Effects of Collaborative Digital Gameplay on Students' Three Dimensions of Engagement in Mathematics

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Abstract

This study attempts to provide an in-depth understanding of the influence of collaborative digital gameplay on students' behavioural, emotional and cognitive engagement in mathematics. This mixed-method study used pre- (N = 45) and post-test (N = 43) engagement surveys and photo-elicitation interviews (N = 6) to investigate how a six-day experiment involving collaborative digital gameplay on Wuzzit Trouble affects students' engagement in mathematics. The quantitative results showed collaborative digital gameplay did not elicit a significant increase in students' engagement in mathematics from pre-test to post-test. Moreover, the qualitative results of analyzing the measurement of three-dimensional engagement showed four factors – learning achievement, teacher support, peer collaboration and task characteristics – were associated with students' engagement in a collaborative digital gameplay classroom. The findings suggest the classroom context plays an important role in three-dimensional engagement, which efficiently improve students' conceptual understanding and arithmetic skills.

Keywords: Collaborative digital gameplay, behavioural engagement, emotional engagement, cognitive engagement, mathematics, primary education

1. Introduction

In primary education, digital games have been discussed and used as supplemental tools to support learning and teaching in the classroom (Callaghan et al., 2018; Kangas et al., 2016). According to Yang and colleagues (2018), educational digital gameplay combines digital games and educational resources. Other studies highlight that digital gameplay helps trigger students' interest and motivation in learning (Rodríguez-Aflecht et al., 2018; Sun, et al., 2018), develops their problem-solving skills (Yang et al., 2018) and has a positive effect on their learning outcomes (Sun et al., 2021a). Hence, digital gameplay has been employed in different educational settings, such as reading (Vanbecelaere et al., 2020), mathematics (Callaghan et al., 2018), science (Fokides & Chachlaki, 2019) and foreign languages (Yang et al., 2018).

This study attempts to provide an in-depth understanding of the influence of collaborative digital gameplay on students' behavioural, emotional and cognitive engagement in mathematics. A face-to-face classroom setting is designed to explore the effects of collaborative digital gameplay on students' engagement in mathematics. Unlike previous studies, which focused on overall engagement (Cornelisz & van Klaveren, 2018), this study considers the three-dimensional engagement because these three dimensions supplement one another and have varying impacts on students' learning activities. Further theoretical and empirical studies are crucial to identify the differences and interactions of the three dimensions of engagement (Fredricks & McColskey, 2012) and examine how classroom factors affect the three dimensions simultaneously (Fredricks et al., 2004). Moreover, engagement is conceptualized as a multifaceted construct. Defining and measuring each dimension can separate antecedents and outcomes of behaviour, emotion and cognition for designing future studies on three-dimensional engagement and digital game-based learning in the educational context (Lam et al., 2012). In short, compared with the studies that focus on overall engagement, this study provides a comprehensive perspective on three-dimensional engagement in primary education. As this study shows, digital gameplay can be identified as an important factor supporting students' learning in mathematics – that is, digital gameplay and other factors appear to influence students' three-dimensional engagement in the mathematics classroom.

2. Theoretical Background

2.1 Collaborative learning

According to Dillenbourg (1999, p. 5), collaborative learning is "a situation in which particular forms of interaction among people are expected to occur, which would trigger learning mechanisms". Therefore, collaborative learning generally occurs when a person is asked to work on a single task with more than one person, and each individual is expected to be responsible for achieving a common goal with one's group members (Tomasello, 2016).

Earlier research shows that collaboration with peers encourages motivation and cognitive engagement (Blumenfeld et al., 2006) and promotes learning (Chang & Hwang, 2017). Furthermore, collaborative learning is a feasible instructional approach, as students can learn how to interact with their peers to solve problems (Hyvönen, 2008).

Although collaborative learning is useful for supporting and improving students' learning, interaction and engagement might not occur as expected, for example, among preschool and junior students in primary schools (Danby et al., 2018; Kangas, 2010). The problems that researchers indicate include communication difficulties (Janssen et al., 2009), the need for more intensified support (Dukuzumuremyi & Siklander, 2018), and conflicts and negative emotions during discussions with group members (Lipponen et al., 2018). To minimize the likelihood of the occurrence of the cited problems, digital gameplay is considered and used in collaborative learning.

2.1.1 Collaborative learning and digital gameplay

The impact of digital gameplay in collaborative learning is increasingly evident (Baek & Touati, 2020). Compared with traditional ways of learning and other types of gameplay, in the face-to-face classroom setting, the digital element in gameplay can make learning more interesting, motivating and effective, especially for young learners (Khoo, 2016; Lipponen et al., 2018). Furthermore, digital games' interactive and multimode features are regarded as beneficial in facilitating students' social learning (Frome, 2019; Lipponen et al., 2018). For example, Chang and Hwang (2017) indicate that collaborative digital gameplay helps students acquire subject knowledge and carry out learning tasks by providing and receiving support from their peers. Through collaboration and interaction during digital gameplay, students' learning achievement and communication skills are fostered and developed (Danby et al., 2018).

During collaborative digital gameplay, students' involvement in interaction can be influenced by age, personal characteristics, study habits and familiarity (Lipponen et al., 2018). Typically, students who are skilled in social communication can play with their peers and solve conflicts better than those who are less skilled (Lipponen et al., 2018). Furthermore, familiarity among peers is beneficial because socio-emotional factors in the group play an important role in collaborative activities (Janssen et al., 2009). Therefore, in this study, the students play the digital game with their desk mates, with whom they are familiar, and they experience collaborative activities daily in school.

2.2 Engagement

Guthrie and colleagues (2012, p. 601) define engagement as "involvement, participation, and commitment to some set of activities". Moreover, as Renninger and colleagues (2018) point out, engagement generally deals with the context of participation, such as school, ballet school and sports team, and individuals' behavioural, emotional and cognitive responses to it. This means that the individuals' engagement "cannot be separated from their environment" (Fredricks & McColskey, 2012, p. 765).

According to Fredricks and colleagues (2004), engagement typically has three dimensions: behavioural, emotional and cognitive. *Behavioural engagement* refers to direct participation in a set of activities in academic learning and extracurricular activities in school, and it is regarded as critical to ensuring students' learning achievement and preventing them from dropping out. *Emotional engagement* encompasses students' positive and negative reactions to and feelings about their activities, teachers, peers and the schools they attend. *Cognitive engagement* emphasizes the amount and the type of psychological investment in learning, as well as the use of self-regulatory and other strategies to direct individuals' cognitive efforts. In keeping with the above descriptions, each dimension has clear features (Lam et al., 2012). However, all the dimensions of engagement co-occur and overlap (Fredricks et al., 2004; Renninger et al., 2018). Therefore, as Fredricks and colleagues (2004) point out, the behavioural, emotional and cognitive dimensions of engagement are conceptualized as a multifaceted construct and can be explored simultaneously.

2.2.1 Engagement and collaborative digital gameplay

According to Jabbar and Felicia (2015), the digital gaming platform makes students engage in gameplay and learning. This is because the various communication potentialities and levels of interactions built into the digital gaming platforms enable a variety of students to enjoy them (Baek & Touati, 2020). Therefore, in this study, a collaborative digital gameplay context is designed to create opportunities to measure and reflect students' three-dimensional engagement in collaborative experiences with the digital game.

Collaborative digital gameplay is recognized as a key factor of student engagement (Khoo, 2016). The enjoyment and motivation can maintain and increase student engagement (Jabbar & Felicia, 2015). Moreover, the various communications and interactions with peers embedded in digital gameplay enable students to have positive relationships with peers and teachers (Baek & Touati, 2020), provide support when needed (Lipponen et al., 2018), and instruct and monitor one another's actions with different strategies (Danby et al., 2018). As Pekrun and Linnenbrink-Garcia (2012) point out, the positive emotions from collaborative digital gameplay can promote effort-making and the use of learning strategies and therefore influence students' learning achievement.

In addition to the aforementioned collaborative learning and digital gameplay, other types of factors influence students' behavioural, emotional and cognitive engagement, for example, teacher scaffolding (Sun et al., 2021b), design of learning activities (Jabbar & Felicia, 2015) and individual needs (Fredricks et al., 2004). In this study, students' behavioural, emotional and cognitive engagement are measured in a collaborative digital gameplay mathematics classroom. The authors expect that by doing so, they can investigate and identify the factors that affect students' three-dimensional engagement in mathematics.

3. Current Study

This study aims to explore the effects of collaborative digital gameplay on students' engagement in mathematics. The following research questions are examined:

1. How does students' engagement in mathematics manifest in collaborative digital gameplay?
2. What factors have an impact on students' three-dimensional engagement in a collaborative digital gameplay classroom?

4. Method

The research is a mixed-method study (Johnson & Christensen, 2020) that combines qualitative components with the quantitative research method. Applying both methods helps increase the findings' validity and reliability by minimizing the impact of the limitations on the study. It also enables the authors to obtain more data to measure the students' behavioural, emotional and cognitive engagement in the collaborative digital gameplay in order to deduce meaningful explanations for the factors related to students' three-dimensional engagement in mathematics. The quantitative data are obtained through a survey about mathematical engagement, and the qualitative data consist of the photo-elicitation interviews. The detailed descriptions of these instruments and data are presented below.

4.1 Participants

This study's participants were 45 second graders, comprising 19 girls and 26 boys, aged eight to nine years old, from one class in a primary school in China. The students participated in the study during their regularly scheduled mathematics class periods, and all participated in the six-day classroom experiment. The students were divided into pairs. Each pair worked with one tablet to access a digital game called *Wuzzit Trouble*. The students had no learning experience with digital games in mathematics before the experiment, and their mathematics teacher was female and had no experience in teaching digital games before participating in the study.

4.2 Wuzzit Trouble

Wuzzit Trouble is an educational digital game developed by BrainQuake in the fall of 2013 (Devlin, 2013) to improve integer-arithmetic problem-solving for students using iPhone operating system (iOS) mobile devices. Wuzzits are coloured creatures trapped in a castle's cages (Kiili et al., 2015). The goal of the game is to free Wuzzits by collecting all the keys. Figures 1 and 2 show examples of the *Wuzzit Trouble* game interface at levels 1 and 3, respectively.

Figure 1. Wuzzit Trouble game interface (level 1)

Figure 2. Wuzzit Trouble game interface (level 3)

In the game, the player turns one or more small cogs to move the large gear and reach the keys. For example, one key is located at number 22 on the large gear, and four small cogs are at 3, 5, 7 and 11 in Figure 2. The player can tap and turn cog 11 two times to reach the key, free the Wuzzit and get the bonus item, which is located at number 11.

Wuzzit Trouble consists of three levels, ranging from basic to complex. Each level has 25 different puzzles and three different star ratings for each puzzle. The number of small cogs ranges from one to four (one cog: basic; four cogs: complex). The small cog can be turned left or right up to five times with a single action by the player, and more stars can be obtained with the fewest rotations (Pope & Mangram, 2015). Therefore, the player needs to "develop multi-step algorithms to solve the puzzles optimally" (Kiili et al., 2015, p. 42).

4.3 Instruments

4.3.1 Mathematical engagement survey

The mathematical engagement survey (Chang et al., 2016) was adopted in this study. It had been used in previous studies to measure the overall mathematics engagement level and the three-dimensional engagement. It also provides an opportunity to make the findings more comparable. Chang and colleagues' (2016) mathematical engagement survey included 33 items, with each dimensional engagement having 11 items. All items employed a 4-point Likert scale (1 = strongly disagree, 2 = somewhat disagree, 3 = somewhat agree and 4 = strongly agree). Some of the items were adapted for this study. For example, the item "I listen to my math teacher carefully while we are doing fractions" was changed to "I listen to my math teacher carefully while we are doing mathematics tasks". The survey was translated into Chinese and then sent to the mathematics teacher for review so that the second graders could understand it easily.

In this study, one pilot test was conducted to obtain reliability statistics using 206 second graders, except for the class that participated in the experiment. After deleting two items about behavioural engagement, the overall reliability results were as follows: $\alpha = 0.829$, behavioural $\alpha = 0.601$, emotional $\alpha = 0.644$ and cognitive $\alpha = 0.710$. Therefore, the engagement survey that included 31 items was used in the experiment.

4.3.2 Photo-elicitation interview

Photo elicitation is defined as a research technique that uses one or more photographs in a research interview (Harper, 2002). The photographs can be produced by the interviewees or the researcher (Bignante, 2010). In this study, the photographs were taken by the first author during the classroom experiment.

In this study, the photo-elicitation interview method was chosen specifically with the participants' ages in mind. Using photographs in an interview creates a relaxed atmosphere where interviewees and interviewers feel more at ease in communicating with each other (Bignante, 2010). It can help interviewees, particularly children, to express themselves freely, associate meaning and understanding in the discussion of photographs and bring various insights into the research (Harper, 2002). In this study, the interview followed each daily classroom experiment, and the student interviewees were required to answer the same questions (see Appendix A) but based on a different photograph brought by the first author each day. The aim was to trigger the interviewees to evoke their daily experience in the classroom and consequently to investigate how their engagement developed and which factors affected their engagement in a collaborative digital gameplay classroom.

4.4 Procedure

The data collection procedure was conducted in the spring term of 2019. To start with, the first author had a meeting with the headmaster, the mathematics teacher and the coordinators to present the information regarding the study. In the second step, the dates and the experiment class were chosen. After the official letter of consent was received from the school, a parents' meeting was held after class. The first author informed the parents about the study and their children's participation, and the digital game *Wuzzit Trouble* was installed during the meeting. The data collection procedure started after the parents' meeting. As illustrated in Figure 3, it included three stages. Stage One involved the collection of pre-test data on all participants' engagement in collaborative digital gameplay. In Stage Two, the six-day experiment was conducted in the participating class. Stage Three comprised the collection of post-test data on all participants' engagement in collaborative digital gameplay.

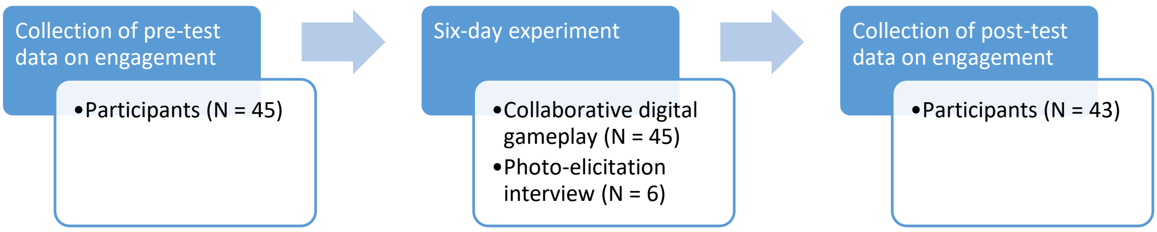

Figure 3. The data collection procedure

In Stage One, all parents signed and returned the informed consent forms to the school after the parents' meeting. The students were led to the computer room, where they filled in the distributed pre-test engagement survey on the first day. All 45 students participated in the pre-test engagement survey.

In Stage Two, the experiment was conducted, starting from the second day and carried over six consecutive days. The experiment was performed in the mathematics classroom, where the mathematics teacher gave brief instructions to help the students understand how to play the game. Thereafter, each pair played *Wuzzit Trouble* on one iPad but could ask for help during the experiment. Either the mathematics teacher or the first author provided support when the students needed it. After the collaborative digital gameplay, a photo-elicitation interview was conducted.

Three pairs totalling six students were selected for the interviews. The Multisource Assessment of Social Competence Scale (Junttila et al., 2006) was translated into Chinese by the first author. The mathematics teacher, who was familiar with each student in the experiment class, was assigned to select the interviewees. In accordance with the daily rating of the students' social competence in school, five boys and one girl with high social competence were selected as the interviewees. Social competence was not the study's focus. However, considering the second graders' young age, the authors made this selection decision because those who were good social communicators could express their viewpoints more articulately than their classmates. All six students agreed to participate in the photo-elicitation interview. Lasting approximately five to seven minutes, each interview was conducted in a reading room in the primary school. Two pairs (two boys, and one boy and one girl) participated in the entire six-day interview, and one pair (two boys) participated in a five-day interview because one day, they left early.

In Stage Three, the same engagement survey (post-test this time) was distributed and filled in by 43 students in the computer room at the end of the six-day experiment. Two students were absent because they were sick.

4.5 Data analysis

4.5.1 Quantitative analyses

To provide a holistic understanding of the students' engagement levels and answer Research Question 1, the authors used the survey data from all participating students to compare the extent to which the students' engagement was affected by collaborative digital gameplay in mathematics. The students' answers in the engagement survey were related to the three-dimensional engagement. Thus, each dimension and the overall engagement were analyzed. The independent samples t-test in SPSS was adopted to compare the pre-test and the post-test engagement survey data, and the coefficient alpha reliability of the engagement survey items was analyzed.

4.5.2 Qualitative analyses

To answer Research Question 2 regarding what kinds of factors contributed to students' engagement in a collaborative digital gameplay classroom, photo-elicitation interviews with six students were recorded and later transcribed. Qualitative content analysis (Mayring, 2014) that was centred on the interview questions was conducted to identify each interviewee's experience in each classroom experiment. The datasets were analyzed in the following phases: In Phase One, the students' answers were read by the first author. In Phase Two, the descriptions (463 in total) regarding three-dimensional engagement were selected from the datasets. In Phase Three, the selected descriptions were labelled based on the measurement of three-dimensional engagement (Fredricks et al., 2004). In Phase Four, similar kinds of labels were classified under the same categories. In Phase Five, all labels and categories were organized into one table. The analysis process was naturally inductive, and the inference procedure was in accordance with the empirical dataset.

4.6 Considerations of ethical issues

This study followed the ethical guidelines of the Finnish Advisory Board on Research Integrity (2012). Because the study participants were children, the ethical considerations needed to be emphasized (Dalli & Te One, 2012). Informed consent, interaction and protection of confidentiality are critical ethical issues when conducting research with children (Dalli & Te One, 2012; Einarsdóttir, 2007). In this study, written informed consent was obtained from the school and the parents before the experiment was conducted. All the children were informed, who understood that their participation was voluntary and that they were free to withdraw at any time (Einarsdóttir, 2007).

In the surveys, the children were told to be autonomous in determining the answers and that their names and solutions would be anonymized. In the interviews, a relaxed atmosphere was created to increase the relationship and the interaction between the first author and the children. The data were handled by using codes (Student 1, Student 2, etc.) to protect each child's identity and guarantee confidentiality throughout the data collection and analysis. All the data were stored on a password-protected mobile hard drive that could be accessed by the first author only.

5. Results

5.1 Comparison of engagement

Research Question 1 focuses on whether students' engagement manifests in the collaborative digital gameplay experience. To obtain the results, the authors performed a reliability analysis and independent samples t-test.

5.1.1 Reliability analysis of the engagement survey

Before analyzing the results of the engagement survey, the authors undertook a reliability analysis of the pre-test and the post-test survey data. As Table 1 shows, the reliability of the three-dimensional engagement in the post-test was higher than in the pre-test. The internal consistency of the post-test was higher than that of the pre-test (Chang et al., 2016).

Table 1. *Reliability of engagement survey*

Engagement	N of items	Pre-test		Post-test	
		Cronbach's alpha (α)	N	Cronbach's alpha (α)	N
Behavioural	9	0.715	45	0.814	43
Emotional	11	0.735	45	0.830	43
Cognitive	11	0.646	45	0.801	43

5.1.2 Independent samples t-test

The independent samples t-test was performed to compare whether the students' engagement level increased in the collaborative digital gameplay classroom. The results of the analysis are shown in Tables 2 and 3.

Table 2. *Paired samples' statistics of pre- and post-mathematical engagement scores*

Engagement		Mean	N	SD
Pair 1 (Behavioural)	pre-test	32.33	43	3.822
	post-test	32.51	43	4.372
Pair 2 (Emotional)	pre-test	34.93	43	5.637
	post-test	35.56	43	6.584

Pair 3 (Cognitive)	pre-test	38.09	43	4.428
	post-test	37.53	43	5.725
Pair 4 (Overall)	pre-test	91.53	43	8.749
	post-test	91.93	43	10.780

As the Table 2 statistics show, the pre-test and the post-test results had small differences. The post-test results were only slightly higher in all cases, except for the cognitive test.

Table 3. *Paired samples t-test for mathematical engagement scores*

Engagement		N	Correlation	Sig.	t	df	Sig. (2-tailed)
Pair 1	pre–post (Behavioural)	43	0.141	0.368	-0.226	42	0.822
Pair 2	pre–post (Emotional)	43	0.167	0.286	-0.520	42	0.606
Pair 3	pre–post (Cognitive)	43	0.129	0.408	0.541	42	0.592
Pair 4	pre–post (Overall)	43	-0.307	0.045	-0.164	42	0.871

Based on the results of the independent samples t-test, as shown in Table 3, the difference between the post-test and the pre-test was not statistically significant. Therefore, the authors could reasonably conclude that the six-day collaborative digital gameplay learning experiment did not elicit a significant increase in the students' three dimensions of engagement in mathematics.

5.2 Factors associated with engagement

The analysis for Research Question 2 was based on the six-day photo-elicitation interview and aimed to figure out which factors would be associated with students' engagement in the collaborative digital gameplay classroom. In light of the factors that were already categorized and addressed in previous research (Fredricks et al., 2004) and based on the analysis of the interviews and the measurement of three-dimensional engagement in this study, four factors are summarized here: learning achievement, teacher support, peer collaboration and task characteristics.

5.2.1 Learning achievement

According to the results, there was a positive connection between academic achievement and emotional and cognitive engagement when the students learned in a collaborative digital gameplay classroom. All six students stated that their emotions became positive when they solved challenging problems during the gameplay. Three students claimed that mastering strategies could trigger them to solve problems efficiently. For example, one student stated:

First, we looked at the number on the small cog, then determined the direction of the cog [that should turn left or right] according to the location of the key. After that, we thought how to get the key easily and faster [Student 6].

5.2.2 Teacher support

Teacher support affected the students' behavioural and cognitive engagement during collaborative digital gameplay. Four students claimed that the mathematics teacher's involvement encouraged them to persist during difficulties and to participate actively in discussions (Renninger et al., 2018). In this study, the mathematics teacher provided brief instructions each experiment day, which helped the students find ways of coping with perceived failures (Sinatra et al., 2015). One student stated:

We used the methods that were taught by the teacher in the classroom. Before today, we did not follow those steps to solve the problems [Student 5].

5.2.3 Peer collaboration

The results of the quantitative and the qualitative analyses showed that collaborating with peers had positive effects on the students' level of three-dimensional engagement. All six students claimed that they could rely on their effort and persistence to solve problems while working with their desk mates and learn conceptual knowledge forward during discussions (Chang & Hwang, 2017). Similar results regarding emotional engagement were found, as the students reported experiencing enjoyment when working with peers. One student stated:

I was excited because playing with a partner is better than [doing so] alone. I like to learn with my partner since she could help me when I encountered problems [Student 4].

Additionally, cognitive engagement was developed when peers actively discussed problem-solving strategies, disputed various viewpoints and commented on each other's ideas (Khoo, 2016).

5.2.4 Task characteristics

The students' responses showed that the educational digital game used during the whole experiment period was positively linked with their three-dimensional engagement. All six students claimed that the digital game stimulated them to make an effort to explore methods of coping with failure and develop their conceptual understanding and arithmetic skills during discussions. Moreover, the digital game allowed them to have fun and activated their interest in mathematics. For example, one student stated:

Learning with the digital game was more interesting than before. Through this digital game, we felt that mathematics was a very interesting thing [Student 2].

Similar results for cognitive engagement were found, as the students claimed that the digital game stimulated them to seek ways of coping with perceived failure and to use knowledge and strategies flexibly (Fredricks et al., 2004).

From the results, peer collaboration and digital gameplay appear to be closely associated with students' three-dimensional engagement. The findings suggest student engagement at the behavioural, emotional and cognitive levels. Meanwhile, learning achievement and teacher support are positively linked with students' cognitive engagement and enhance their emotional/behavioural engagement.

6. Discussion

This empirical study examined the effects of collaborative digital gameplay on students' three-dimensional engagement in a second-grade classroom to improve student engagement in mathematics. It also provided factors that can be adopted to increase all engagement levels in the classroom context.

Research Question 1 concerned students' three dimensions of engagement manifested in the collaborative digital gameplay. The results of the independent samples t-test revealed no significant difference in any of the engagement levels from pre-test to post-test. A possible explanation is that the experiment period was not long enough for the participants to assess how their levels of engagement differed from their baseline levels. Another explanation is related to the engagement survey, as it was challenging for lower primary school participants to fill out 31 items to express their gameplay learning experience effectively. The third possible explanation is that the mathematics teacher provided insufficient instructions about collaborative digital gameplay. Therefore, to compensate for this limitation, the photo-elicitation interview was integrated concurrently and served as the dominant dataset in this study.

Regarding Research Question 2, the study aimed to investigate the factors associated with student engagement. The results indicated that students' three-dimensional engagement was associated with four factors. One factor – learning achievement – was found to improve students' emotional and cognitive engagement. The results showed that the more the students perceived an improvement in their problem-solving and arithmetic skills, the more they engaged emotionally and cognitively in the classroom. Likewise, learning achievement affected student engagement and was one of the outcomes linked to engagement among primary, secondary and high school students (Fredricks et al., 2004). The findings confirmed that students' arithmetic and problem-solving skills were improved when they participated in their learning via peer discussion and digital gameplay. Moreover, the study showed that students' cognitive engagement, such as the use of strategies and exploration of methods of coping with perceived failure, is closely linked with the development of their conceptual understanding and arithmetic skills.

In addition to learning achievement, this empirical study identified other factors − teacher support, peer collaboration and task characteristics – that contributed to students' three-dimensional engagement. According to Fredricks and colleagues (2004), these three factors were applicable to the classroom context. This study's results indicated that students' behavioural engagement was closely associated with their classroom context. Teacher support and peer collaboration were positively connected with different aspects of behavioural engagement, including higher participation in the task and learning forward during discussions (Hyvönen, 2008). The digital game used in this study also allowed the students to continue participating behaviourally and cognitively (Lipponen et al., 2018). Emotions are critical to students' learning involvement and achievement (Pekrun & Linnenbrink-Garcia, 2012). The results showed that both peer collaboration and digital gameplay were positively associated with students' emotional engagement. All students' expectations about their peers and digital games became higher when they were learning collaboratively with the digital game. Moreover, the results suggested that positive emotions stimulated students to explore learning strategies and solve problems collaboratively (Pekrun & Linnenbrink-Garcia, 2012).

The study's findings positively connected cognitive engagement to teacher support, peer collaboration and digital gameplay, consistent with this study's context. Perhaps these factors' integration into the mathematics class can enhance students' cognitive engagement and develop their conceptual understanding and arithmetic skills. Therefore, teachers and researchers should create a well-formulated classroom context to meet students' perceptions of their work levels and needs, adjust learning and teaching activities based on individual students' needs and abilities, and provide mixed methods and approaches by connecting digital gameplay with other strategies and elements (Callaghan et al., 2018).

In summary, the six-day experiment provided empirical evidence supporting the use of collaborative digital gameplay in a mathematics classroom to improve students' behavioural, emotional and cognitive engagement. The development of the three-dimensional engagement across the experimental intervention indicated a close association between the four factors and the three-dimensional engagement. Moreover, the classroom context, which involved teacher support, peer collaboration and task characteristics, was highly connected with the students' three-dimensional engagement in the classroom.

7. Conclusion

This study aimed to explore the effects of collaborative digital gameplay on student engagement in mathematics. The participants' engagement levels were examined using a mathematical engagement survey and a photo-elicitation interview to compare the influence of students' three-dimensional engagement in the context of collaborative digital gameplay. This study's main findings are as follows: First, the students' engagement level did not increase significantly in the six-day classroom experiment. Second, four factors − learning achievement, teacher support, peer collaboration and task characteristics − were closely associated with the students' three-dimensional engagement in a collaborative digital gameplay classroom. The study also revealed that the classroom context influenced the three-dimensional engagement, which could efficiently improve students' learning achievement in mathematics.

This study's contributions are as follows: First, the three-dimensional engagement was considered and investigated in exploring the effect of collaborative digital gameplay. Therefore, the study filled the gap in the research that focused on overall engagement. This study's findings are expected to contribute to the exploration and discussion of the effects of collaborative digital gameplay on overall engagement and the three presented dimensions. Second, despite the limitations in research instruments and the sample size (as mentioned below), this study used empirical evidence to provide a deep comprehension of the effects of four factors on students' three-dimensional engagement in the context of collaborative digital gameplay. This way, researchers and teachers could use the above-mentioned factors to design and develop the appropriate classroom context that could improve students' positive emotions, meet their learning needs and fulfil their perceptions and expectations.

One limitation of this study is the number of participants. Although the sample size comprised just over 40 participants, their class was the only second-grade class that used tablets for daily teaching in the primary school. Therefore, the participants carried on as usual without improving or modifying their behaviours because of the classroom experiment. The second limitation is the selection of the six student interviewees, who all had high social competence. The authors made this decision because the participants were young, and those who were good in social communication could express their viewpoints more clearly and in greater depth than their peers. The third limitation is the overlapping nature of the engagement dimensions. This is because the conceptualization and the measurement of engagement have not been agreed on; either three-dimensional or four-dimensional engagement is identified in the research. Based on these concerns, the authors adopted the three-dimensional (behavioural, emotional and cognitive) engagement.

Despite these limitations, this study should serve as a foundation for future research, which should further identify the factors that could significantly affect the three-dimensional engagement in the mathematics classroom. Moreover, since the study's findings revealed both peer collaboration and digital gameplay as closely associated with students' three-dimensional engagement in mathematics, future research might explore and develop various forms of classroom contexts, using digital games and collaboration in other subject areas to improve students' three-dimensional engagement and satisfy different types of students' demands and needs. Finally, because this study investigated students' three-dimensional engagement with digital games in a face-to-face classroom setting, future research could probe the use of digital games, both in school and at home, and figure out how parental involvement in children's learning influences the latter's three-dimensional engagement.

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Appendix

Appendix A: Questions used during the photo-elicitation interview

<table>
<tr><th>Engagement</th><th>Questions</th></tr>
<tr><td>Behavioural</td><td>1) What were you doing with your partner in the situation?
2) Did you have a discussion with your partner today about the mathematics problems in the game?
• If yes, how did you discuss these with your partner?
• If no, why didn’t you discuss these with your partner?</td></tr>
<tr><td>Emotional</td><td>3) How did you feel in the situation today: happy, interested, excited or bored?
• Could you please let me know the reason?
4) Did you like learning mathematics with your partner today?
• If yes, why did you like learning with your partner?
• If no, why didn’t you like learning with your partner?</td></tr>
<tr><td>Cognitive</td><td>5) How did you solve the mathematics problems with your partner today?
6) Did you use different strategies to solve mathematics problems today?
• If yes, could you please let me know what kinds of strategies you used today?</td></tr>
</table>