: Evidence from the global game jam. In *Proceedings of the 14th European conference on games based learning*. https://doi.org/10.34190/GBL.20.063

Schettino, C. (2016). A framework for problem-based learning: Teaching mathematics with a relational problem-based pedagogy. *Interdisciplinary Journal of Problem-Based Learning, 10*(2), 12. https://doi.org/10.7771/1541-5015.1602

Siagan, M. V., Saragih, S., & Sinaga, B. (2019). Development of learning materials oriented on problem-based learning model to improve students' mathematical problem solving ability and metacognition ability. *International Electronic Journal of Mathematics Education, 14*(2), 331–340.

Stoyanova, M., Tuparova, D., & Samardzhiev, K. (2017). Impact of motivation, gamification and learning style on students' interest in maths classes–a study in 11 high school grade. In *International conference on interactive collaborative learning* (pp. 133–142). Cham: Springer. September.

Suh, A., Wagner, C., & Liu, L. (2018). Enhancing user engagement through gamification. *Journal of Computer Information Systems, 58*(3), 204–213.

Walker, A., Leary, H., Hemlo-Silver, C. E., & Ertmer, P. A. (Eds.). (2015). *Essential readings in problem-based learning: Exploring and extending the legacy of Howard S. Barrows*. Purdue University Press.

Xi, N., & Hamari, J. (2019). Does gamification satisfy needs? A study on the relationship between gamification features and intrinsic need satisfaction. *International Journal of Information Management, 46*, 210–221.