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Primary school students' perceptions of scaffolding in digital game-based learning in mathematics

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ABSTRACT

The present study explores approaches to teacher scaffolding in digital game-based learning in primary mathematics classrooms as well as the effects on students' perceptions of learning in a digital game in which scaffolding was provided. A total of 141 primary school students and four mathematics teachers participated in the experiment, and qualitative data were collected through classroom observations and student interviews. The results identified whole-class and one-to-one scaffolding strategies, both of which had an important effect on students' learning activities and perceptions of mathematics in the context of digital games in primary education.

1. Introduction

Teachers play a key role in digital game-based learning, which can be beneficial to students in primary education (Sun, Siklander, & Ruokamo, 2018; Chen & Law, 2016; Haataja et al., 2019). According to Haruehansawasin and Kiattikomol (2018), teachers take on the role of facilitator to activate students' learning during gameplay, such as providing support based on students' needs, controlling the learning and gameplaying process, encouraging students to participate in the discussion, and providing different resources and instant feedback. Dukuzumuremyi and Siklander (2018) point out that teachers act as "the role models and orchestrators" of learning tasks when digital technologies used in the classroom (p. 167). In addition, other studies indicate that students need teacher scaffolding to solve problems and build connections between subject knowledge and the knowledge learned in digital games (Chen & Law, 2016; Haataja et al., 2019; Pata, Sarapuu, & Lehtinen, 2005). However, according to Barzilai and Blau (2014, p. 65), integrating teacher scaffolding into gameplay can "negatively impact learners' perceptions of learning and enjoyment in the game." Therefore, it is crucial to understand and design appropriate teacher scaffolding in the digital game-based learning environment so that students' learning achievement and engagement can be influenced in a positive manner (Barzilai & Blau, 2014; Chen & Law, 2016; Pata et al., 2005; Rienties et al., 2012). In this study, we explore approaches to teacher scaffolding in a primary mathematics digital game to solve arithmetic problems as well as examine the effects on students' perceptions of mathematics learning in a digital game in which teacher scaffolding is provided.

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1.1. Scaffolding

Scaffolding was introduced by Wood, Bruner, and Ross (1976) as tutoring or assistance that "enable[s] a child or novice to solve a problem, carry out a task or achieve a goal which would be beyond his unassisted efforts" (p. 90). According to Makar, Bakker, and Ben-Zvi (2015), scaffolding is temporary support supplied by a teacher or knowledgeable person to help students solve problems that they are unable to solve independently. This support can be offered in different ways, for example, modeling, posing questions, etc. (Dukuzumuremyi & Siklander, 2018; Muhonen, Rasku-Puttonen, Pakarinen, & Poikkeus, 2016; Van de Pol, Volman, & Beishuizen, 2010). Research on scaffolding generally focuses on one-to-one or small-group tutoring, and the teacher plays an important role in the scaffolding process by providing adaptive and in-time support that improves students' learning processes (Chen & Law, 2016; Makar et al., 2015; Muhonen et al., 2016; Wood et al., 1976). In this study, teachers conduct scaffolding in whole-class and one-to-one settings, which makes it possible to provide appropriate support for various students to become familiar with the digital games and solve integer-arithmetic problems during gameplay in the classroom.

Tropper, Leiss, and Hänze (2015) suggest that the scaffolding process involves three steps: 1) *contingency*, which includes responsive, adaptive, and in-time support for students' current performance; 2) *fading*, which refers to the gradual withdrawal and decrease in support following improvement in students' performance and capacity; and 3) *the transfer of responsibility*, which means that the responsibility of the learning process is transferred from the teacher to the students. These three steps are closely interconnected. When teachers provide contingent support, and it results in improved student understanding and performance, the teachers can then withdraw and decrease their support. Subsequently, the fading of support leads to a responsibility shift from the teacher to the students so that they can regulate and conduct their learning independently (Muhonen et al., 2016; Pata et al., 2005; Tropper et al., 2015; Van de Pol et al., 2010).

According to Van de Pol et al. (2010), scaffolding is an interactive process between teachers and students, which requires active participation from both parties. Contingency is the first crucial step in the process of scaffolding. To provide adaptive support and intervention, an effective diagnosis of students' current levels of understanding is essential, and dialogue between teachers and students is a good tool for achieving this diagnosis (Muhonen et al., 2016; Pata et al., 2005; Tropper et al., 2015; Van de Pol et al., 2010). Muhonen et al. (2016) emphasize that dialogic interactions between teachers and students have an important effect on students' learning and development. Scaffolding through dialogue provides opportunities for students to present what they have not understood on their own while also stimulating and developing their thinking and understanding (Makar et al., 2015; Muhonen et al., 2016; Pata et al., 2005).

1.2. Digital game-based learning in mathematics

Mathematics is a core discipline. It provides practical knowledge for daily life and plays an important role in personal development (Kiili, Devlin, & Multisilta, 2015; Huang, Huang, & Wu, 2014). However, mathematics is often a discouraging subject for many students in primary and secondary education. For example, Luhan, Novotna, and Kriz (2013) show that mathematics is often classified as an unfavored course among students, because they see it as dreary, difficult, and useless. Researchers find that individuals who have trouble with mathematics learning can be at a disadvantage in their career expectations and professional lives (Kiili et al., 2015a; Kiili, Devlin, Perttula, Tuomi, & Lindstedt, 2015). Therefore, it is important to develop effective methods for increasing students' interest in mathematics, improving their understanding of conceptual knowledge, and enabling them to develop their arithmetic skills (Kiili et al., 2015a; Pope & Mangram, 2015).

In mathematics education, digital game-based learning is considered a fundamental learning tool that can help students acquire conceptual knowledge (Meletiou-Mavrotheris & Prodromou, 2016), practice arithmetic skills (Drijvers, Doorman, Kirschner, Hoogveld, & Boon, 2014), and facilitate their engagement in the classroom (Bakker, van den Heuvel-Panhuizen, & Robitzsch, 2016; Meletiou-Mavrotheris & Prodromou, 2016). The potential of digital game-based learning in education has been widely recognized for several decades (Chang et al., 2016; Iten & Petko, 2016; Nousiainen, Kangas, Rikala, & Vesisenaho, 2018). Digital games, which offer enjoyment and pleasure, may reduce students' anxiety and frustration and support mathematical development (Kiili et al., 2015a; Barkatsas, Kasimatis, & Gialamas, 2009; Chang et al., 2016; Huang et al., 2014; Pope & Mangram, 2015). Digital games are not only fun (Iten & Petko, 2016), interactive (Huang et al., 2014), and great for the prospect of immediate feedback (Drijvers et al., 2014) but also allow students to try tasks many times, even when making mistakes (Bakker et al., 2016), giving students opportunities to participate and explore (Chen & Law, 2016; Chen, Wong, & Wang, 2014). Researchers believe that digital game-based learning can provide a context that facilitates an increase in students' learning interest (Siklander, Kangas, Ruhalahti, & Korva, 2017; Iten & Petko, 2016), improve their learning confidence (Huang et al., 2014), and enables a greater willingness to learn (Chen et al., 2014; Iten & Petko, 2016; Pope & Mangram, 2015).

1.3. Scaffolding in digital game-based learning

Although digital game-based learning provides students with opportunities to explore and motivates them to learn in a different way, there are challenges in the use of digital games in learning. Challenges include technological difficulties, time management (Watson, Mong, & Harris, 2011), behavioral regulation (Bell & Gresalfi, 2017; Watson et al., 2011), and emotional control (Chen & Law, 2016; Vandercruysse, Vandewaetere, Cornillie, & Clarebout, 2013), and combining these games within traditional classrooms (Bell & Gresalfi, 2017; Chen & Law, 2016; Watson et al., 2011). Despite the difficulties, many teachers and educational researchers see promise in the use of scaffolding in supplementing digital game-based learning so that it benefits students' understanding and deep learning (Barzilai & Blau, 2014; Chen & Law, 2016; Kangas, Koskinen, & Krokfors, 2017; Nousiainen et al., 2018; Waiyakoon, Khlaisang, & Koraneekij, 2015). When students start playing a game, they feel that they have the ability to finish the game tasks. However, if the underlying mathematical task is overly difficult for the students, their continued play will not be productive in terms of mathematics learning. In such a situation, teacher scaffolding, which is provided in the game-based learning environment, can maintain students' interest and engagement in a way that continues to produce the desired learning (Barzilai & Blau, 2014; Chen & Law, 2016; Haataja et al., 2019).

Scaffolding can help students build a link between the knowledge learned in the game and subject knowledge (Barzilai & Blau, 2014; Rienties et al., 2012). For example, an increasing number of studies indicate that teachers serve as a guide in digital game-based learning as they structure the game task, reduce the complexities (Barzilai & Blau, 2014), make thinking strategies explicit (Haataja et al., 2019), and direct students' attention to the learning outcomes (Rienties et al., 2012; Watson et al., 2011). Scaffolding makes it possible for students to have the opportunity to proceed in a deeper manner (Barzilai & Blau, 2014), control their problem-solving learning process (Waiyakoon et al., 2015), and achieve their learning goals (Rienties et al., 2012; Waiyakoon et al., 2015). In addition to making learning more accessible to students, a teacher who provides guidance and encouragement (Muhonen et al., 2016; Rienties et al., 2012)—by asking students questions and allowing them to share their knowledge and experiences (Muhonen et al., 2016)—can positively influence students' emotions regarding learning (Chen & Law, 2016) and lead to students' persistence in learning, even in the face of difficulties (Barzilai & Blau, 2014).

In the present study, we explored the ways in which teacher scaffolding is provided in digital game-based learning in primary mathematics classrooms and the effects of students' perceptions of learning in a digital game in which teacher scaffolding is provided. The following research questions guided the study:

1. How do students perceive mathematics scaffolded by teachers in a digital game-based learning classroom?
2. How does teacher scaffolding in digital games affect students' perception of mathematics learning?

2. Methods

2.1. Context and participants

The data were collected from five mathematics classrooms, including statistics on students and teachers, covering three weeks in three primary schools in China. With the fourth author's support, the experiment was conducted in the autumn of 2018. Table 1 presents descriptions of the participating students and teachers.

The participating students (age 9–11 years; boys $N = 77$, girls $N = 64$) had experience with learning mathematics through games (e.g., playing cards) in their schools. However, the students did not have learning experience with digital games in mathematics before the experiment. The participants also included four Chinese mathematics teachers, all of whom (Teacher 1–Teacher 4) were female and had no experience teaching digital games before the experiment.

2.2. Research design

The participating schools provided tablets for the participants. The research design is shown in Fig. 1.

A meeting was held at School A before the experiment was conducted. The first author presented information regarding the study (background, aims, methods, the digital game Wuzzit Trouble, schedule, etc.) to the teachers and headmasters. Teacher training on game-based learning was offered by the first author before and during the experiment. The training contents before the experiment included pedagogical activities for teachers in game-based learning, the definition and process of scaffolding, and scaffolding in the different phases of game-based learning. The training during the experiment was to provide practical scaffolding strategies based on the problems observed in the current digital game-based learning classrooms. In addition, the first author stayed in the classrooms, making it possible to observe the classrooms and collect detailed observational data. Interviews with students were conducted at the end of the experiment. The fifth author provided a digital game application called Wuzzit Trouble, which was used in the experiment

Table 1
Description of participants.

Schools	Number of participants	
	Students (S)	Teachers (T)
School A	Class 1: $N = 36$	Class 1: Teacher 1
(Grade 4)	Class 2: $N = 37$	Class 2: Teacher 1
School B	Class 1: $N = 21$	Class 1: Teacher 2
(Grade 5)	Class 2: $N = 20$	Class 2: Teacher 3
School C	Class 1: $N = 27$	Class 1: Teacher 4
(Grade 4)		
Total	141	4

Note: School A decided that the same mathematics teacher (Teacher 1) would scaffold Class 1 and Class 2.

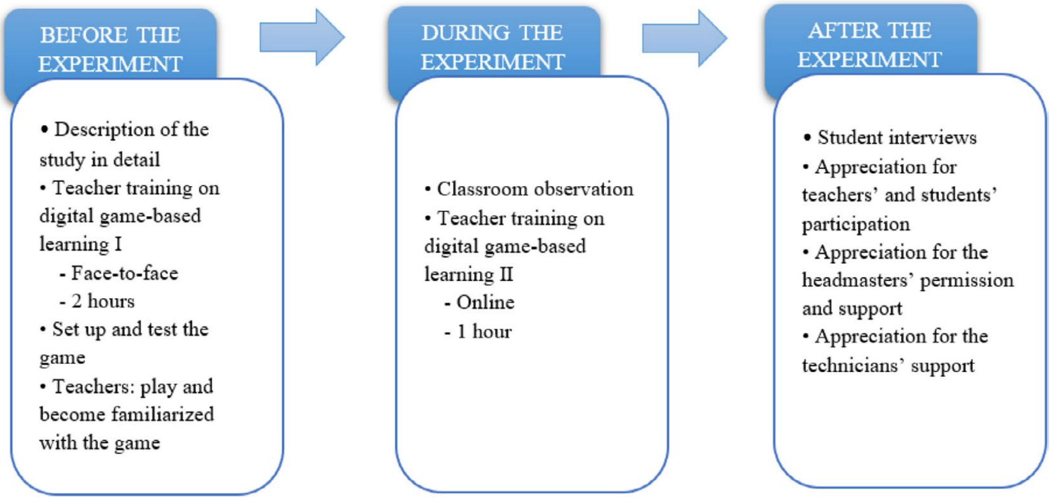

Fig. 1. Process of the experiment.

Fig. 2. The Wuzzit Trouble game interface.

(Fig. 2).

Wuzzit Trouble is a tablet-based mathematics game available through the iTunes App Store and Google Play. "Wuzzits" are variously colored creatures that have been trapped in cages in a castle (Kiili et al., 2015b; Pope & Mangram, 2015). The goal of the game is to free the Wuzzits by obtaining all the keys. Wuzzit Trouble has three difficulty levels, there are 25 integer-arithmetic problems within each level, and new players have to start at the first level (Kiili et al., 2015b). Players must rotate one or more small cogs to move the large gear wheel, which can cause the keys to move, and finally, reach the keys (Kiili et al., 2015b). For example, in Fig. 2, three keys are located at numbers 8, 46, and 60 on the large gear, and there are three cogs (4, 6, and 10). To reach the key located at number 46, we can tap and turn cog 10 four times to the right and then tap and turn cog 6 once to the right to reach the key. When playing Wuzzit Trouble, players must decide which direction to move the cog and which key they should pick first (Pope & Mangram, 2015). Most integer-arithmetic problems have more than one solution, and various numbers of stars (one, two, or three) and points can be obtained by releasing Wuzzits with fewer rotations (Kiili et al., 2015b; Pope & Mangram, 2015). During gameplay, no problem-solving support or feedback is given in the interface. Therefore, teacher scaffolding can be beneficial for students when they play Wuzzit Trouble in mathematics learning.

Table 2
Description of the data collection methods.

Methods	Description of data collection
Observation	Five classes (students: $N = 141$; teachers: $N = 4$) were observed by the first author The observational process lasted 10 school days Observational content: teachers' scaffolding activities in the orientation and gameplay phases
Interview	Thematic interviews with students ($N = 25$) conducted by the first author at the end of the experiment School A: 10 students in Grade 4 (boys: 6, girls: 4) School B: 10 students in Grade 5 (boys: 7, girls: 3) School C: 5 students in Grade 4 (boys: 3, girls: 2) Two in-depth interview questions Question 1: Did your mathematics teacher scaffold you in the game-based learning process? If yes, how? If no, what was the teacher doing at that time? Question 2: Do you think that teacher scaffolding is helpful for you to learn mathematics? If yes, why? If no, why?

2.3. Data collection

Qualitative data were collected throughout the experiment via classroom observations and student interviews. A description of the data collection methods is provided in Table 2.

The schools organized an after-school activity for the experiment so that the participating students and teachers could use Wuzzit Trouble in the classrooms. In each after-school activity, the students used Wuzzit Trouble to practice and solve integer-arithmetic problems, and the teachers provided scaffolding when needed. The activity lasted approximately 25 min each day. Five classes were observed in the experiment, and the first author collected observational data over 10 school days. The observational data involved teacher scaffolding in the orientation and gameplay phases. Scaffolding during orientation included introducing background information and the gaming process and familiarizing students with the game and learning goals. During the gameplay, scaffolding included dialogic interaction, in-time instruction, adaptive support, encouragement, etc.

At the end of the experiment, the first author conducted interviews. In this study, we selected interviewees based upon their ability to reflect on the topics considering the age of the participating students. Twenty-five students were selected by their mathematics teachers, who were teaching and familiar with their students, to participate in personal thematic interviews. Each interview lasted approximately 5 min and was conducted in an empty classroom. The students were required to present their perspectives and opinions in greater depth according to their learning experience in the 10-day digital game-based learning environment. The first four authors determined the areas of questioning for the interviews in advance, including reflections on the teacher scaffolding in digital game-based mathematics learning; 195 student answers (as sentences) were collected, and all interviews were recorded. The language used in the data collection was Chinese. The analysis was conducted in the original language, and the excerpts included in this article were translated by the first author.

2.4. Data analysis

We analyzed the interview data in three stages. In the first stage of the analysis, we transcribed the dataset with a web application, and then the first author consolidated and organized the data. The entire dataset was analyzed using qualitative content analysis (Mayring, 2014).

In the second stage, we began the analysis with a data overview in which we identified all responses as the participants' viewpoints and opinions, without differentiating between them (Table 3). We found 100 related quotations that could be considered descriptions and reflections related to teacher scaffolding in the digital game-based learning environment.

In the third stage, we classified the quotations into content categories using an open-coding procedure to find the data categories. The first cycle of this stage produced 18 subcategories, which were sorted into two main categories. One category consisted of 10 subcategories and focused on descriptions of teacher scaffolding in the digital game-based learning classroom. The other category included eight subcategories and centered on students' perception of mathematics learning when teacher scaffolding was provided in digital game-based learning classrooms. We then reviewed the subcategories with further integration, so the final classification consisted of 10 subcategories within two categories (Table 4). One category was the processes behind the whole-class and one-to-one

Table 3
An example of a student's responses.

Question 2: Do you think that teacher scaffolding is helpful for you to learn mathematics? If yes, why? If no, why?		
Student number	Yes/no	Responses
8	Yes	R1: Master mathematical knowledge R2: Improve interest in mathematics R3: Get good grades in mathematics R4: Because arithmetic skills are facilitated, daily life is also influenced, e.g., shopping in supermarkets

Table 4
Final classification of data categories.

Category 1		Category 2
Whole-class scaffolding:	One-to-one scaffolding:	Reflections on scaffolding:
- Problems demonstration - Solutions shared by students - Solving steps presented by teachers - Summary of methods and strategies	- Asking to think first - Guiding to analyze problems - Offering hints	- Development of arithmetic skills - Activation interest in mathematics - Encouragement to explore

scaffolding strategies, which included seven subcategories. The other category contained reflections on teacher scaffolding, which included three subcategories. A detailed description of these categories and subcategories is presented in the Results section.

We did not transcribe the classroom observations, but the first author took notes about key classroom events, such as "scaffolding moments," which described what kinds of teacher scaffolding were used and how interactional situations occurred in the digital game-based learning environment. These scaffolding moments were then sorted according to the phases (orientation and/or gameplay) in which they occurred in the classroom and were used to support the findings from the interviews.

2.5. Ethical considerations

The study followed the ethical guidelines of the Finnish Advisory Board on Research Integrity (2012). When conducting research with children, ethical issues must be considered (Dalli & Te One, 2012; Einarsdóttir, 2007). As Einarsdóttir (2007) points out, informed consent, confidentiality, interactions, and protection are important ethical matters in all research, especially in research with children. In this study, although written informed consent was not obtained, the headmasters used a parents' meeting to inform the students' parents about the experiment and their children's participation. The students understood that their participation was voluntary and that they were free to withdraw at any time (Einarsdóttir, 2007). Anonymity and confidentiality were guaranteed in the study. The participants' names were anonymized, and all the data were stored on a password-protected mobile hard drive accessible only by the first author.

3. Results

3.1. Teacher scaffolding strategies

To answer the first research question, we analyzed the classroom observations and student interviews, and identified how teachers scaffolded students' mathematics learning in primary digital game-based learning classrooms. In view of the scaffolding strategies addressed in previous research (Chen & Law, 2016; Makar et al., 2015; Muhonen et al., 2016; Van de Pol et al., 2010), and based on the analysis of observations and interviews in this study, we identified two teacher scaffolding strategies: whole-class scaffolding and one-to-one scaffolding (Fig. 3).

3.1.1. Whole-class scaffolding

Whole-class scaffolding occurred in the orientation and gameplay phases. Scaffolding in the orientation phase involved introducing information about the game, demonstrating the gaming process, illustrating the goals of the game, and familiarizing students with the game. The classroom observations showed that most students listened to the teachers, and some students asked relevant questions about the game. According to the observations, it was clear that the students preferred digital games in practicing and solving integer-arithmetic problems in mathematics and that the atmosphere of the classrooms was active and lively. The observations also revealed that the teachers' classroom organizing strategies (locking tablet screens, stopping teaching, clapping hands, etc.) played an important role in whole-class scaffolding.

Following the orientation phase, whole-class scaffolding occurred in the first few days of gameplay. The main reason was that the teachers had found that most students were experiencing difficulty with similar types of problems. Student 15 stated, "Generally, [the

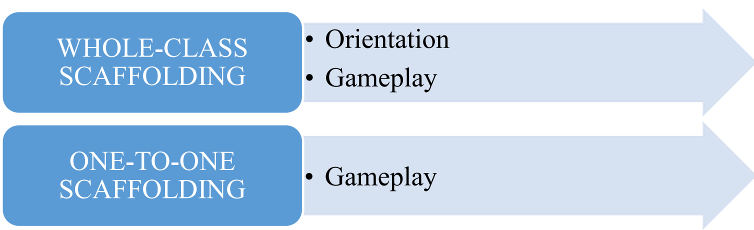

Fig. 3. Teacher scaffolding strategies.

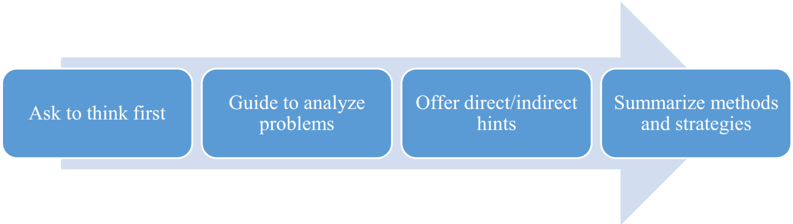

Fig. 4. Processes of the one-to-one scaffolding in gameplay.

mathematics teacher] presented the problem in the digital game on the smartboard. She taught us how to analyze the problem and wrote down methods and steps for solving [problems] on the blackboard." Student 8 said:

For example, there was a difficult problem, and most of us could not solve it. She [the mathematics teacher] would present that problem on the smartboard or blackboard and then instruct us as to how to analyze and solve it. She also asked students who understood well to share their [steps for solving the problem].

The classroom observations and student interviews showed that whole-class teacher scaffolding enabled congruity between most students' level of experience and conceptual understanding, which helped determine the students' learning needs in a clear and in-depth manner. The students then became familiar with the gaming process and were able to control their problem-solving in a deeper manner during their learning with the digital game.

3.1.2. One-to-one scaffolding

One-to-one scaffolding occurred during the gameplay phase. When an individual student could not solve the problem independently, the teachers provided in-time instruction and adaptive support. The processes underlying the one-to-one scaffolding as discussed in the student interviews are summarized in Fig. 4.

All the student interviewees stated that the teachers did not give them the answers directly but instructed them to think and analyze the problems through dialogue (e.g., ask questions). The teachers then provided hints when necessary and summarized the methods and steps for solving the problem when this was deemed necessary. Some students noted: "She [the mathematics teacher] did not tell me the answer but let me think independently. Then she taught me the steps of problem solving" (Student 4). "When I could not solve this problem, the teacher would provide me with some hints; I felt it was very good" (Student 19). Student 6 stated:

For example, multiples of the numbers. The teacher reminded me to think about what multiples were in the numbers, what relations there were between the numbers, and which number could be matched with the cog. Through this, I solved the problem and completed the task.

In comparison to whole-class scaffolding, one-to-one teacher scaffolding concerned individual student performance. Therefore, the teachers used the concrete and effective scaffolding strategies above to encourage the students to explore, as well as to trigger their interest and help them learn independently.

The classroom observations and student interviews showed that contingency, fading, and transfer of responsibility occurred in the whole-class and one-to-one scaffolding strategies. The dialogue interactions between the teacher and student(s) in the digital game-based learning classroom made it possible for the teacher to diagnose the student(s)' current level of understanding and thus, provide adaptive support; moreover, the dialogue interactions played a crucial role in the process of "handing over knowledge and skills" (Muhonen et al., 2016, p. 144). The observations and interviews suggested that the two scaffolding strategies are suitable for use in supporting students' learning activities in digital game-based learning in primary mathematics classrooms, and that, as a result, the integration of teacher scaffolding into digital game-based learning can have an important effect on students' learning and development in mathematics in primary education.

3.2. Influence of teacher scaffolding

The second research question focused on the influence of teacher scaffolding on students' perception of mathematics learning through the digital game. Teacher scaffolding in the orientation and gameplay phases was reflected in the students' comments during the interviews (Fig. 5). The students discussed their perception of teacher scaffolding in developing arithmetic skills, activating interest in mathematics, and encouraging exploration.

Fifty-seven percent of the students agreed that the teachers' adaptive support and in-time instructions helped the students understand the content knowledge and improve their mathematical thinking ability, which gave them the opportunity to proceed and control their problem-solving learning process. For example, some students commented as follows: "It [the teacher's instruction] could open my mind, which stimulated me into not thinking only about one point but thinking about many points" (Student 7). "Because when I mastered the solving methods [with the teacher's support], I could learn by analogy and solve more problems" (Student 22). "If you did not know the solving methods, you could not solve the problem. You would be irritable and feel bad. So, the result was to dislike mathematics and refuse to do [mathematical problems]" (Student 9).

Approximately 24% of the students reported that the teachers' tutoring activated the students' interest in mathematics to a higher

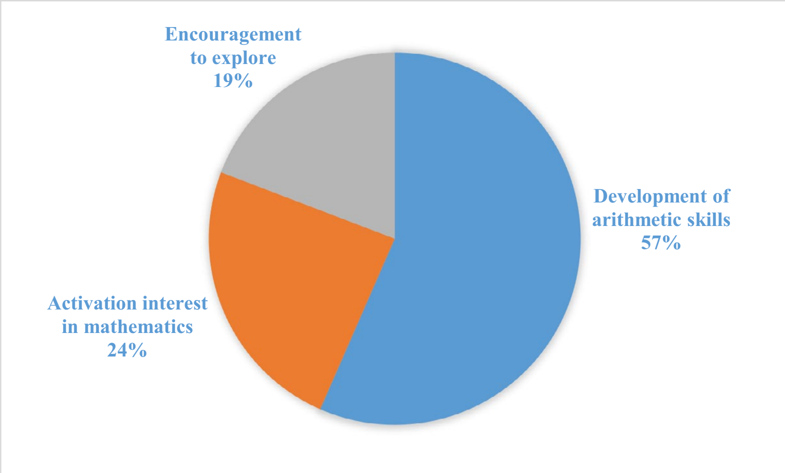

Fig. 5. Students' (N = 25) reflections on teacher scaffolding in the orientation and gameplay phases.

level and increased their willingness to learn mathematics. One student stated that the teacher's support “made us like mathematics more. I was more interested in mathematics” (Student 14). Another student noted how the teacher's support “made me enjoy mathematics consistently” (Student 12).

Nineteen percent of the students also reported that the teachers' encouragement affected the students' emotions, stimulating them to think independently and explore, despite difficulties. As Student 23 reflected, “When I could not solve the problem, I would give up after thinking for a while. But the teacher's encouragement inspired me to explore persistently.” Student 2 reflected, “Some classmates do not like to learn mathematics if there is no teacher encouragement. However, when [they receive] encouragement, they like learning better.”

According to the student interviews, teacher scaffolding had an important effect on the students' learning activities in digital games and perception of mathematics learning in primary education. Adaptive support and intervention were conducive for students to connect the knowledge learned in the digital games with the subject knowledge, enabling them to understand related content, practice, and solve integer-arithmetic problems. Meanwhile, the teachers' tutoring and encouragement increased the students' interest in mathematics, creating an environment for the students to more easily explore and making thinking and strategies explicit. Therefore, the students were willing to solve integer-arithmetic problems. Furthermore, teacher scaffolding in digital game-based learning was useful in terms of activating the students to interact with the learning environment and focus on specific content knowledge, thus affecting their learning outcomes in mathematics in primary education.

4. Discussion

In this study, we described and explored the ways in which teacher scaffolding is provided in digital game-based learning and the effects of students' perceptions of mathematics learning in a digital game in which teacher scaffolding was provided. Two teacher scaffolding strategies were identified in the study—whole-class and one-to-one scaffolding—both of which had an impact on students' knowledge learning, arithmetic skills, and interest development in mathematics. These results are important, as they contribute to addressing the gap in previous knowledge by highlighting various teacher scaffolding strategies and describing means of sustaining effective scaffolding in digital game-based learning in primary education.

The first research question focused on the kinds of teacher scaffolding strategies provided in digital game-based learning in primary mathematics classrooms. The results showed that the whole-class and one-to-one scaffolding strategies were distinct and identified from the data of student interviews and classroom observations, and second, each scaffolding strategy was distinguishable in the different phases (orientation and/or gameplay). According to the scaffolding strategies categorized in previous research (Chen & Law, 2016; Makar et al., 2015; Muhonen et al., 2016; Van de Pol et al., 2010), one-to-one and small-group scaffolding is the focus and typically is addressed, whereas few researchers have examined whole-class scaffolding because of its complications in the classroom (Makar et al., 2015). However, in this study, the analyses of the student interviews indicated that whole-class scaffolding in the digital game-based learning environment was significant in the orientation phase and during the first few days of gameplay when the students began practicing and solving integer-arithmetic problems. Whole-class scaffolding was directed by specific strategies espoused by teachers who played the role of leaders (Muhonen et al., 2016). When individual students then solved integer-arithmetic problems with digital games, the one-to-one teacher scaffolding included recognizing students' difficulties, providing relevant clues and suggestions, directing students to see the important points, offering more detailed information, focusing students' attention on the learning content, etc. (Kangas et al., 2017; Nousiainen et al., 2018; Van de Pol et al., 2010). The results revealed that the interactive dialogues were more balanced between the student and the teacher, and the teacher's role became that of a tutor and guide who supported and instructed individual students via one-to-one scaffolding (Kangas et al., 2017; Nousiainen et al., 2018; Watson et al., 2011).

The findings suggest that teachers' classroom management strategies, in particular, locking tablet screens, stopping teaching, and clapping hands, play an important role in ensuring the success of the scaffolding strategy, especially in relation to whole-class scaffolding in the digital game-based learning environment. In addition, technological tools, such as smartboards and slide projectors, used by teachers can ensure that scaffolding is available and beneficial to every student who needs it (Kangas et al., 2017; Nousiainen et al., 2018).

The second research question focused on the influence of teacher scaffolding in students' perception of mathematics learning using a digital game in primary education. The findings indicated that the three scaffolding steps (contingency, fading, and transfer of responsibility) were closely intertwined and had an impact on the students' knowledge learning and arithmetic skills development in primary mathematics classrooms. In this study, the teachers provided questions, diagnoses, explanations, instruction, and hints that were contingent on the level of individual students (Kangas et al., 2017; Tropper et al., 2015; Van de Pol et al., 2010; Wood et al., 1976). The teachers gradually withdrew support when they found that the students could independently solve integer-arithmetic problems with digital games. In the end, when the students proceeded to a higher level in the digital game, no support was needed or provided, and the teachers deemed the students responsible for their own learning (Muhonen et al., 2016; Tropper et al., 2015; Van de Pol et al., 2010).

We also found that the teacher scaffolding encouraged the students to independently explore and activate their interest in mathematics. When they had trouble with integer-arithmetic problems, the students experienced anxiety and helplessness, which led to difficulties in digital game-based learning. However, the teachers' in-time support and direction helped the students achieve greater energy and confidence, which was useful for learning content knowledge (Barzilai & Blau, 2014; Rienties et al., 2012). The analyses indicated that the students' assessments of their mastery of mathematical knowledge and arithmetic skills increased their interest in mathematics. Thus, teacher scaffolding served the students effectively by developing and deepening their knowledge building and learning outcomes in mathematics (Barzilai & Blau, 2014; Muhonen et al., 2016). Moreover, the findings of the study showed that in a digital game-based learning classroom, mathematics teachers transformed from traditional teachers into tutors and guides who support and instruct students in their learning process (Kangas et al., 2017; Nousiainen et al., 2018; Watson et al., 2011). This transformation allowed the students to experience and explore mathematics knowledge, activate their interest in mathematics, and develop their content understanding and arithmetic skills (Sun et al., 2018; Bakker et al., 2016; Chang et al., 2016; Drijvers et al., 2014; Meletiou-Mavrotheris & Prodromou, 2016).

However, this study had several limitations. One limitation was the interview protocol. Although two in-depth interview questions were used in the study, researchers knew little about scaffolding in traditional mathematics classrooms. Therefore, it was challenging for students to experience and reflect deeply how their teachers' scaffolding differed from previous scaffolding and what scaffolding the teachers generally did not conduct in the traditional classrooms. Future studies are needed to define more areas of questioning for the interview and to conduct student interviews in a more relaxed environment to obtain deeper reflections and evidence from students. The other limitation of the study is the translation of the data. The data were translated from Chinese to English by the first author, as only the first author was involved in the whole data collection process. The third limitation is the description of the study provided to the students' parents. Because of the authors' schedules, we were not present at the parent meetings to discuss the study. However, the headmasters of the three participating schools informed the children's parents about the experiment and their children's participation.

Nevertheless, even if the data are specific to these schools and students, and the study focused on capturing the experience of teacher scaffolding in digital game-based learning in primary mathematics classrooms, the explanations and conclusions are useful for understanding how students engage in digital game-based learning environments where teacher scaffolding is provided (Nousiainen et al., 2018). Although the study concentrated on mathematics education, the influence found in relation to teacher scaffolding can also be found in other educational contexts. Integrating teacher scaffolding into digital game-based learning can be applied to other subjects in school education.

Furthermore, the results of the study point to implications for teachers and teacher education in digital game-based learning. On one hand, the set of scaffolding strategies could be summarized and listed based on the students' perceptions regarding digital game-based learning, which included support for students' knowledge learning and arithmetic skills (questions, diagnosis, hints, instruction, explanation, and summary) and support for their motivation and emotions (guidance, control of frustration, and encouragement). On the other hand, the findings suggest that teachers can variously design and develop ways in which to integrate scaffolding into digital game-based learning environments, such as for the whole class or for individual students, for high-participating students or low-participating students, with or without technological tools, etc.

This study sought to identify different approaches to teacher scaffolding and the correlated influence on mathematics in a digital game-based learning environment. Future research should probe additional scaffolding approaches and examine which scaffolding characteristics may effectively facilitate learning through the use of digital games. There is a need for further studies exploring the manner in which teachers' competencies can develop alongside the integration of digital games into daily teaching.

5. Conclusion

This study of primary school students' digital game-based learning experience provided evidence that the use of teacher scaffolding can have an effect on students' knowledge learning, arithmetic skills, and interest development in mathematics. Specifically, whole-class and one-to-one scaffolding are beneficial in digital game-based learning in primary education. Whole-class scaffolding is important for students to start practicing and solving integer-arithmetic problems in the orientation phase and during the first few days of gameplay, while one-to-one scaffolding concerns the individual student's performance during the gameplay. The results suggest that the integration of two teacher scaffolding strategies in various phases of digital game-based learning process can improve students' learning activities, as well as perception of mathematics learning in primary education.

Declaration of competing interest

None.

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