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Liping Sun

Digital Game-Based Learning:

Developing a Pedagogical Model for Primary Mathematics Education

LAPIN YLIOPISTO
UNIVERSITY OF LAPLAND

Acta electronica Universitatis Lapponiensis 375

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LAPIN YLIOPISTO
UNIVERSITY OF LAPLAND

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University of Lapland
Faculty of Education

Supervised by

Professor Heli Ruokamo, University of Lapland

Associate Professor Signe Siklander, University of Oulu

Reviewed by

Professor Kristian Kiili, Tampere University

Professor (Emeritus) Erno Lehtinen, University of Turku

Opponent

Professor Kristian Kiili, Tampere University

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To my cherished family

ABSTRACT

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Since they contribute to the learning environment and significantly influence all levels of education, digital games are used as educational tools in various learning activities. However, implementation barriers and other difficulties limit the effective use of such games in the classroom, affecting students' motivation and learning enhancement. The present study was conducted to address this pedagogical gap through the development of a novel learning environment involving digital games, with the overarching purpose of facilitating primary mathematics education via digital game-based learning.

The specific aim of the study was to develop a pedagogical model that would highlight appropriate ways in which digital game-based learning can be applied. To this end, theoretical and pedagogical approaches that explicate game-based learning were determined, and a theoretical and empirical pedagogical model for digital game-based learning in primary mathematics education was designed. The research focused on the following themes: (a) teacher scaffolding strategies and effects and (b) collaborative digital gameplay for engagement. Various theoretical and methodological perspectives were considered. Design-based research, a case study, and a systematic literature review were used to answer the research questions.

Three datasets were utilized from studies reported in three previous articles. In the first two studies, the participating students used a digital game called Wuzzit Trouble to solve integer arithmetic problems. The first study investigated the various approaches to teacher scaffolding in digital game-based learning classrooms and their influence on students' perceptions of mathematics learning through the digital game. The second examined the effects of collaborative digital gameplay on three dimensions of student engagement in mathematics. The data collection methods for these two studies included classroom observations, individual interviews, photo-elicitation interviews, and pre- and post-surveys. The third study involved a systematic literature review and analysis of relevant research papers on teacher scaffolding strategies for different stages of game-based learning and their correlative influence on students' learning.

The main result of the present study was a pedagogical model for digital game-based learning in mathematics. This represents a culmination of educational theories, previous studies related to game-based learning, and the results of the three studies mentioned above. The model provides a pedagogical foundation for mathematics teachers and educational practitioners to design innovative digital game-based learning environment in the classroom. It captures the phases of orientation, gameplay, and expectation in the digital game-based learning process—that is, teachers adopt various approaches to scaffold students in the orientation and gameplay phases, in turn supporting students' learning activities and outcomes in the expectation phase. The results of the study lay a theoretical foundation for learning and teaching with digital games in education. They also provide a design process for and meaningful perceptions of digital game-based learning in mathematics and can help identify areas for further empirical research and development in primary education. Future research directions and design principles are suggested in this paper.

Keywords: digital game, game-based learning, pedagogical model, mathematics, primary education

TIIVISTELMÄ

Liping Sun
Digitaalisiin peleihin perustuva oppiminen – pedagogisen mallin kehittäminen alemman perusasteen matematiikan koulutuksen tarpeisiin
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Digitaalisia pelejä käytetään oppimisvälineinä, koska ne tukevat oppimisympäristöä ja niillä on merkittävä vaikutus kaikilla koulutusasteilla. Toteutuksen esteet ja muut vaikeudet silti rajoittavat pelien tehokasta käyttöä opiskelussa ja vaikuttavat opiskelijoiden motivaatioon ja oppimisprosessin etenemiseen. Tässä tutkimuksessa pyrittiin vastaamaan kyseiseen pedagogiseen haasteeseen kehittämällä uusi oppimisympäristö digitaalisten pelien avulla. Perustarkoituksena oli edistää alemman perusasteen matematiikan koulutusta digitaalisiin peleihin perustuvan oppimisen avulla.

Erityistavoitteena oli kehittää pedagoginen malli, joka tuo esille tarkoituksenmukaisia tapoja soveltaa digitaalisiin peleihin perustuvaa oppimista. Tavoitteen saavuttamiseksi määriteltiin teoreettisia ja pedagogisia lähestymistapoja, jotka havainnollistavat peleihin perustuvaa oppimista sekä kehitettiin teoreettinen ja empiirinen pedagoginen malli digitaalisiin peleihin perustuvalle oppimiselle alemman perusasteen matematiikan koulutuksessa. Tutkimuksen keskiössä olivat seuraavat teemat: a) opettajien tukistrategiat ja niiden vaikutukset sekä b) yhteisöllinen digitaalinen pelaaminen osallistamisen tukena. Tutkimuksessa käsiteltiin myös eri teoreettisia ja metodologisia näkökulmia. Tutkimuskysymyksiin vastattiin kehittämistutkimuksen, tapaustutkimuksen ja systemaattisen kirjallisuuskatsauksen avulla.

Käytössä oli kolme tietoaineistoa tutkimuksista, joista on julkaistu kolme artikkelia. Kahdessa ensimmäisessä tutkimuksessa opiskelijaosallistujat käyttivät digitaalista peliä nimeltä Wuzzit Trouble, jolla tehtiin laskutoimituksia kokonaisluvuilla. Ensimmäinen tutkimus käsitteli lähestymistapoja opettajan antamaan tukeen digitaalisiin peleihin perustuvassa luokkahuoneessa sekä niiden vaikutusta opiskelijoiden käsityksiin matematiikan oppimisesta digitaalisen pelin avulla. Toisessa tutkimuksessa keskityttiin yhteisöllisen digitaalisen pelaamisen vaikutuksiin matematiikassa kolmella opiskelijan osallistamisen tasolla. Näihin kahteen tutkimukseen oli kerätty aineistoa käyttäen muun muassa luokassa tapahtuvaa havainnointia, yksilöhaastatteluja, valokuvamenetelmään perustuvia haastatteluja sekä esi- ja jäl-

kikyselyjä. Kolmanteen tutkimukseen kuului systemaattinen kirjallisuuskatsaus ja analyysi relevanteista tutkimuksista, joissa on tarkasteltu opettajien tukistrategioita peleihin perustuvan oppimisen eri vaiheissa ja strategioiden vaikutusta opiskelijan oppimiseen.

Tämän tutkimuksen päätuotoksena oli digitaaliseen peleihin perustuvan oppimisen pedagoginen malli matematiikassa. Se edustaa kasvatusteorioiden huippua, on jatkoa aikaisemmille peleihin perustuvan oppimisen tutkimuksille ja liittyy yllä mainittujen kolmen tutkimuksen tuloksiin. Malli luo pedagogisen pohjan matematiikan opettajille ja muille kasvatusalan ammattilaisille kehittää innovatiivisia digitaalisiin peleihin perustuvia oppimisympäristöjä. Se kattaa orientaatio-, peli- ja tavoitevaiheet digitaalisiin peleihin perustuvassa oppimisprosessissa. Toisin sanoen opettajat käyttävät eri lähestymistapoja tukeakseen opiskelijoita orientaatio- ja pelivaiheissa, ja vastaavasti avustavat opiskelijoita oppimisaktiviteeteissa ja osaamistavoitteiden saavuttamisessa tavoitevaiheen aikana. Tutkimustulokset luovat teoreettisen perustan oppimiselle ja opetukselle digitaalisten pelien avulla. Ne esittelevät myös digitaalisiin peleihin perustuvan matematiikan oppimisen suunnitteluprosessin ja mielekkään tavan hahmottaa aihetta. Samoin ne voivat auttaa tunnistamaan empiirisen jatkotutkimuksen ja -kehittämisen tarpeita alemman perusasteen koulutuksessa. Tutkimuksessa esitetään myös jatkotutkimuksen linjauksia ja suunnitteluperiaatteita.

Avainsanat: digitaalinen peli, peleihin perustuva oppiminen, pedagoginen malli, matematiikka, alemman perusasteen koulutus

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In 2017, I started my PhD studies in Media Education at the University of Lapland. This dissertation is the milestone of my PhD journey, which has been part of my life in Finland. During the journey, I have had the opportunity to grow as a researcher. Accordingly, there are many wise people who have contributed to my study throughout this research process, to whom I would like to express my gratitude.

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Rovaniemi, November 2023
Liping Sun

List of Original Publications

The dissertation is based on the following original three articles, which will be referred to in the text by their Roman numerals I to III.

Study I

Sun, L., Ruokamo, H., Siklander, P., Li, B., & Devlin, K. (2021). Primary school students' perceptions of scaffolding in digital game-based learning in mathematics. *Learning, Culture and Social Interaction*, *28*.

Study II

Sun, L., Ruokamo, H., Kangas, M., & Siklander, P. (2022). Effects of collaborative digital gameplay on students' three dimensions of engagement in mathematics. *International Journal of Game-Based Learning*, *12*(1).

Study III

Sun, L., Kangas, M., Ruokamo, H., & Siklander, S. (2023). A systematic literature review of teacher scaffolding in game-based learning in primary education. *Educational Research Review*, *40*.

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1 INTRODUCTION

1.1 Research Background

Games are among the most enjoyable and motivating activities, especially for children and teenagers (Bang et al., 2022; Kordaki, 2011; McFarlan et al., 2002; So et al., 2019). According to the Game-Based Learning Market Report 2021 (Research and Markets, 2021), the global game-based learning market was worth US$5.8 billion in 2020. Further, in 2020, there were approximately 2.081 billion active digital game players worldwide (Statista, 2018). Playing digital games is popular and a basic activity among children (Castellar et al., 2014; Ruipérez-Valiente & Kim, 2020). A recent Ofcom (2019) report on media usage and attitudes noted that 36% of 3–4-year-old children play games for around six hours per week, 63% of 5–7-year-olds for seven hours per week, 74% of 8–11-year-olds for 10 hours per week, and 76% of 12–15-year-olds for nearly 14 hours per week. Considering the popularity of digital games, researchers have explored and identified their use for educational purposes (Castellar et al., 2015; Fokides, 2018; Host'ovecký & Novák, 2017; Meletiou-Mavrotheris & Prodromou, 2016; Siew, 2018; Vandercruysse et al., 2017).

Studies have shown that digital games have the potential to provide engaging, motivational, and interactive learning environment when used as educational tools, leading to improved learning outcomes (Boot et al., 2008; Castellar et al., 2015; Gros, 2007; Lowrie & Jorgensen, 2015; Meletiou-Mavrotheris & Prodromou, 2016; Omrod, 2014; Siew, 2018). Meletiou-Mavrotheris and Prodromou (2016) emphasized that digital games can be used to facilitate students' engagement in problem-solving activities and increase their interest in subject learning. Garris et al. (2002) asserted that students generally pay more attention to a learning activity if it involves a game, positively affecting learning outcomes (Fokides, 2018; Sandberg et al., 2011; Tobias et al., 2011).

Interactivity is one of the most significant features of digital games, with embedded interactive elements important for promoting students' involvement and creativity (Brezovszky et al., 2019; Furió et al., 2013; O'Neil et al., 2005; Siew, 2018). Another feature of digital games is the feedback provided during gameplay, which encourages students to use relevant knowledge and explore new strategies, thereby positively affecting their attitudes toward subject learning (Bakker et al., 2016; Egenfeldt-Nielsen, 2005; Kirriemuir, 2002; Kolovou & Van den Heuvel-Panhuizen, 2010; Hidi & Renninger, 2006; Lehtinen et al., 2015; Moreno & Mayer, 2005; Prensky, 2001). Furthermore, digital games tend to be more fun and motivating than other forms of interactive media (O'Neil et al., 2005; Papastergiou, 2009; Tan et al., 2008; Yeh et al., 2019) and provide safe and dynamic learning environment for students to explore their skills without feeling uncomfortable (Holton et al., 2010; Kiili, 2010; Kiili, Lainema, et al., 2014). However, it is not sufficient to simply transform traditional learning into learning that depends exclusively on the characteristics of digital games, since such games are not always effective (Hamari et al., 2014; Hsu & Wang, 2018; Young et al., 2012; Zou et al., 2021). Without a suitable design and learning approach, a digital game may be boring, distracting, and add little value to educational outcomes (DiNardo & Broussard, 2019; Young et al., 2012; Zou et al., 2021).

The purpose of the present study is to facilitate primary education in mathematics via digital game-based learning. The specific aim is to determine appropriate ways in which such learning can be applied in education by developing a pedagogical model. This study contributes to primary mathematics education through the design of a creative and innovative learning environment that supports students' learning activities in primary mathematics classrooms. As Sun et al. (2021) stated, the use of digital games in the classroom requires both teachers and students to be comfortable with exploring and participating in such a learning environment.

With the broad application of digital games in the field of education, digital game-based learning has drawn increasing levels of research attention (Meletiou-Mavrotheris & Prodromou, 2016; Sun, Ruokamo, et al., 2021). This approach to learning is defined as "an instructional method that incorporates educational content or learning principles into video games with the goal of engaging learners" (Shearer, 2011, p. 6, as cited in Siew, 2018). Digital game-based learning is based on the following factors: providing students with challenging activities to surmount (Mavridis et al., 2017); enabling the flexible use of prior knowledge to solve problems in games (Cicchino, 2015; Kim et al., 2009; Papastergiou, 2009); encouraging students to communicate and collaborate with their peers (Kordaki, 2011; Sun et al., 2022); and motivating learners to predict the results of their decisions and actions (Bouras et al., 2004; Cicchino, 2015; Kim et al., 2009; McCall, 2012). These aspects support the integration of digital game-based learning into various educational settings, such as mathematics (Callaghan et al., 2018; Kiili & Ketamo, 2018; Sun, Ruokamo, et al., 2021; Sun et al., 2022).

Mathematics is regarded as a fundamental subject in which arithmetic skills and logical deduction are the foundations of scientific and technological knowledge (Siew, 2018; Yeh et al., 2019). As one of the most important subjects in primary education, it helps students learn not only mathematical knowledge but also crucial skills, including logical and flexible mathematical thinking (Baroody, 2003; Nunes et al., 2016) and problem-solving skills (Ke & Clark, 2020). Despite the significance of mathematics in primary education, many students consider it to be one of the most difficult subjects to master at school (Fokides, 2018; Yeh et al., 2019). Therefore, there is a need to implement appropriate teaching methods and use novel tools in primary mathematics education to overcome these problems and provide students with opportunities to increase their interest in mathematics and enhance their understanding of conceptual knowledge and arithmetic skills (Fokides, 2018; Kiili et al., 2015; Pope & Mangram, 2015).

The main result of the present study is the design of a pedagogical model for digital game-based learning in primary mathematics education, which involved the synthesis of different educational perspectives. Specifically, scaffolding (Makar et al., 2015; Muhonen et al., 2016; Pata et al., 2005; Tropper et al., 2015; Van de Pol et al., 2010; Wood et al., 1976) and collaboration (Dillenbourg, 1999; Roschelle & Teasley, 1995; Tomasello, 2016) in digital game-based learning were combined to construct the pedagogical model. Scaffolding refers to the support and guidance provided by teachers or peers during a learning activity (Wood et al., 1976) and is a dynamic intervention that depends on the students' current situation and responses (Van de Pol et al., 2010). The research identifies that teacher scaffolding serves students effectively by deepening their knowledge building and learning outcomes in mathematics (Makar et al., 2015; Sun, Ruokamo et al., 2021). Collaboration with peers is an effective educational approach (Johnson et al., 2007; Terenzini et al., 2001) that increases students' motivation and engagement and promotes learning (Järvelä et al., 2010; Tolmie et al., 2010; Tomasello, 2016). The use of scaffolding or collaboration has promise in supplementing digital game-based learning to engage students, as many researchers have reported (e.g., Baek & Touati, 2020; Barzilai & Blau, 2014; Chang & Hwang, 2017; Chen & Law, 2016). An important issue explored in the present study is how teacher scaffolding and collaboration can be applied in digital game-based classrooms to keep students engaged in learning, and thus support their learning outcomes in primary mathematics education.

1.2 Wuzzit Trouble

A digital game-based learning classroom that provides a friendly and interactive educational environment formed the main context of this study. A digital game called Wuzzit Trouble[1] was used in this study[2] to determine the manner in which it supports students' learning and engagement in mathematics. Wuzzit Trouble is an educational digital game developed by BrainQuake in 2013 (Devlin, 2013). It has a user-friendly interface to improve students' mathematical thinking and problem-solving skills in integer arithmetic. This tablet-based game is available through the iTunes App Store or Google Play, and it can be played on mobile devices with iOS

1 https://www.brainquake.com/

2 Heli Ruokamo, a BrainQuake advisor, recommended Wuzzit Trouble for this study.

(e.g., iPhone, iPad, and iPod Touch). As shown in Figure 1, Wuzzits are creatures caged in a castle, and the goal of the game is to free them by obtaining all the keys needed (Devlin, 2013; Pope & Mangram, 2015).

Figure 1
A Screenshot of the Wuzzit Trouble Game Interface (Level 3)

Note. Copyright 2013–2024 by BrainQuake.

Wuzzit Trouble consists of three levels ranging from basic to complex. Each level has 25 puzzles and a variety of star ratings (one, two, or three), with points given for each puzzle. The small cogs (see Figure 1) range from one to four in number (1–2 cogs: basic; 3–4 cogs: complex), and new players always start at the first level (Kiili et al., 2015; Sun, Ruokamo, et al., 2021). In the game, the player must rotate the small cogs and move the large gear wheel so that they can reach the keys (Kiili et al., 2015; Sun, Ruokamo, et al., 2021). The small cogs can be turned to the left or right up to five times within a single action, while more stars and points can be acquired by releasing Wuzzits with fewer rotations (Pope & Mangram, 2015; Sun, Ruokamo, et al., 2021). Most of the integer arithmetic problems in Wuzzit Trouble have more than one solution, so the player needs to "develop multi-step algorithms to solve the puzzles optimally" (Kiili et al., 2015, p. 42).

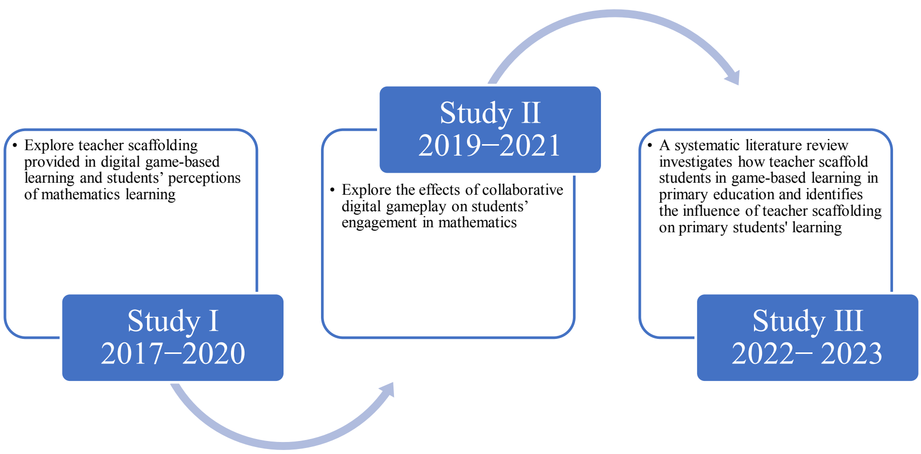
Devlin (2013), one of the creators, stated that unlike other casual games, Wuzzit Trouble is "built on top of sound mathematical principles" (p. 18), which means that anyone who plays the game will learn and practice good mathematical thinking. Pope and Mangram (2015) stated that Wuzzit Trouble "provides a safe zone" for players to take risks and see mistakes as learning opportunities (p. 16). In addition, Kiili et al. (2015) noted that Wuzzit Trouble is not only a representation of certain types of integer arithmetic problem partitions but also of symbolic algebra. The addition of optional bonus items on the wheel makes Wuzzit Trouble a game filled with complex mathematical performance tasks (Kiili et al., 2015). Collecting bonus items enables players to obtain additional points, and the items need to be collected before finding the final key. Thus, the game asks players to reason out optimal strategies during the playing process (Kiili et al., 2015; Pope & Mangram, 2015). With this restriction in Wuzzit Trouble, complex algorithmic reasoning is required to optimize one's scores (Kiili et al., 2015).

Wuzzit Trouble can be used in many ways to realize various learning goals (Kiili et al., 2015; Pope & Mangram, 2015). The basic level provides valuable practice that can enhance players' number sense, while the complex tasks require players to utilize their problem-solving skills, including algebraic and algorithmic thinking (Kiili et al., 2015). These features make Wuzzit Trouble suitable for use by primary school students both in school and at home (Devlin, 2013).

1.3 The Study Process

In designing the pedagogical model, I sought to highlight the potential of using digital games in primary mathematics education. My research into digital game-based learning began in 2017, the empirical data were gathered in autumn 2018 and spring 2019, and a systematic literature review was conducted in 2022. Figure 2 shows the timeline of the research process.

Figure 2
The Research Process



Digital game-based learning in primary mathematics education was investigated in three studies. In Studies I and II, a digital game-based learning classroom was designed and the influence of digital gameplay on primary-level mathematics teaching and learning examined. The data for Study I were collected in autumn 2018. The aims of the study were to explore teacher scaffolding approaches in digital game-based learning and examine their effects on students' perceptions of learning via a digital game. Teacher scaffolding was conducted in different settings and had a positive effect on mathematics students (Sun, Ruokamo, et al., 2021). The paper for Study I was submitted to a peer-reviewed journal in 2019 and published online in 2020 and in print in 2021.

The data for Study II were collected in spring 2019, and students' behavioral, emotional, and cognitive engagement levels were measured in a collaborative digital gameplay classroom. Collaborative learning and engagement were the two key concepts underpinning the theoretical framework of this study. The students played the digital game with their desk mates, and the factors affecting the three dimensions of student engagement in mathematics were investigated and identified. The paper for this study was published in a peer-reviewed journal in 2021.

Study III was a systematic literature review launched in April 2022. Literature in the field of learning science was reviewed to explore the teacher scaffolding strategies used in the orientation and gameplay stages of game-based learning and their correlative influence on students' learning. A report on this systematic literature review was submitted to a peer-reviewed journal in July 2022 and published in June 2023. Table 1 describes each author's contributions to the three articles corresponding to the three studies described above.

Table 1
Descriptions of the Authors' Contributions to Each Study

Studies and articles	Liping Sun's contributions	Other authors' contributions
Study I (Article 1)	• Collected and analyzed the data (145 participants) • Interpreted the results • Drafted the manuscript • Modified and finalized the article • Revised the article based on the review procedure	• The second and third authors provided guidance. • The fourth author contributed to the data collection in primary schools. • The fifth author installed the code for Wuzzit Trouble.
Study II (Article 2)	• Collected and analyzed the data (45 participants) • Interpreted the results • Drafted the manuscript • Modified and finalized the article • Revised the article based on the review procedure	• The second and third authors provided methodological guidance. • The fourth author provided theoretical guidance.
Study III (Article 3)	• Collected and analyzed the data (24 articles) • Explained the results • Drafted the manuscript • Modified and finalized the article • Revised the article based on the review procedure	• The second author provided theoretical guidance. • The third and fourth authors provided methodological guidance.

As shown in Table 1, all authors provided valuable perspectives and contributed to the research on digital game-based learning in primary mathematics education. The findings obtained by combining various educational perspectives and methodologies helped us deepen our understanding of digital game-based learning and subsequently to develop a pedagogical model that can support teachers in planning, conducting, and assessing their practical approaches to teaching mathematics, while students can benefit from learning through digital games. With this background, the present study aims to provide valuable insights that will add to the ongoing discussion on digital game-based learning in primary mathematics education.

In mathematics learning at the primary education level, students learn how to combine knowledge, think logically, and identify relationships in everything in which they are involved (Brezovszky et al., 2019; Devlin, 2013; Siew, 2018; Van den Heuvel-Panhuizen et al., 2013). Therefore, the study findings can support teacher educators to identify new ideas for developing game-based learning pedagogy in teacher education—in particular, in primary mathematics education. For researchers and designers in education and other fields, these findings provide meaningful perspectives of digital game-based learning as well as a direction for further empirical research and development in primary mathematics education.

1.4 The Study's Aims and Research Question

The aims of the study were to explore and expand on the theoretical and pedagogical approaches that explicate digital game-based learning and to design a pedagogical model for digital game-based learning in primary mathematics education. More specifically, this study aimed to do the following:

- Explore the ways in which teacher scaffolding is provided in digital game-based learning classrooms and the influence of these classrooms on students' perceptions of learning in mathematics (Study I)
- Examine the effects of collaborative digital gameplay on the three dimensions of student engagement in mathematics (Study II)
- Identify the different teacher scaffolding strategies implemented in teacher–student interactions during the orientation and gameplay stages and their correlative influence on students' learning in primary education (Study III)

To achieve these aims, the data from each of the three studies in this research were taken together to answer the following main research question:

What kinds of scaffolding strategies do teachers implement in digital game-based learning and what are students' gaming and mathematics learning experiences in collaborative digital game-based learning classrooms in which teacher scaffolding is provided?

The rest of this dissertation is structured into six chapters, followed by the three original research publications. In the following chapter, the theoretical framework of the research is presented, and the methodological choices are outlined in Chapter 3. In Chapter 4, the three studies that form the basis of this research are summarized and evaluated, and the construction and development of the pedagogical model are described in Chapter 5. In Chapter 6, the outcomes of the study and their scientific and practical implications are discussed and suggestions for future research are provided.

2 THEORETICAL FRAMEWORK

This chapter outlines the theoretical framework that underpins and forms the basis for the pedagogical model for digital game-based learning presented in this dissertation. The pedagogical model was developed during the research process by merging the following three theoretical frameworks: scaffolding, collaboration, and engagement. The studies undertaken as part of this research process (Studies I–III) also impacted the development of the model. In the following sections, the theoretical perspectives supporting the research and the pedagogical model are presented in greater detail.

2.1 Scaffolding

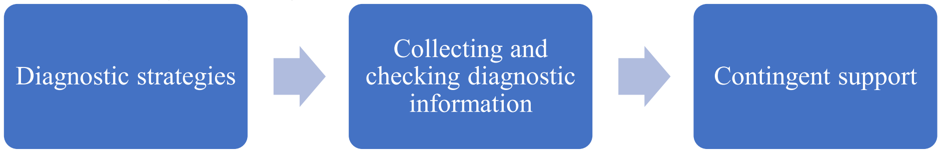
2.1.1 Defining Scaffolding

Over the last couple of decades, the concept of scaffolding has received a large amount of attention in educational research (Atmatzidou & Thessaloniki, 2017; Belland et al., 2013; Chen & Law, 2016; Van de Pol et al., 2010). The metaphor of scaffolding refers to tutoring or assistance that "enables a child or novice to solve a problem, carry out a task or achieve a goal which would be beyond his unassisted effort" (Wood et al., 1976, p. 90). The idea of scaffolding is closely linked to Vygotsky's (1978) sociocultural theory and the concept of the zone of proximal development (ZPD) (Vygotsky, 1978). The ZPD is the distance between what a student can do independently and what they can do with the help of a more knowledgeable other (Vygotsky, 1978). When scaffolding support is provided within a student's ZPD and tailored to the student's current or actual understanding, it facilitates the student's engagement and learning outcomes (Van de Pol et al., 2012; Van de Pol et al., 2014, 2015). Scaffolding has been considered in various studies in the context of dyadic interactions (Wood et al., 1978), interactions between a teacher and a small group of students (Sun et al., 2022; Van de Pol et al., 2014), and whole-class teaching (Smit et al., 2013; Sun, Ruokamo, et al., 2021).

Van de Pol et al. (2010) identified three key characteristics of scaffolding in their review: (a) contingency, (b) fading, and (c) transfer of responsibility. Contingency, which was first introduced by Wood et al. (1978), refers to adaptive support that is responsive to a student's existing understanding (Van de Pol et al., 2012; Van de Pol et al., 2015). Fading—that is, the gradual withdrawal of support—allows the responsibility for learning or for a task to be transferred to the student, which is the ultimate aim of scaffolding (Van de Pol et al., 2010, 2012). However, as Van de Pol et al. (2012) indicated, the transfer of responsibility is effective only when it is carried out in a contingent manner. Therefore, contingency is viewed as a key prerequisite for the process of scaffolding (Van de Pol et al., 2011; Van de Pol & Elbers, 2013). The process of contingent teaching is outlined in Figure 3.

Figure 3

Process of Contingent Teaching



As shown in Figure 3, diagnostic strategies serve as tools for contingent teaching (Van de Pol et al., 2010). Diagnosing students' existing or current understanding is an essential part of scaffolding (Pea, 2004; Puntambekar & Hübscher, 2005). To provide tailored support based on students' understanding of a subject, the teacher first needs to probe into this understanding by asking questions (Wittwer & Renkl, 2008). Diagnostic questions are generally open-ended ones that do not provide any directions for thinking or involve prompts on how to answer (Van de Pol et al., 2011; Van de Pol et al., 2014). Open-ended diagnostic questions enable teachers to obtain detailed information about students' existing knowledge (Van de Pol et al., 2014). After collecting and checking the information that their students already understand, teachers can provide contingent support that is adaptive to the diagnostic information obtained (Van de Pol et al., 2014).

Many researchers have recognized the importance of diagnosis for scaffolding, referring to it as dynamic assessment (Lajoie, 2005; Macrine & Sabbatino, 2008; Pea, 2004; Swanson & Lussier, 2001), formative assessment (Shepard, 2005), or monitoring and checking students' understanding (Garza, 2009). In sum, the process of scaffolding, and especially the contingency of support, has been shown to promote students' learning.

2.1.2 Scaffolding in Game-Based Learning

Game-based learning is an increasingly popular instructional approach in both formal and informal educational settings (Bui et al., 2020; Cai et al., 2022; Chen et al., 2020; Fokides, 2018; Mayer, 2019). However, digital games may not always be effective in facilitating learning due to various situational factors, such as the challenge of applying prior knowledge by novice or inexperienced students (Lee & Chen, 2009; Parasleva et al., 2010), poor self-regulation abilities of students

(Bell & Gresalfi, 2017; Sun et al., 2018; Yang & Lu, 2021), difficulties in acquiring knowledge (Lucht & Heidig, 2013), technological challenges, and time management issues (Kirriemuir & McFarlane, 2003). Despite these difficulties, some researchers have suggested that scaffolding can help enhance students' engagement and learning outcomes in game-based learning (Abdul Jabbar & Felicia, 2015; Barzilai & Blau, 2014; Chen & Law, 2016).

With the development of computer-assisted learning and game-based learning, scaffolding is no longer limited to interactions among individuals, such as teacher–student or student–student interactions, but has been extended to software-based tools and technology resources that support students' learning activities and achievement (Belland, 2014; Cai et al., 2022; Puntambekar & Hübscher, 2005). According to Chen and Law (2016), software-based tools embedded in a game, such as question prompts or explanatory feedback (Adams & Clark, 2014; Chen & Law, 2016), are classified as hard scaffolding, while interactions involving teachers or student peers, such as teacher scaffolding or student scaffolding, are classified as soft scaffolding.

Some studies have reported that hard scaffolding can help students make connections between knowledge acquired from the game and knowledge from the subject (Barzilai & Balu, 2014; Mayer et al., 2020). However, some studies have shown that hard scaffolding is not always effective because such approaches are not adaptive to the existing learning needs of students (e.g., Adams & Clark, 2014; Bulu & Pedersen, 2010; Chen et al., 2013; Ge & Land, 2004; Hsu & Tsai, 2013).

Student–student interactions during collaboration is regarded as a kind of soft scaffolding (Chen & Law, 2016; Ge & Land, 2004; Monjelat et al., 2017). Some studies have shown that student scaffolding in game-based learning allows students to provide and receive explanations, construct ideas together, control frustrations when needed, and guide each other effectively (e.g., Hämäläinen, 2008; Monjelat et al., 2017; Sánchez & Olivares, 2011). However, Wouters et al. (2013) reported that student scaffolding in game-based learning has no significant impact on the requirement of domain-specific knowledge, although it could increase learning outcomes and motivation. Considering the mixed results of hard scaffolding and student scaffolding, teacher scaffolding—the other soft scaffolding approach in game-based learning—was the focus of the present study.

Teacher scaffolding plays a critical role in game-based learning through the integration of digital games with subject content to optimize the teaching and learning process (Sun et al., 2023; Sun, Ruokamo, et al., 2021). Several studies have demonstrated that teachers act as facilitators of the learning process and provide adaptive support to help students deal with the difficulties they face, and thereby acquire the target knowledge and skills (Chuang et al., 2021; Ertmer & Glazewski, 2005; Greening, 1998; Liu et al., 2018; Wong et al., 2017). Many studies have also shown that teachers can serve as guides during game-based learning to help students build a link between subject knowledge and knowledge obtained through the game (Barzilai & Blau, 2014; Haataja et al., 2019). In addition, teachers' encouragement has been found to positively affect students' engagement, enjoyment, and persistence in learning (Barzilai & Blau, 2014; Chen & Law, 2016; Muhonen et al., 2016; Rienties et al., 2012).

However, some studies have indicated that the scaffolding provided by teachers during game-based learning, such as teacher-led discussions (Boticki et al., 2015; Bragg, 2012) and explicit instructions (e.g. Chuang et al., 2021; Wong et al., 2017), negatively influence students' learning. This could be because teachers break away the three key characteristics of scaffolding and the purpose of game-based learning (Sun et al., 2023). When teacher scaffolding is provided but not withdrawn gradually, students are not motivated to think about and engage in the game-based learning experience; consequently, the responsibility of learning does not get transferred from the teacher to the students (Van de Pol et al., 2010; Wong et al., 2017).

In the pedagogical model presented in this dissertation, teacher scaffolding is included in each of the different phases of digital game-based learning to emphasize that teachers play a key role in determining how teaching and learning take place (Chen & Law, 2016; Haataja et al., 2019; Sun et al., 2018). However, since game-based learning cannot be considered from only one theoretical perspective, collaboration was taken into account in this study. In the following section, collaboration, which in my view can also be used to influence students' game-based learning, is discussed.

2.2 Collaboration

2.2.1 Defining Collaboration

Research on collaborative learning began in the 1970s and developed with the growth of increasingly global world and Internet technologies (Baker, 2015). According to Dillenbourg (1999), collaborative learning is "a situation in which particular forms of interaction among people are expected to occur, which would trigger learning mechanisms" (p. 5). It is an effective educational approach (Johnson et al., 2007; Terenzini et al., 2001) that involves two or more students learning together as they work on a joint task, with each student responsible for achieving a common goal with their group members (Dillenbourg, 1999; Tomasello, 2016). Collaborative learning is based on the view that learning is a social activity that occurs when students interact with their social environment (Vygotsky, 1978).

In principle, this type of learning is grounded in the early works of Jean Piaget and Lev Vygotsky (Chounta, 2019; Lehtinen, 2003; Loes, 2022). Table 2 presents Piaget and Vygotsky's theoretical perspectives that contribute to the theory of collaborative learning.

Table 2
The Contribution of Piaget and Vygotsky's Theoretical Perspectives of Collaborative Learning

Psychologist	Theoretical perspective	Students' collaborative activities	Students' outcomes
Jean Piaget	The potential of the learning environment affects students' development (1926, 1950)	When students are in an environment that allows them to interact with peers in the learning process, the exposure to intellectual diversity may facilitate their learning, making them reexamine their beliefs and perspectives (1926, 1950).	The learning tasks that students complete collaboratively results in cognitive conflict, which furthers their cognitive knowledge and skills (Dillenbourg et al., 1996; Loes, 2022; O'Donnell & Hmelo-Silver, 2013).
Lev Vygotsky	The concept of the zone of proximal development (ZPD) (1978)	When capable peers operate within the student's ZPD, they will provide appropriate support during the implementation of the task, enabling the student to internalize the knowledge and develop cognitively (O'Donnell & Hmelo-Silver, 2013; Vygotsky, 1978).	Collaborative activities enhance student growth because of the developmental differences between the students involved (Lehtinen, 2003; O'Donnell & Hmelo-Silver, 2013).

Based on the theoretical perspectives of Piaget and Vygotsky shown in Table 2, researchers have argued that cognitive conflicts that arise in social interactions can enhance students' cognitive performance (Mugny & Doise, 1978; Piaget, 1980). Moreover, collaboration can facilitate the learning process for both low- and high-level students (O'Donnell & Hmelo-Silver, 2013; Lehtinen, 2003). Chounta (2019) stated that learning is not only the outcome of collaborative activities but also describes the entire process of working with peers in a social context toward a common goal.

Dillenbourg (1999) identified the following three critical criteria for describing situations in which students collaborate: interactivity, synchronicity, and negotiability. In a collaborative learning environment, students participate in joint activities synchronously, share their viewpoints, negotiate ideas, and attempt to convince their peers about specific task details (Baek & Touati, 2020; Dillenbourg, 1999; Tomasello, 2016). More importantly, students perform similar behaviors and put effort into achieving a common goal (Chounta, 2019; Tomasello, 2016). In collaborative learning, negotiation is necessary not only to develop common goals but also to be aware of any goal differences that may be the result of differences in actions (Dillenbourg, 1999). Davidson and Major (2014) stated that the goal of collaborative learning is to make students more responsible for their learning through the co-construction of knowledge, thereby transferring the responsibility away from the teacher.

Although collaborative learning has been identified as an instructional approach to deepen learning, student interaction and engagement may not occur as expected, especially among students in preschool and primary school (Danby et al., 2018; Lipponen et al., 2018). The problems that may arise include interaction difficulties (Fuks et al., 2006; Janssen et al., 2009), the need for intensified support (Dukuzumuremyi & Siklander, 2018), and peer conflict and negative emotions during discussions (Lipponen et al., 2018). Notably, the use of game-based learning can minimize the chances of the above problems occurring.

2.2.2 Collaboration in Game-Based Learning

Game-based learning provides opportunities for constructive peer interactions, which can lead to successful learning activities (Chounta, 2019). Collaborative game-based learning has gained attention among researchers, and its impact is increasingly evident (Baek & Touati, 2020; Liao et al., 2019). Hsiao et al. (2014) stated that students may gain more knowledge from face-to-face collaborative gameplay than from individual learning if the educational games used allow them to engage in more interactions and discussions. In addition, Baek and Touati (2020) found that collaborative gameplay, which involves synchronous communication, symmetry of characters, and collective problem-solving tasks, can create better situations for group performance than cooperative learning, wherein students work interdependently. Chang and Hwang (2017) reported that students can learn subject knowledge, perform learning tasks more effectively, and enhance their collaborative skills by providing and receiving peer support during collaborative gameplay. Through collaborative game-based learning, students can learn how to interact and construct knowledge together, which is essential for their critical thinking, verbal negotiation, problem-solving (Baek & Touati, 2020; Hyvönen, 2008; Roschelle & Teasley, 1995), decision-making, and social skills (Stephen & Plowman, 2008; Wohlwend, 2010).

Although collaborative game-based learning has a positive effect on students' learning engagement and achievement, it is not self-evident that students collaborate when playing digital games (Chang & Hwang, 2017; Lipponen et al., 2018). Collaboration requires students' active participation and motivation to achieve common goals through the co-construction of knowledge (Abdul Jabbar & Felicia, 2015; Jone & Isroff, 2005; Tomasello, 2016). During collaborative gameplay, students' interactions may be influenced by aspects such as age, personal characters, learning habits, and familiarity (Chang & Hwang, 2017; Howes, 2011; Janssen et al., 2009; Lipponen et al., 2018). To engage in problem-solving during gameplay, students require communication skills to consider their peers' points of view, organize gameplay participation, and construct and maintain meaningful conversations about problem-solving (Danby et al., 2018; Janssen et al., 2009; Roschelle & Teasley, 1995). In addition, familiarity and amicable relationships between peers contribute to interaction and problem-solving during collaborative gameplay (Janssen et al., 2009; Lipponen et al., 2018). Janssen et al. (2009) stated that group members who are familiar with each other find it easier to communicate and negotiate viewpoints and reduce misunderstandings. Consequently, collaborative activities related to task regulation and group processes are more efficient for these group members than for those who are unfamiliar.

In most classroom- or technology-based collaborative learning situations, the role of the teacher differs between one-to-one and whole-class situations (Baker, 2015; Lipponen et al., 2018). Previous studies (e.g., Baek & Touati, 2020; Hollingshead & McGrath, 1995; Janssen et al., 2009; Lipponen et al, 2018) showed that the primary responsibilities of a teacher during collaborative learning are to create and organize student groups. Theoretically, teachers can assign student groups based on prior knowledge, gender differences, group size, relationships, and so on (Baker, 2015; Dunleavy et al., 2009; Hollingshead & McGrath, 1995). However, it is not easy to put these items into effect in practical educational settings, so teachers typically ask students who sit near each other to collaborate on learning tasks (Baker, 2015; Sun et al., 2022). Furthermore, Stephen and Plowman (2008) stated that students' active participation during gameplay depends on the sensibility and reaction capacity of the teacher who provides support. Therefore, it is important that teachers are available to guide, encourage, and support students during collaborative gameplay (Barzilai & Blau, 2014; Dukuzumuremyi & Siklander, 2018; Lipponen et al., 2018; Rienties et al., 2012).

In the pedagogical model presented in this dissertation, collaboration is considered in the gameplay phase, while the teacher scaffolding is associated with students' engagement in collaborative gameplay. Many researchers have suggested that the integration of scaffolding and collaboration in game-based learning is necessary for the optimization of student engagement and learning outcomes (Chen & Law, 2016; Liao et al., 2019; Lin & Reigeluth, 2016; Sun et al., 2022; Wong et al., 2011). In the following section, I discuss engagement in game-based learning.

2.3 Engagement

2.3.1 Defining Engagement

According to Guthrie et al. (2012), engagement is "involvement, participation, and commitment to some set of activities" (p. 601). Engagement may describe one's involvement with specific content, such as mathematics, but more typically, it refers to a broad range of cognitive and emotional experiences and social and academic behaviors, such as completing the assigned tasks and following the rules (Fredricks et al., 2004; Fredricks & McColskey, 2012; Renninger & Bachrach, 2015). Fredricks and McColskey (2012) stated that an individual's engagement "cannot be separated from their environment" (p. 765). Therefore, student engagement commonly refers to students' sustainable and active involvement in a learning environment, which affects their learning activities, learning outcomes, and decision to drop out of school (Appleton et al., 2008; Fredricks et al., 2004; Renninger & Bachrach, 2015).

According to Fredricks et al. (2004), engagement is a multidimensional construct involving behavioral, emotional, and cognitive dimensions. Descriptions of each engagement dimension and its measurement are presented in Table 3.

Table 3
Three Dimensions of Engagement and their Measurement

Engagement	Description	Measurement
Behavioral	Participation and involvement in academic, social, and extracurricular activities, regarded as essential to achieving learning outcomes and preventing dropout (Blumenfeld et al., 2005; Connell & Wellborn, 1991; Finn, 1989; Fredricks et al., 2004).	Effort, persistence, behavioral aspects of attention, and perseverance when facing difficulties and obstacles (Buhs & Ladd, 2001; Fredricks et al., 2004; Van Braak et al., 2020).
Emotional	Emotional reactions to school, teachers, peers, or academics (Blumenfeld et al., 2005; Fredricks et al., 2004; Fredricks & McColskey, 2012).	Positive (e.g., interest, happiness, fun, and enjoyment) and negative (e.g., sadness, boredom, frustration, and discouragement) emotional responses to activities and participants (Fredricks et al., 2004; Garcia, 2012; Pekrun & Linnenbrink-Sinatra et al., 2015).
Cognitive	Level of psychological investment in learning as well as the level and types of self-regulatory and other strategies adopted to direct cognitive efforts (Appleton et al., 2008; Blumenfeld et al., 2005; Fredricks et al., 2004; Sinatra et al., 2015; Walker et al., 2006; Wehlage & Smith, 1992).	Deep consideration, flexible problem-solving, coping with perceived failure, preference for difficult tasks, and the use of strategies (Blumenfeld et al., 2005; Fredricks et al., 2004; Sinatra et al., 2015).

When considering the descriptions and measurements shown in Table 3, each dimension has clear and distinctive features (Lam et al., 2012). However, all the dimensions of engagement overlap to some extent and are incorporated with each other (Fredricks et al., 2004). For example, motivation and self-regulation are reflected in each dimension of engagement (Sinatra et al., 2015). Thus, as Fredricks et al. (2004) indicated, the behavioral, emotional, and cognitive dimensions of engagement conceptualize a multifaceted construct and can be explored simultaneously (Guthrie et al., 2012; Sinatra et al., 2015).

Many studies have shown that engagement has short-term and long-term influences on school students (Lam et al., 2012). In the short term, it affects students' "learning, grades, and conduct in school" (Lam et al., 2012, p. 403), and in the long term, it relates to students' "academic achievement, self-esteem, and socially appropriate behaviours" (p. 403). Furthermore, Skinner and Pitzer (2012) proposed that engagement determines students' daily experiences in school and provides a straight pathway to learning and long-time academic success. Therefore, it is essential to figure out what types of factors influence students' behavioral, emotional, and cognitive engagement.

Fredricks et al. (2004) reviewed the impacts of the educational environment on student engagement and concluded that school-level factors are correlated with behavioral engagement and that both classroom factors and individual needs are associated with three-dimensional engagement during the primary, secondary, and high school years. Furthermore, Renninger et al. (2018) highlighted that some factors, such as interaction with others, task characteristics, and context structure, are able to change students' level of engagement. Lam et al. (2012) reported that instructional and socially related contextual factors have a significant effect on junior secondary school students' three-dimensional engagement and that personal factors have a strong positive impact on the same.

2.3.2 Engagement in Game-Based Learning

Research has shown that games provide opportunities for student engagement and learning through gameplay (Nebel et al., 2017; Abdul Jabbar & Felicia, 2015). Abdul Jabbar and Felicia (2015) categorized four key gaming elements (motivational, interactive, fun, and multimedia) related to behavioral, emotional, and cognitive engagement and stated that gaming platforms are popular because they include a multitude of mechanisms (Abourin & Lester, 2014; Gee, 2003; Shaffer, 2006), engage students in learning (Dickey, 2005; Whitton, 2011), motivate students' ability to think (Ermi & Mayra, 2005), and sustain students' engagement in both enjoyable and motivating ways (Abdul Jabbar & Felicia, 2015; Baek & Touati, 2020).

Many educational researchers have stated that digital games are beneficial for encouraging student engagement (Abourin & Lester, 2014; Chang et al, 2016; Khoo, 2016; Liao et al., 2018; Sun et al., 2022). Chang et al. (2016) measured fifth-grade students' three-dimensional engagement by comparing their learning of fractions using an educational video game named APP and using paper-and-pencil drills. The results showed that playing APP resulted in a greater increase in students' behavioral and emotional and overall engagement than did paper-and-pencil drills. Similarly, Liao et al. (2018) conducted an experiment to compare the effectiveness of a game-based writing environment and an online writing environment in improving third-grade students' participation, performance, and interest in writing. They found that the increase in behavioral and cognitive engagement was higher for the game-based writing environment group than for the online writing environment group.

Digital games can contribute to student engagement, of which peer collaboration during gameplay is a key factor (Abdul Jabbar & Felicia, 2015; Baek & Touati, 2020; Chang & Hwang, 2017; Sun et al., 2022). Danby et al. (2018) pointed out that students' social interactions in digital games allow them to understand how to participate in peer activities and share knowledge, engage in digital practices with various strategies, request and receive help during gameplay, and handle emotional problems in a social context. Furthermore, Pekrun and Linnenbrink-Garcia (2012) indicated that the positive emotions that arise from collaborative gameplay facilitate effort making and the use of learning strategies, thereby affecting students' learning outcomes.

In addition to the aforementioned digital games and peer collaboration, other factors influence students' behavioral, emotional, and cognitive engagement, one of which is teacher scaffolding. Researchers have stated that teacher scaffolding is critical for motivating students and helping them maintain and improve their engagement in game-based learning (Baek & Touati, 2020; Meletiou-Mavrotheris & Prodromou, 2016; Pentaraki & Burkholder, 2017; Sun, Ruokamo, et al., 2021; Wong et al., 2011). Sun et al. (2022) reported that the teacher's brief instruction and encouragement on each experimental day affected the students' behavioral and cognitive engagement during collaborative digital gameplay. Moreover, in Wilkerson et al.'s (2018) study, teacher-directed prompts helped students who had trouble producing a working simulation in the Simulation, Measurement, and Stop-Action Moviemaking (siMSAM) environment engage in modelling and reasoning.

Learning achievement is another influencing factor and correlated with student engagement in game-based learning. Sun et al. (2022) showed that when students perceive their problem-solving and arithmetic skills to have improved, they become more emotionally and cognitively engaged in collaborative gameplay. Learning achievement not only influences students' engagement but is also an outcome of engagement among primary, secondary, and high school students (Callaghan et al., 2018; Fredricks et al., 2004; Sinatra et al., 2015). As Guthrie et al. (2012) stated, a high level of student engagement leads to learning achievements in the classroom context. In the context of game-based learning, active participation in and exploration of digital games are forerunners of students' learning achievements (Sun et al., 2022).

Fredricks et al. (2004) summarized the factors that influence student engagement in the classroom context—namely, teacher support, peers, classroom structure, autonomy support, and task characteristics. The present study focuses on teacher scaffolding, peer collaboration, and digital games as factors applicable to the game-based learning context. In this context, students become behaviorally, emotionally, and cognitively engaged in gameplay when the game tasks and activities are challenging and fun and their relationships with their teacher and peers are of high quality (Sun et al., 2022). Increased three-dimensional engagement promotes the effort-making behaviors of students and enables them to employ deep processing strategies to understand subject knowledge (Lam et al., 2012; Pekrun & Linnenbrink-Garcia, 2012). Furthermore, progress with regard to engagement is a principal element that helps students effectively cope with frustration in the classroom and leads to the development of learning outcomes (Lam et al., 2012; Skinner & Pitzer, 2012).

In sum, game-based learning is grounded in the connection between educational games and learning theories. Researchers and educators agree that considering game-based learning from multiple theoretical perspectives enables the creation of a structure to organize and integrate iterative learning experiences with digital games. Teacher scaffolding, collaboration, and engagement are useful in this approach and can contribute to learning outcomes in game-based learning.

3 METHODS

Three prior studies (see Table 4) have been considered in the present research, all of which contributed to the design of a pedagogical model for digital game-based mathematics learning in primary education. In this chapter, the research design is described in detail. An overview and an evaluation of the three studies are presented in Chapter 4, while Chapter 6 provides a discussion of the studies.

Table 4
Summary of the Research Design

Aims and contributions	Research questions	Research and data collection methods and research data	Data analysis methods	Publication
Study I: To explore teacher scaffolding in digital game-based learning and students' perceptions of mathematics learning – An in-depth understanding of teacher scaffolding strategies and their correlated influence on students' learning activities in the context of digital games in primary education	1. How do students perceive mathematics learning scaffolded by teachers in digital game-based learning classrooms? 2. How does teacher scaffolding in digital games affect students' perceptions of mathematics learning?	*Design-based research and a case study* **Classroom observation** in five classes: Students (n = 141) Teachers (n = 4) **Thematic interviews:** students (n = 25)	**Qualitative content analysis**	Refereed international scientific journal: Sun, L., Ruokamo, H., Siklander, P., Li, B., & Devlin, K. (2021). Primary school students' perceptions of scaffolding in digital game-based learning in mathematics. *Learning, Culture and Social Interaction, 28*.
Study II: To explore the effects of collaborative digital gameplay on students' engagement in mathematics – An in-depth understanding of the role of the classroom context in affecting the three dimensions of student engagement in mathematics	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?	*Design-based research and a case study* **Mathematical engagement survey:** pre-test (n = 45) and post-test (n = 43) **Photo-elicitation interviews:** students (n = 6)	**Quantitative analysis** using SPSS software: reliability analysis (Cronbach's alpha), independent samples t-test (mean, standard deviation, correlation, two-tailed p-value) **Qualitative content analysis** of the photo-elicitation interviews with students	Refereed international scientific journal: Sun, L., Ruokamo, H., Kangas, M., & Siklander, P. (2022). Effects of collaborative digital gameplay on students' three dimensions of engagement in mathematics. *International Journal of Game-Based Learning*, *12*(1).

Study III: To identify the different teacher scaffolding strategies used in teacher–student interactions within game-based learning and their correlative influence on students' learning – An in-depth understanding of different teacher scaffolding strategies at various stages of game-based learning and their correlative influence on students' learning	1. What games have been used in game-based learning research? 2. What kinds of scaffolding strategies are used by teachers in teacher–student interactions within game-based learning in primary education? 3. What empirical evidence exists regarding the influence of the scaffolding strategies used in game-based learning on primary students' education?	*Design-based research* **Systematic literature review (SLR)** Selected articles (*n* = 24)	**Qualitative content analysis**	Refereed international scientific journal: Sun, L., Kangas, M., Ruokamo, H., & Siklander, S. (2023). A systematic literature review of teacher scaffolding in game-based learning in primary education. *Educational Research Review, 40.*

Table 4 presents a summary of the research design for each of the three studies, which have each been reported in research articles and published in peer-reviewed international scientific journals. Descriptions of the design-based research (DBR), case study, and SLR approaches used, including the research context and data collection and analysis methods, are presented in the following sections.

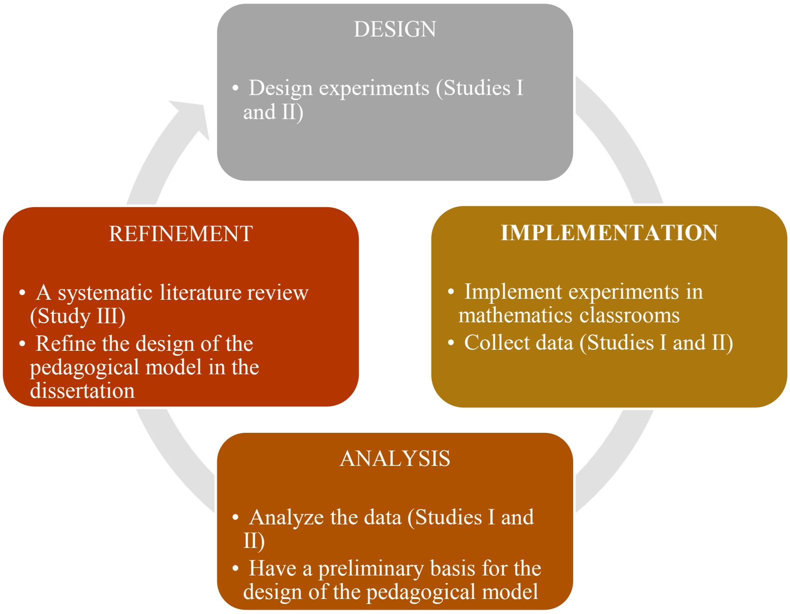
3.1 Design-Based Research

DBR, the methodological approach adopted by this study (Barab & Squire, 2004; Brown, 1992; Collins et al., 2004; Design-Based Research Collective, 2003; Wang & Hannafin, 2005), is a "paradigm for the study of learning in context through the systematic design and study of instructional strategies and tools" (Design-Based Research Collective, 2003, p. 5). Anderson and Shattuck (2012) characterized DBR as follows:

> Being situated in a real educational context, focusing on the design and testing of a significant intervention, using mixed methods, involving multiple iterations, involving a collaborative partnership between researchers and practitioners, evolution of design principles, comparison to action research, practical impact on practice. (pp. 16–18)

The goal of the DBR approach is to generate learning theories, teaching and learning, and design procedures (Barab & Squire, 2004; Design-Based Research Collective, 2003; McKenney & Reeves, 2013). DBR facilitates the understanding of teaching, learning, and design based on practical issues (Gresalfi & Barnes, 2016; Orrill et al., 2003). Learning phenomena can be studied in real-world contexts but not in laboratories, and theoretical problems concerning the nature of learning should be solved in actual environment, such as in classroom or after-school settings (Collins et al., 2004). DBR requires researchers to collaborate with participants, other researchers, educational practitioners, teachers, and students to manage the research process, improve the original design, and advance both practical and theoretical aims (Brown, 1992; Gresalfi & Barnes, 2016; Wang & Hannafin, 2005). Therefore, researchers also act as designers involved in social interactions with participants in the repeated cycle of design, implementation, analysis, and redesign (Brown, 1992; Design-Based Research Collective, 2003; Wang & Hannafin, 2005). In the present study, DBR was used to elaborate on how the pedagogical model for digital game-based learning was designed in a real classroom scenario and to better understand teaching and learning issues in primary mathematics education (Edelson, 2002; Zheng, 2015). This approach was deemed suitable for developing a pedagogical model of digital game-based learning in mathematics. In a real-life context, DBR involves examining a particular intervention through the continuous iteration of design, enactment, analysis, and redesign (Brown, 1992; Cobb et al., 2003; Wang & Hannafin, 2005), with development and research taking place through repetitive cycles (Design-Based Research Collective, 2003; Gresalfi & Barnes, 2016). Due to the iterative nature of the DBR process, only one cycle of DBR was conducted in the present study, consisting of four phases (see Figure 4).

Figure 4
The First Cycle of DBR and its Phases



As shown in Figure 4, the first phase of the DBR cycle involved designing the experiments for Studies I and II, the aim of which was to obtain knowledge for the design of the pedagogical model. These experiments were based on those carried out in prior studies and on a variety of learning theories that support game-based learning. The experiments were implemented in mathematics classrooms, and data were collected at three primary schools in Beijing in autumn 2018 (Study I; see Sun, Ruokamo, et al., 2021) and one primary school in Shanghai in spring 2019 (Study II; see Sun et al., 2022). The third phase involved analyzing the qualitative and quantitative data obtained from the two empirical studies mentioned above to understand teaching and learning process in digital game-based learning environment. The results of these two studies provided a preliminary basis for the design of a pedagogical model for digital game-based learning, which was then improved in Study III. In the final phase of the DBR cycle, an SLR was launched with the aim of gathering more information about teaching scaffolding strategies at various game-based learning stages and their correlative influence on students' learning in primary education. Based on learning theories and the results of the three studies, the pedagogical model was designed and improved. A refined version of the pedagogical model is presented in Chapter 5 of this dissertation.

Collaboration between researchers and practitioners can guarantee the quality of a DBR study (Anderson & Shattuck, 2012; Mckenney & Reeves, 2013). In this study, the researchers conducted a codesigning session at the beginning of the DBR process to develop an initial experimental design. Furthermore, collaboration with the educational practitioners and teachers in the target primary schools was crucial for designing and implementing the experiments and, in turn, for the design of the pedagogical model. In 2023, the pedagogical model was discussed in depth by the researchers. The refined pedagogical model is presented in this dissertation, and the future development of digital game-based learning in primary education is discussed.

In the DBR process, theories on teaching and learning needs should be used to confirm existing practical problems and ensure the value of the research (Collins et al., 2004; Design-Based Research Collective, 2003). The ensuing interventions must then embody particular theoretical perspectives of teaching and learning, which can contribute to understanding "the relationships among theory, designed artifacts, and practice" (Design-Based Research Collective, 2003, p. 6). Wang and Hannafin (2005) stated that the theory-driven nature of DBR plays a critical role in supporting the framework and design processes adopted, which further determine the theoretical development of design and innovation in education. In this research, the three studies were grounded in specific theoretical frameworks, including scaffolding, collaboration, and engagement, which supported tasks that ranged from determining the main theoretical goals to selecting the data collection and analysis methods and designing the instruments and artifacts.

DBR is linked to flexible research designs and many data collection and analysis methods that are widely used in qualitative or quantitative research (Anderson & Shattuck, 2012; Barab & Squire, 2004; Zheng, 2015). Wang and Hannafin (2005) indicated that using a combination of methods and collecting data from numerous resources can help increase the reliability, validity, and adaptability of research. Therefore, it was determined that the DBR approach would aid the effective integration of digital games into teaching and learning in educational contexts and in answering the research questions, thereby increasing the quality of the present study. Data for this study were collected using classroom observations and interviews as the qualitative methods, pre- and post-surveys as the quantitative methods, and an SLR.

According to Wang and Hannafin (2005), DBR requires research results to be connected to the design process and the research setting; therefore, the design needs to be optimized based on the setting and the participants' concerns. For the present study, the design experiments and their implementation in primary mathematics classrooms provided a preliminary basis for the design of the pedagogical model. The DBR approach was especially important because it emphasizes the development and refinement of theories using traditional methods and extends the application of the design to new settings (Barab & Squire, 2004; Collins et al., 2004; Wang & Hannafin, 2005). In the future, I will invite educational practitioners and classroom teachers as co-designers to implement and analyze the pedagogical model, which will enable me to systematically consider and modify different aspects of the design (Amiel & Reeves, 2008; Barab & Squire, 2004; Collins et al., 2004), improve the instructional design, and identify new design feasibilities (Amiel & Reeves, 2008; Wang & Hannafin, 2005). This will enable the use of the pedagogical model in creating an innovative learning environment for primary mathematics education.

3.1.1 Case Study

During the DBR process, the case study approach was used to investigate and elucidate digital game-based learning and develop a pedagogical model. The case study served as the methodological approach for data collection, with the aim of understanding digital game-based teaching and learning process in mathematics classrooms. As noted above, the DBR approach was utilized for the development of the pedagogical model, along with the case study and SLR approaches to understand digital game-based learning in primary mathematics education.

Case studies generally utilize many types of data collection and analysis methods that connect subjective and objective data during DBR iterations (Cohen et al., 2007; Wang & Hannafin, 2005). Case studies can be used to increase the validity and applicability of an ongoing DBR (Wang & Hannafin, 2005). They can be used to measure instructional design and practical implementations as well as to understand the learning process during classroom experiments. These two approaches are also supplementary, with both involving studying real people in real-life contexts using multiple instruments that can enable researchers to understand ideas clearly. Although the DBR approach is generally linked to educational research, case studies are utilized in various fields, including the social sciences, medicine, business, and law (Barab & Squire, 2004; Cohen et al., 2007; Johnson & Christensen, 2014).

Case studies constitute a specific type of research approach, and the idea of studying cases has existed for a long time (Johnson & Christensen, 2014). In general, a case study can be used to examine a single case in detail within a bounded system (Flyvbjerg, 2006; Johnson & Christensen, 2014). According to Yin (2009), a case study is "an empirical inquiry that investigates a contemporary phenomenon in depth and within its real-life context, especially when the boundaries between [the] phenomenon and [the] context are not clearly evident" (p. 18). The case study approach is especially valuable because researchers are not required to control behavioral events and can focus on contemporary events to answer how and why questions (Cohen et al., 2007; Yin, 2009). Data for the present study were collected from two case studies (Study I and Study II) in primary schools in Beijing and Shanghai to understand students' opinions on learning with the use of digital games and the perspectives of students and teachers regarding how digital game-based learning can contribute to mathematics learning.

According to Cohen et al. (2007), case studies can give rise to theoretical statements that must be sustained with evidence. Therefore, various types of data from a range of sources of evidence, such as documents, interviews, observations, and questionnaires, are commonly used and managed in case studies (Flyvbjerg, 2006;

Nousiainen et al., 2018). Prior developments of theoretical perspectives also guide data collection and analysis in case studies (Yin, 2009). Accordingly, several learning theories and previous studies on game-based learning directed the qualitative and quantitative data collection and analysis in the two case studies considered for the present dissertation (Studies I and II). By describing, categorizing, elucidating, and explaining the research issues, I was able to determine unique, dynamic features that explained the current phenomenon and situation, which was the main objective of the case studies (Cohen et al., 2007; Yin, 2009).

There are three types of case studies: intrinsic, instrumental, and collective (Cohen et al., 2007). In the current research, both case studies were instrumental in nature. When designing the cases, I focused on how and why the chosen digital game operated and could be integrated into primary mathematics classrooms. Thus, examining the cases led to insights into digital game-based learning and formed the preliminary basis for the design of the pedagogical model (Cohen et al., 2007; Johnson & Christensen, 2014). Further details about the two case studies (Studies I and II) are presented in Section 3.2.

3.1.2 Systematic Literature Review

An SLR was conducted under the umbrella of DBR to investigate the research topic and obtain the requisite knowledge by synthesizing prior studies (Borrego et al., 2014). The case study approach was used to gather knowledge about game-based teaching and learning process in mathematics classrooms, and the results formed a preliminary basis for the design of the pedagogical model. Thereafter, the SLR approach facilitated an in-depth investigation of how teacher scaffolding occurs in the different stages of game-based learning and its correlated influence on students' learning in primary education. Borrego et al. (2014) stated that the SLR approach can be used to summarize, appraise, and mediate evidence by providing synthesized reviews on significant issues (Petticrew & Roberts, 2006). The SLR approach can thus contribute to the advancement of research topics by facilitating evidence-based activities (Cook et al., 1997; Egger & Smith, 2001; Horvath & Pewsner, 2004), objective assessments of past efforts, and the identification of new research directions (Borrego et al., 2014).

An SLR that utilizes a strict methodology in a documented and structured process results in a more reliable and valid conclusion than does a narrative literature review (Cook et al., 1997; Petticrew, 2001; Sawyer, 2017). An SLR is a secondary research method used in various disciplines, such as education and psychology, and in interdisciplinary fields such as engineering education (Borrego et al., 2014; Finfgeld-Connett, 2014; Palsa & Ruokamo, 2015). According to Borrego et al. (2014), the SLR approach has strong potential as a model and in seminal work because it involves discovering patterns and identifying, linking, and associating trends across multiple studies. The aim of an SLR is to search for previous studies from datasets and large-scale bodies of literature, gather relevant data, and analyze the results to maximally improve the accuracy of the conclusions (Cook et al., 1997; Petticrew, 2001). Notably, the use of clear inclusion criteria when conducting an SLR is viewed as an effective means of ensuring the accuracy of the conclusions and avoiding bias (Borrego et al., 2014; Horvath & Pewsner, 2004; Sun et al., 2018). In the present study, the SLR approach was used to gather research articles on the relevance of different teacher scaffolding strategies implemented in game-based learning in primary education as well as to analyze their correlative influence on students' learning (Sun et al., 2023). Two search strategies were utilized to obtain relevant and valid data. One strategy was to identify search terms that were close to the keywords of the current study. The other involved retrieving information from scientific databases that were chosen for their multidisciplinary range and their relevance to the research topic. Inclusion criteria were also used to choose appropriate and focused studies (Boelens et al., 2017; Horvath & Pewsner, 2004). In addition, the PRISMA guidelines were followed to ensure that the SLR was systematically conducted (Page et al., 2021).

A significant reason for conducting an SLR is to gather various researchers' ideas on the same topic and generate a strong picture that can be used to address the research questions (Boelens et al., 2017; Gough et al., 2012; Horvath & Pewsner, 2004). By mapping and assessing existing studies, researchers can identify the relationships between concepts and practice (Onwuegbuzie et al., 2010; Palsa & Ruokamo, 2015), formulate research questions, and further develop existing research designs and methods (Boelens et al., 2017; Cook & West, 2012; Horvath & Pewsner, 2004). In this study, I focused on how teachers scaffold students in game-based learning, analyzed different teacher scaffolding strategies used in teacher–student interactions during the orientation and gameplay stages, and gathered evidence of the influence of scaffolding strategies on primary students' education.

3.2 Data Collection and Analysis Across the Three Studies

The aim of this research was to explore the influence of game-based learning on teaching and learning in formal education as well as to design a pedagogical model for digital game use in primary mathematics education. The studies conducted as part of this research focused on various aspects of game-based learning in education. The aims of these studies influenced the methodology chosen. A large volume of data was obtained from these studies, specifically via a DBR, case studies, and an SLR. The data were mostly qualitative, but some were quantitative. The data obtained to answer the research questions included students' perspectives and classroom observations as well as data from previous studies. The data for the two case studies (Study I and II) consisted of first-hand data, and the data for the SLR (Study III) came from datasets and large-scale literature. All data were primary in nature. Table 5 presents a summary of the data collection and analysis methods for the three studies.

Table 5
Data Collection and Analysis Methods

Study	Research situation	Role of the researcher	Data collection	Data	Data analysis method
Study I	Students played the digital game individually, while teachers provided scaffolding.	The researcher observed the classroom sessions, wrote field notes, and acted as an interviewer.	Data were collected from after-school mathematics activities in three primary schools.	Field notes: students (n = 141); teachers (n = 4) Transcription of individual interviews: students (n = 25)	Qualitative content analysis
Study II	Students used the digital game in pairs, while the teacher provided brief instructions.	The researcher acted as an interviewer.	Data were collected from regularly scheduled mathematics classes in one primary school.	Pre- and post-surveys: students (n = 45) Transcription of individual photo-elicitation interviews: students (n = 6) number of interviews (5- or 6-day interviews)	Quantitative analysis using SPSS software: reliability analysis (Cronbach's alpha), independent samples t-test (mean, standard deviation, correlation, two-tailed p-value) Qualitative content analysis
Study III	The researcher identified search terms and scientific databases for information retrieval.	The researcher acted as a reviewer.	Six scientific databases were searched for relevant research articles, in line with PRISMA guidelines.	International peer-reviewed research articles (n = 24)	Qualitative content analysis

3.2.1 Data Collection and Analysis Process: Study I

Two case studies (Studies I and II) were conducted to collect data on digital game-based learning in primary mathematics classrooms. During the study periods, data were collected through multiple avenues, which is typical for the DBR and case study approaches (Collins et al., 2004).

Study I was conducted in autumn 2018 and involved five classes at three primary schools in Beijing (see Sun, Ruokamo et al., 2021). The purpose of this study was to explore teacher scaffolding approaches in digital game-based learning and students' perceptions of learning when scaffolding was provided in mathematics classrooms.

Permission to conduct the research was granted by the three primary schools. The participants included 141 students (boys: $n = 77$, girls: $n = 64$; Grade 4: $n = 100$, Grade 5: $n = 41$) and four female teachers. The participants' ages ranged from nine to 11 years. All students had experienced mathematics learning through games (e.g., playing cards) at school, but their learning experiences before the study did not extend to digital games. The participant teachers were Chinese mathematics teachers, none of whom had prior experience using digital games. Therefore, teacher training on digital game-based learning was provided before and during the study. The training content before the study involved pedagogical activities for teachers, the definition and process of scaffolding, scaffolding in the various phases of digital game-based learning, and the use of the digital game Wuzzit Trouble. During the study, teachers were trained in establishing practical scaffolding strategies based on the problems observed in digital game-based learning classrooms. The first teacher training session was carried out face to face and lasted about two hours, while the second was carried out online and lasted about one hour.

The data were collected via classroom observations and interviews with the participants during after-school activities over 10 school days. Each school organized an after-school activity and provided tablets so that the participating students and teachers could play Wuzzit Trouble in the classroom. The activity lasted around 25 minutes each day. The time of the after-school activity differed for each class, so I was able to observe all five classes and collect observational data over the 10 school days. During the observations, I took field notes on the teachers' scaffolding strategies in the orientation phase, which included introducing background information, describing the gaming process, and familiarizing the students with the game and learning goals, and the gameplay phase, which involved dialogic interactions, in-time instruction, adaptive support, and encouragement. The observational data consisted of 4247 words.

During the after-school activities, I conducted interviews with the participating students. Interviewee selection was based on the ability to reflect on the topics, while considering the age of the respondents. A total of 25 students were selected by their mathematics teachers, who were familiar with their students, to participate in the personal thematic interviews. Each interview lasted 4–6 minutes and was conducted in an empty classroom. The interview questions were thematic in nature and had been determined in advance. The themes that arose in the interviews were related to the role of the teacher, the teacher scaffolding provided during the game-based learning process, and assessments of teacher scaffolding in mathematics learning. The interviews included questions such as "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?" and "Do you think that teacher scaffolding is helpful for you to learn mathematics? If yes, why? If no, why?" I encouraged the students to present their personal perspectives freely and to provide examples with their answers. All interviews were recorded, totaling around 100 minutes.

The data were collected in Chinese, the analysis was conducted in Chinese, and excerpts of 195 student answers were translated for the original publication. Qualitative content analysis of the thematic interviews and classroom observations was then performed (Mayring, 2014). The unit of analysis of the thematic interviews was an utterance that in some ways reflected the research questions (Cohen et al., 2007; Johnson & Christensen, 2014). The interview data were analyzed in three stages. In the first stage, the dataset was transcribed using a web application, and the data were consolidated and organized. In the second stage, the data were reviewed several times, and all responses that revealed the students' perspectives and opinions were identified but not differentiated. Following this, 100 quotations that could be viewed as descriptions of or reflections on teacher scaffolding in the digital game-based learning environment were highlighted. Encoding is a crucial characteristic of qualitative analysis, and it can help researchers identify similar information in textual data (Cohen et al., 2007). Accordingly, in the third stage, the quotations were assigned to content categories, which were determined using an open coding process. The first cycle of this stage produced 18 subcategories, which were sorted into two main categories. The subcategories were then reviewed, with further integration based on the pre-planned themes. The final classification consisted of two categories and 10 subcategories.

To analyze the classroom observations, I took down field notes on key classroom events, such as scaffolding moments, which described the scaffolding strategies used by the teachers and the interactional situations that occurred in the digital game-based learning classrooms. These scaffolding moments were encoded, sorted based on the learning phases (orientation and/or gameplay) in which they had occurred, and used to support the findings of the thematic interviews.

3.2.2 Data Collection and Analysis Process: Study II

The second case study was conducted in a primary school in Shanghai in the spring term of 2019. Its purpose was to provide an in-depth understanding of the effects of collaborative digital gameplay on students' behavioral, emotional, and cognitive engagement in mathematics (see Sun et al., 2022). The participants were 45 second graders consisting of 19 girls and 26 boys aged 8–9 years from a single class. The participant selection was based on the participating school's assessment that the level of the digital game used in the study was suitable for second graders. Furthermore, the participants' class was the only second-grade class that had used tablets for daily teaching and learning. Permission to conduct the research was granted by the primary school in question, and an official letter of consent was obtained. The students participated in the study during their regularly scheduled mathematics class periods, and all joined the six-day classroom experiments. During the study, the students were divided into pairs, with each pair working with one tablet to access the digital game. The students had no digital gameplay learning experience in the primary school before participating in the study.

Study II followed a mixed-methods research design that combined qualitative components with the quantitative research method (Johnson & Christensen, 2014). The quantitative data were obtained from a survey on mathematical engagement, while the qualitative data were collected through photo-elicitation interviews. A mathematics engagement survey (Chang et al., 2016) applied in previous studies was used to measure overall mathematical engagement and the three dimensions of engagement—behavioral, emotional, and cognitive (e.g., Chang et al., 2016). The mathematical engagement survey included 33 items, with 11 for each dimension of engagement. A four-point Likert scale (1 = strongly disagree, 2 = somewhat disagree, 3 = somewhat agree, and 4 = strongly agree) was used for all items. However, some items from the original survey were adapted to 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 sent to the mathematics teacher for review to ensure that the second graders would find it easily understandable.

The revised and translated survey was pilot tested with 206 second graders, excepting the class that took part in the experiment. The data were then analyzed to check the reliability of the statistics of the survey. This pilot test was mentioned in the research. Two items regarding behavioral engagement were omitted from the final version of the engagement survey. Therefore, an engagement survey that included 31 items was used in the experiment, including nine items for the behavioral dimension (e.g., "I participate in discussion in the mathematics class"), 11 items for emotional dimension (e.g., "I am interested in learning new things in mathematics"), and 11 items for cognitive dimension (e.g. "Sometimes, I follow my best guess when I do not know the answer").

Before the classroom experiment, quantitative data were collected in a computer room at the primary school. The mathematics teacher and I instructed the students on how to fill out the survey and provided help as needed. It took about 20 minutes for the students to fill out the pretest survey, and all 45 students participated in it. At the end of the six-day classroom experiment, in the computer room, the same engagement survey was distributed to and filled out by the students. This took about 20 minutes, and 43 students participated in the posttest engagement survey, while two students were absent because they were unwell.

Photo-elicitation interviews were conducted daily after the classroom experiment. I translated the Multisource Assessment of Social Competence Scale (Junttila et al., 2006) and asked the mathematics teacher, who was familiar with every student in the experimental class, to select the interviewees. Based on the daily ratings of the students' social competence levels in school, three groups (five boys and one girl in total) with high social competence were selected as the interviewees. Although social competence was not the focus of this study, this selection decision was made because of the second graders' young ages—those with high social communication skills could express their perspectives more effectively than their class peers. Each interview lasted 5–7 minutes and was conducted in a reading room at the primary school. Each student was asked the same six questions related to their learning experience during collaborative digital gameplay, which were based on the development of behavioral (e.g., "What were you doing with your partner in the situation?"), emotional (e.g., "Did you enjoy learning mathematics with your partner today? If yes, why did you enjoy learning with your partner? If no, why didn't you enjoy learning with your partner?"), and cognitive (e.g., "How did you solve the mathematics problems with your partner today?") engagement. On each experimental day, I stayed in the classroom and took photographs for the interviews. The students answered the same questions based on these photographs and were encouraged to express themselves freely. Two groups, one with two boys and the other with one boy and one girl, participated in all six days of interviews, while a third group, with two boys, participated in only five interviews, since they had left early one day.

Following the data collection, the survey data were analyzed using SPSS version 24 for Windows. Cronbach's alpha coefficient was used to measure the internal consistency of the items in the pre- and posttests. Furthermore, independent samples t-tests and two-tailed p-values were used to examine the possible differences between the post- and pretests. The means and standard deviations were determined for each dimension of engagement in the post- and pretests, since they could provide relevant information about the impact of collaborative digital gameplay learning experiences on the three dimensions of student engagement in mathematics.

A qualitative content analysis of the photo-elicitation interview data was performed to gain insights into the student interviewees' experiences in the classroom experiments. After transcribing the interviews, I scrutinized the content based on the theoretical background and preplanned factors. The analysis was an iterative procedure that involved the following phases: (a) reading the students' answers; (b) reading the data a second time and selecting descriptions relevant to the research questions from the datasets for initial encoding; (c) labeling the selected descriptions based on measurements of the three dimensions of engagement (Fredricks et al., 2004) for a second round of encoding; (d) classifying similar kinds of labels into the same categories; and (e) compiling and organizing all labels and categories into one table. The analysis procedure was naturally inductive, and the inference process was consistent with the empirical dataset.

3.2.3 Data Collection and Analysis Process: Study III

An SLR was used as the data collection method in the third study because the aim was to gather research papers on the relevance of teachers' scaffolding strategies in teacher–student interactions and game-based learning in primary education. This approach enabled me to analyze and identify the influences of teacher scaffolding on primary students' learning.

Two search strategies were used to identify research papers related to the research topic. First, scaffolding ("digital game" OR "video game" OR "serious game" OR "mobile game" OR "educational game" OR "learning game" OR "game-based learning") ("primary education" OR "primary school students") were chosen as search terms based on previous searches (Hainey et al., 2016; Kangas et al., 2017; Ke, 2016; Perttula et al., 2017). The second strategy involved searching the following electronic scientific databases based on multidisciplinary range, accessibility, and relevance to the theme: ScienceDirect (Elsevier); Web of Science; SpingerLink; EBSCO (Academic Search Elite, Eric-Education); Eric-Education Collection (ProQuest); and Scopus.

It is important to provide clear inclusion and exclusion criteria when conducting an SLR to ensure the accuracy of the conclusions and avoid bias (Borrego et al., 2014; Horvath & Pewsner, 2004). In the present study, the PRISMA framework (Page et al., 2021) was deployed to select relevant papers. This procedure was split into four phases—namely, identification, screening, eligibility, and inclusion. The selection criteria for each phase can be found in the published article for Study III (Sun et al., 2023).

The search terms led to the retrieval of 842 research papers from six electronic scientific databases. An initial screening of these papers was performed by reviewing the titles and abstracts based on the inclusion criteria, identifying 157 research papers. Of these, 19 were found to be duplicates upon synthetically examining the screening results. Next, I assessed the eligibility of the 138 shortlisted full-text articles by reading the full papers and selecting those that aligned with the inclusion criteria. A total of 53 papers meeting the selection criteria were considered for final extraction. In the final phase, the quality of each paper (n = 53) was assessed based on the research questions. Finally, 24 papers that addressed both research questions were included and used for coding and analysis in the final literature synthesis.

Qualitative content analysis was subsequently used for the synthesis of the chosen research papers. Qualitative content analysis enables the synthesis of meaning and the discovery of specific content from written documents, transcripts, and visual or audio media (Borrego et al., 2014; Seuring & Gold, 2012). It is a flexible method that allows researchers to make decisions grounded on the research questions and data (Borrego et al., 2014; Mayring, 2000). The use of qualitative content analysis in an SLR requires researchers to have a clear purpose and essential principles so that the analysis can guide all the decisions to accommodate the methodology (Borrego et al., 2014; Mayring, 2000; Seuring & Gold, 2012). Generally, this method of analysis involves reading the entire textual data several times, creating coding categories and categorizing the data, and reporting frequencies (Borrego et al., 2014) as well as comparing theory and data to find similarities and differences (Mayring, 2000). Qualitative content analysis was deemed a suitable tool for exploring different scaffolding strategies implemented in teacher–student interactions during game-based learning and their correlative influence on students' learning.

Based on the research questions, the analysis focused on the different scaffolding strategies implemented at different stages of game-based learning and their influence on students' learning in primary education. Analyzing the retrieved research papers involved four phases. In the first phase, information was extracted from the selected studies and evaluated, and then a coding table was created to document the information (Kangas et al., 2017; Randolph, 2009). The information was categorized as basic or scaffolding information and then coded into two tables. In the second phase, the codes were organized and labeled according to relevant areas of importance to construct descriptive themes (Perttula et al., 2017). In the third phase, studies with similar types of labels were grouped into the same categories to develop the themes. In the fourth phase, analytical themes were constructed in more detail. By distinguishing and classifying the themes, the scaffolding strategies used in teacher–student interactions and the associated students' level of attainment (SLA) were separately categorized into one table, while those related to the influence of teacher scaffolding on primary school students' learning were organized into another. In addition, Cramer's V was adopted to measure how strongly the scaffolding strategies used in game-based learning influenced the primary school students' learning.

4 OVERVIEW AND EVALUATION OF THE STUDIES

In the present study, I explore how digital game-based learning can be harnessed for education, investigate the theoretical and pedagogical approaches in primary educational contexts, and design a pedagogical model for digital game-based learning in primary mathematics education. This chapter provides both an overview and evaluation of the main findings of each study (Studies I–III) conducted during my research and learning process.

4.1 Study I: Students' Perceptions of Teacher Scaffolding in Digital Game-Based Learning

Sun, L., Ruokamo, H., Siklander, P., Li, B., & Devlin, K. (2021). Primary school students' perceptions of scaffolding in digital game-based learning in mathematics. *Learning, Culture and Social Interaction, 28*.

4.1.1 Overview

This study represented the first step taken to understand the prerequisites for designing a pedagogical model for digital game-based learning in primary mathematics education. The specific research questions of Study I were as follows: How do students perceive mathematics learning scaffolded by teachers in digital game-based learning classrooms? How does teacher scaffolding in digital games affect students' perceptions of mathematics learning?

Qualitative content analysis of the student interviewees' descriptions and reflections resulted in two categories and 10 subcategories of responses. The first category concerned the use of teacher scaffolding strategies and processes and consisted of seven subcategories. The second category was for reflections on teacher scaffolding and included three subcategories. The subcategories for the teacher scaffolding strategies and processes were as follows: problem demonstration, solutions shared by the students, solving the steps presented by the teachers, asking to think first, guidance to analyze the problems, offering hints, and a summary of methods and strategies. Considering the scaffolding strategies addressed in previous research (Chen & Law, 2016; Makar et al., 2015; Muhonen et al., 2016; Van de Pol et al., 2010), four subcategories (subcategories 1, 2, 3, and 7) were classified as whole-class scaffolding strategies and the other four (subcategories 4, 5, 6, and 7) as one-to-one scaffolding strategies.

Whole-class scaffolding occurred in the orientation phase and the first few days of the gameplay phase. The findings showed that teacher scaffolding in the orientation phase helped arouse the students' interest in digital games, particularly in practicing and solving integer arithmetic problems, and ensured that the classroom atmosphere was lively and active. Teacher scaffolding in the gameplay phase was found to bridge students' current level of experience and conceptual understanding, which was beneficial for identifying students' learning needs in a clear manner, and familiarizing them with the gaming process and problem-solving methods. It was also observed that the teachers' classroom management strategies, such as clapping hands and asking students to lock their tablet screens, played a critical role in whole-class scaffolding.

One-to-one scaffolding occurred during the gameplay phase when individual students were unable to solve the problem independently. The teachers did not provide direct answers but instead provided adaptive instruction and guidance by identifying the students' current levels of understanding through dialogic interactions. The findings also showed that the teachers' hints and summaries of problem-solving methods, which concerned individual student performance, triggered the students' interest and encouraged them to explore solutions independently.

An analysis of the students' perceptions of mathematics learning revealed three subcategories of reflections on teacher scaffolding: development of arithmetic skills, activation of interest in mathematics, and encouragement to explore. The student interviews revealed that the teachers' adaptive support and interventions helped the students connect subject knowledge with the knowledge gained through the digital game, thereby increasing their mathematical thinking skills and understanding of the content. Furthermore, the findings showed that teacher scaffolding led to an increase in the students' interest in mathematics and willingness to learn, while encouragement from the teachers influenced the students' emotions, resulting in their critical thinking and exploration of integer arithmetic problems.

In sum, this study showed that teacher scaffolding played a significant role in digital game-based learning in primary mathematics education. I used two classifications—whole-class and one-to-one scaffolding—to distinguish the different teacher scaffolding strategies used in digital game-based learning environment. Whole-class scaffolding strategies involved the teachers playing the role of a leader (Muhonen et al., 2016), which was critical for the students to start practicing and solving problems with digital games. One-to-one scaffolding concerned individual students' performance during gameplay, with the teachers serving as tutors and guides to support and instruct individual students through interactive dialogue (Kangas et al., 2017; Nousiainen et al., 2018; Watson et al., 2011). The findings of this study suggested that integrating the two types of teacher scaffolding strategies in different phases of the digital game-based learning process could accelerate students' learning and improve their perceptions of mathematics learning in primary education.

4.1.2 Evaluation

One of the strengths of the study was that it generated insights into teacher scaffolding in a digital game-based learning environment. In this study, 25 students were interviewed at the end of the experiment. The purpose of the thematic interviews was to determine the students' perceptions of teacher scaffolding and mathematics learning in the digital game-based learning classroom. I chose this method to be able to connect with the observational data collected in the classroom. The thematic interviews allowed me to explain what I wanted to impart to the students, maintain a relaxed atmosphere to increase interactions with them, and encourage them to speak freely.

Classroom observations are generally used in educational research. In this study, observational data were collected from five classes over 10 school days, and key classroom events, such as scaffolding moments, were noted. The purpose of the classroom observations was to identify the types of teacher scaffolding strategies and interactional situations that arose in digital game-based learning environment. Based on the classroom observations, scaffolding moments were identified and used to support the interview findings. The large amount of data obtained from the interviews and classroom observations was characteristic of DBR and the case study approach (Collins et al., 2004).

Another strength of this study was the use of multiple ways to conduct DBR (Barab & Squire, 2004; Wang & Hannafin, 2005). I started the DBR cycle by developing a theoretical design before meeting with the participating schools. Since the researcher's participation and engagement in design sessions play an important role in DBR (Barab & Squire, 2004; Wang & Hannafin, 2005), I actively participated in the discussions and experiments as a designer, researcher, and motivator. Although this participation did not completely fulfill the requirements of DBR, it helped uncover important information on digital game-based learning in primary education.

One weakness of the study was that the teachers only played a minor role in implementing the experiment, compared to my own involvement. Unlike in general DBR, the teachers did not influence the design of this experiment; they only participated in it. Another weakness of the study had to do with the analysis of classroom observations. The research focused on capturing teacher scaffolding experiences in digital game-based learning in primary mathematics. Although the scaffolding moments that emerged from the key classroom events were helpful for understanding the scaffolding strategies the teachers used in such a learning environment, there were matters that needed further exploration, such as a systematic comparison of the variation of teachers' behavior and students' interpretations. Therefore, in future studies, it will be necessary to analyze different types of collected data in more detail so as to strengthen the research results.

The findings of this study have important implications for teachers and teacher education in digital game-based learning. First, they indicate that scaffolding strategies can be summarized and listed based on students' perceptions of digital game-based learning. Furthermore, teachers can design and develop a variety of ways to integrate scaffolding into digital game-based learning environment for other subjects in school education. Further research is needed to explore the ways in which teachers' competencies can be developed alongside the integration of digital games into their daily teaching experiences.

Overall, Study I resulted in the identification of two types of teacher scaffolding strategies—whole-class and one-to-one scaffolding—in different phases of the digital game-based learning process. The study showed that the use of teacher scaffolding influenced students' knowledge learning, arithmetic skills, and interest development in mathematics. These findings are valuable for researchers and teachers who wish to explore additional scaffolding approaches and determine which scaffolding features facilitate learning with digital games. As the starting point for research and development, this study stimulated my curiosity about students' collaboration in digital game-based learning, which I considered in the following study (Study II). Further, the findings of this study piqued my interest in the teacher scaffolding strategies used in game-based learning in primary education (Study III). I assumed that the studies would complement each other and deepen my perceptions of digital game-based learning environment for primary students.

4.2 Study II: Exploring the Three Dimensions of Student Engagement in Collaborative Digital Gameplay

Sun, L., Ruokamo, H., Kangas, M., & Siklander, P. (2022). Effects of collaborative digital gameplay on students' three dimensions of engagement in mathematics. *International Journal of Game-Based Learning*, *12*(1).

4.2.1 Overview

The purpose of Study II was to explore students' behavioral, emotional, and cognitive engagement from the perspective of collaborative digital gameplay. Accordingly, the following research questions were examined: How does students' engagement in mathematics manifest in collaborative digital gameplay? What factors have an impact on students' three-dimensional engagement in a collaborative digital gameplay classroom?

The quantitative data were analyzed using an independent samples *t*-test (paired samples *t*-test) and a reliability analysis (Cronbach's alpha). The Cronbach's alpha of three-dimensional engagement was higher in the posttest than in the pretest, which indicated the high internal consistency of the posttest and that the variables could be used to describe students' three-dimensional engagement. However, the independent samples *t*-test showed that the difference between the posttest and pretest was not statistically significant, which meant that the six-day collaborative digital gameplay learning experiment did not elicit a significant increase in the students' three-dimensional engagement in mathematics.

A possible explanation for this is that the six-day experiment period was not long enough to assess changes in the students' levels of engagement. Moreover, the 31 items in the engagement survey were challenging for second graders to complete, as it was difficult for them to effectively express their gameplay learning experiences. To determine and compare the development of engagement practices among lower primary students, I would have needed to collect data that reflected the changes in the students. In future studies, extending the length of the experiment and carefully considering the age of the participants will help strengthen the results. In the present study, the daily photo-elicitation interview was integrated concurrently and was the source of the dominant dataset, which compensated for the identified limitation.

Based on the factors categorized and addressed in previous research (Fredricks et al., 2004) and on the analysis of the student interviews, the following four factors associated with the students' three-dimensional engagement during collaborative digital gameplay were identified: learning achievement, teacher support, peer collaboration, and task characteristics.

The findings of the interviews revealed a positive link between *learning achievement* and emotional and cognitive engagement. The students interviewed reported positive emotions and that mastery strategies motivated them to solve challenging problems during the game. The results of the interviews also showed that *teacher support* affected the students' behavioral and cognitive engagement. The students claimed that the teachers' involvement encouraged them to engage in active discussions with their peers and persist with difficult puzzles. Notably, *peer collaboration* affected students' three-dimensional engagement levels. According to the students, working with peers made them increase their efforts and use various strategies to solve the problems and experience enjoyment. *Task characteristics* were also positively linked with the students' three-dimensional engagement. The students revealed that the digital game activated their interest, resulting in their efforts to explore and flexibly utilize relevant knowledge and strategies.

Thus, this study yielded empirical evidence showing how the use of collaborative digital gameplay in a mathematics classroom impacted the students' behavioral, emotional, and cognitive engagement. The findings of the qualitative results revealed close associations between the four factors and three dimensions of engagement. In addition, the classroom context, which involved teacher support, peer collaboration, and specific task characteristics, was linked to the students' three-dimensional engagement in mathematics learning.

4.2.2 Evaluation

This study had several strengths as well as weaknesses. One clear strength was that the pedagogical design and teaching arrangement were planned and implemented in collaboration with mathematics teachers and coordinators. Therefore, the six-day experiment went smoothly, and no changes or problems were encountered. This collaboration in the research process enabled me to collect data from multiple sources, thereby increasing the validity and reliability of the research (Design-Based Research Collective, 2003). The experiment complied with the principles of DBR (Barab & Squire, 2004; Wang & Hannafin, 2005).

Another strength was the use of the photo-elicitation interview method. Since the students were young, the use of photographs during the interviews created a relaxed atmosphere that facilitated smooth communication (Bignante, 2010). The interviews followed each day's classroom experiment, and the students were required to answer the same questions based on the photograph I produced. The aim of the photo-elicitation interviews was to investigate the development of student engagement and determine the factors that affected engagement during collaborative digital gameplay. The photo-elicitation interviews enabled the students to draw on their daily experiences in the classroom, associate meaning and understanding in the discussion of the photographs, and offer different insights into the research (Harper, 2002).

This study also had some weaknesses. Specifically, I observed that certain situations were in need of improvement during the research process. The teacher should have used different tasks with varying gameplay elements to attract the students' attention and motivate them to solve problems. However, I could not proceed with redesigning the learning tasks with the mathematics teacher due to time limitations. In this respect, the experiment did not adequately abide by the principles of DBR.

Another weakness was the size of the study—only 45 students played the digital game and participated in the experiment. Large sample sizes are needed to attain a high quality of research, particularly for studies employing a quantitative method. This problem was addressed by using various types of data collection methods and collecting data in different locations. It is important to note that although the number of participants in the study was low, the participants' class was the only second-grade class that used tablets for daily teaching and learning. Therefore, the students conducted themselves as usual, with no improvements or modifications in their behaviors because of the classroom experiment.

The goal of this study was to obtain an in-depth understanding of students' behavioral, emotional, and cognitive engagement in primary mathematics via collaborative digital gameplay. The results had many implications for the development of the pedagogical model. As pointed out, digital gameplay and collaboration can be combined effectively in primary school learning environment, and young students may benefit from playing digital games and from collaborative learning with peers. In the future, I will identify further factors that significantly affect the three dimensions of student engagement. In addition, since the study findings revealed that both peer collaboration and digital gameplay are closely associated with students' three-dimensional engagement in mathematics, there is a need to research and develop different classroom contexts, using digital games and collaboration in other subject areas to improve the three dimensions of student engagement and satisfy various student needs and demands. The findings of Studies I and II provided a preliminary basis for the design of a pedagogical model for digital game-based learning, which was then improved by Study III.

4.3 Study III: Different Teacher Scaffolding Strategies in Game-Based Learning and their Correlative Influence on Students' Learning

Sun, L., Kangas, M., Ruokamo, H., & Siklander, S. (2023). A systematic literature review of teacher scaffolding in game-based learning in primary education. *Educational Research Review*, *40*.

4.3.1 Overview

The aim of this study was to provide an overview of the current state of scaffolding strategies implemented in teacher–student interactions within game-based learning in primary education and the influence of teacher scaffolding on primary students' learning. With this in mind, the SLR method was used for the study, focusing on recent international peer-reviewed research (from 2011 to the end of March 2022).

The analysis of the papers included revealed that teachers use various scaffolding strategies in teacher–student interactions. These strategies were then distinguished based on the stage of learning—orientation or gameplay. The findings showed that introduction is the most commonly used scaffolding strategy in the orientation stage. Introductions are generally carried out with the whole class and aimed at familiarizing students with the game to be played and establishing the learning goals. Many studies showed that assistance and reviews are also provided during the orientation stage of game-based learning. Teachers' assistance, such as technical help and instructions for the game, can facilitate students' understanding of related content during learning sessions (Hooshyar et al., 2021). Meanwhile, a quick review of what was learned in previous sessions allows teachers to share new knowledge before gameplay.

Scaffolding strategies such as guidance, encouragement, feedback, and intervention were found to be heavily implemented during the gameplay stage. The study showed teacher-directed prompts, modeling, explicit instructions, and teacher-led discussions to be the most frequently used guidance strategies. Teachers provide encouragement with the aim of ensuring that students concentrate on learning activities and persist in their tasks. Notably, just-in-time feedback was found to be one of the central components of scaffolding and the most frequently used strategy in the gameplay stage. In addition, evidence showed intervention, including triggering interactions, time management, and classroom organization, to be a scaffolding strategy that teachers frequently implement during the gameplay stage.

The findings showed that the different scaffolding strategies used in teacher–student interactions for game-based learning can improve SLA. Introduction, one used in the orientation stage, can help develop a student's level of attainment from SLA 1 to SLA 3. This is probably because the aim of the orientation stage in game-based learning is to provide students with sufficient knowledge about the game. In addition, the two scaffolding strategies used in the gameplay stage—guidance and feedback—can help develop students' level of attainment from SLA 4 to SLA 5. Asking relevant questions during gameplay and observing students' gameplay are common approaches used by teachers to diagnose students' current understanding.

The influence of teacher scaffolding on students' learning in the orientation stage was distinguished and classified into three categories: familiarization with the game, familiarization with the learning activity, and reflection on prior knowledge. The results indicated a strong association between scaffolding strategies in the orientation stage and students' game-based learning. Further, the study showed that teachers' introductions can help students become familiar with the game, gaming process, and learning activity being conducted, thereby ensuring that students possess proper knowledge of the gameplay process and attain the expected learning results. Meanwhile, there was evidence showing that scaffolding provided during the orientation stage can help students review and reflect upon their prior knowledge.

I identified and classified the following five areas in which teacher scaffolding influences students' learning in the gameplay stage: knowledge acquisition, knowledge connection, engagement, skills development, and enjoyment. The results showed that scaffolding strategies in the gameplay stage and students' learning are moderately associated. Some of the studies included in the review showed that scaffolding strategies (e.g., guidance) can help students obtain and consolidate their subject knowledge and improve their engagement, whereas other studies emphasized the negative influence of such strategies (e.g., teacher-led discussions) on students' knowledge acquisition. Nevertheless, the SLR provided evidence that teachers' guidance during the gameplay stage can help students connect subject knowledge with in-game activities.

Engagement was found to have the greatest influence on students' learning. Eleven of the included studies reported that scaffolding strategies, including directed prompts, intervention, and encouragement, positively influence students' learning, while two stated that teacher scaffolding has a negative influence on students' engagement when playing games. Moreover, teacher scaffolding strategies for skills development, which includes problem-solving, collaborative, and social skills, were found to be highly relevant in the gameplay stage. The study showed that guidance and intervention strategies have both positive and negative effects on students' problem-solving and collaboration skills and that guidance has a positive effect on students' social skills. In addition, enjoyment was found to have the least significant influence on students' learning. The results of the study showed that guidance and encouragement from teachers in the gameplay stage can motivate students' interest in the subject and the game-based learning experience.

This study inspired my investigation of different teacher scaffolding strategies in game-based learning environment in primary education. The research results confirmed and supported previous findings, indicating that it is feasible to use teacher scaffolding in the orientation and gameplay stages of game-based learning. However, further research is recommended on the use of different scaffolding strategies to teach primary students via game-based learning (Kangas et al., 2017; Sun, Chen, et al., 2021).

4.3.2 Evaluation

The clear strength of the study was the use of the SLR approach to search for and analyze large databases. As an appropriate way to gather related research articles, the SLR made fundamental contributions to gaining insights into teacher scaffolding strategies implemented in game-based learning and their influence on students' learning in primary education. The strictly documented and structured SLR process led us to attain reliable and valid conclusions.

Furthermore, evidence from this study showed that teachers implement different scaffolding strategies in teacher–student interactions during the orientation and gameplay stages of game-based learning. This finding supports the argument that teachers play a significant role in the different stages of game-based learning (Hmelo-Silver & Barrows, 2006; Kangas et al., 2017; Laine et al., 2016; Muhonen et al., 2016; Sun et al., 2018; Watson et al., 2011). Furthermore, it emphasizes that a teacher's role is not only that of a facilitator but also a guide whose major task is to provide appropriately tailored support when students encounter difficulties (Hermkes et al., 2018; Kangas et al., 2017).

Another advantage of the study is that it yielded a rich understanding of the influence of teacher scaffolding on students' game-based learning in primary education. The findings showed that the scaffolding strategies that teachers implement in teacher–student interaction during the orientation stage can increase primary students' interest in the game and learning activities (Sun, Ruokamo, et al., 2021). Nevertheless, these scaffolding strategies may have both positive and negative effects on students' learning, potentially because of teachers breaking away from the three key characteristics of scaffolding as well as the purpose of game-based learning

(Sun et al., 2023). Therefore, the study supported the argument that, because of their age, primary students benefit from teachers closely intertwining the three key characteristics of scaffolding and dynamically generating scaffolding in game-based learning (Barzilai & Blau, 2014; Chen & Law, 2016; Haataja et al., 2019; Sun, Chen, et al., 2021; Sun, Ruokamo, et al., 2021; Van de Pol et al., 2010).

This study also had some weakness. One weakness was the selection of the papers for inclusion. In this study, we followed the PRISMA guidelines to ensure the literature search of the electronic scientific databases was conducted systematically (Page et al., 2021). However, because of there being a limited number of studies on the research topic, it was possible that papers that did not fully meet the inclusion criteria were included for review in this study. Therefore, in the future, the inclusion and exclusion criteria should be described in more detail. Furthermore, at least two researchers should read the content of each paper to determine the eligibility of the selected studies according to the inclusion and exclusion criteria.

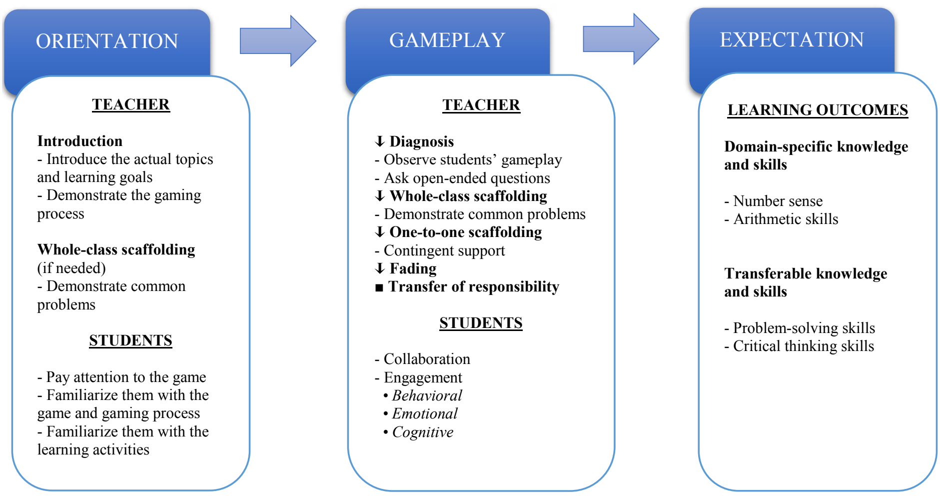
Another weakness of this study was that some of the included studies provided limited descriptions of teacher scaffolding strategies, particularly those used in the gameplay stage of game-based learning. Therefore, the themes in this study were developed based on the research questions, and the categories of teacher scaffolding strategies implemented in teacher–student interactions and their influence on primary students' game-based learning were systematically described. Nevertheless, there is a need for systematic longitudinal research on teacher scaffolding in game-based learning in the future.

This study had significant implications for future research on teacher scaffolding and aided in the development of a pedagogical model for digital game-based learning in primary mathematics education. It provided a valuable framework for supporting primary school students with appropriate scaffolding strategies in game-based learning. Furthermore, this study provided insights into utilizing the influences of teacher scaffolding on primary students' learning in game-based learning environment, such as finding a balance between scaffolding and students' individual learning when designing a game-based learning process. The research also contributed to the discussion on developing game-based learning pedagogy in teacher education and provided direction for future research. Based on the findings of this study, a pedagogical model was defined, developed, and subsequently improved. The refined version of the model is presented in the following chapter.

5 THE PEDAGOGICAL MODEL FOR DIGITAL GAME-BASED LEARNING IN MATHEMATICS

This chapter presents a pedagogical model that combines theoretical insights into teaching and learning in digital game-based learning classroom and the empirical studies conducted as part of this research. If we are to design digital game-based learning classroom, we need an appropriate pedagogical model. Accordingly, the one introduced herein differentiates the important phases and elements impacting students' gaming and mathematics learning experiences. Digital game-based teaching and learning process involve various phases, and the learning outcomes associated with the expectation phase are included in the pedagogical model. The elements of this model are based on the theories and findings of the empirical studies (Studies I–III), and the model has been designed for a specific context—the primary mathematics classroom. The pedagogical model is shown in Figure 5.

Figure 5
The Pedagogical Model for Digital Game-Based Learning in Mathematics



As shown in Figure 5, the elements of this pedagogical model include teachers' scaffolding approaches and students' learning activities, which are defined in the orientation and gameplay phases of the digital game-based learning process. The possible learning outcomes are included in the expectation phase of the model, consisting of domain-specific and transferable knowledge and skills. The relationships among the three phases are conditional, as indicated by the one-way arrows in the model (see Figure 5). Garris et al. (2002) emphasized that the integration of active learning experience and instructional support can "provide an effective learning environment" (p. 446). In the pedagogical model, the teacher performs the crucial role of deciding how the teaching and learning process will proceed, which then influences students' participation and involvement in digital game-based learning (Chen & Law, 2016; Haataja et al., 2019; Sun et al., 2018). Consequently, the relationships between the teacher and students in the orientation and gameplay phases direct students' learning outcomes in the expectation phase (Barzilai & Blau, 2014; Muhonen et al., 2016). The main phases and elements of the pedagogical model are discussed in the following sections.

5.1 Orientation

Digital game-based learning usually starts with the orientation phase, the purpose of which is to provide students with sufficient knowledge about digital games and help them focus on the goals of the digital game to be played (Chee & Tan, 2012; Kangas et al., 2017). In the pedagogical model, one of the scaffolding strategies, introduction, takes place in the orientation phase, with the teacher playing the roles of leader and motivator (Kangas et al., 2017; Sun, Ruokamo, et al., 2021; Sun et al., 2023).

In the orientation phase, introduction involves providing background information about the game to be played, demonstrating the gaming process, illustrating the goals of the game and the expected learning outcomes, and helping the students become familiar with the game (Studies I and III; see Sun, Ruokamo, et al., 2021; Sun et al., 2023). Belland et al. (2013) indicated that it is important to make students know and understand precisely what they will engage in as well as the expected results from the engagement when they learn through games.

Furthermore, whole-class scaffolding is also presented in the orientation phase. It should be noted that in this phase, whole-class scaffolding is provided only if needed. When the teacher finds it is challenging to familiarize the majority of students with the game and gaming process, whole-class scaffolding should be provided to the students. Otherwise, there is no need to provide whole-scaffolding scaffolding.

It is recommended that teachers consider the use of classroom management strategies in the orientation phase. The findings of Studies I and III (Sun, Ruokamo, et al., 2021; Sun et al., 2023) and previous studies indicated that classroom management strategies—for example, a pause in teaching, clapping hands, and interrupting play—can ensure students pay attention to the game and increase their engagement in gameplay activities (Hansen & Sanders, 2010; Sun, Chen, et al., 2021; Sun, Ruokamo, et al., 2021; Vélez-Agosto & Rivas-Vélez, 2018).

In the orientation phase, students gain interest in the digital game to be played, easily familiarize themselves with the gaming process and learning activities, and enjoy practicing and solving puzzles. In this pedagogical model, introduction (and whole-class scaffolding) in the orientation phase enables the creation of an active and lively digital game-based learning classroom, which is necessary for students to begin practicing and solving arithmetic problems with digital games. The teacher can also check the progress of each student and identify the mathematical problems that they find difficult (Ketamo et al., 2013; Sun, Ruokamo, et al., 2021).

5.2 Gameplay

During the gameplay phase, the teacher's role is that of a tutor and guide who supports and instructs students in their mathematics learning. Meanwhile, students collaborate with their peers and explore solutions to arithmetic problems using their conceptual knowledge. The following sections present the teacher scaffolding approaches and student learning activities that take place in the gameplay phase.

5.2.1 Teacher Scaffolding

During the gameplay phase, when students are responsible for solving puzzles in the digital game, the teacher's major tasks are to diagnose student's understanding and provide whole-class scaffolding and one-to-one scaffolding whenever needed (Chiu, 2004; Hermkes et al., 2018; Sun et al., 2023).

Diagnosis. Diagnosing students' existing or current understanding is a fundamental part of scaffolding, and diagnostic strategies are good tools for such diagnosis (Pea, 2004; Puntambekar & Hübscher, 2005; Van de Pol et al., 2010; Van de Pol et al., 2011; Van de Pol et al., 2014; Wittwer & Renkl, 2008). Observing students' gameplay and asking open-ended questions during gameplay were common approaches used by the teacher, enabling them to obtain detailed information about students' current understanding (Van de Pol et al., 2014). After collecting and checking the information that the students already understand, the teacher can choose the appropriate scaffolding strategies accordingly (Makar et al., 2015; Muhonen et al., 2016; Pata et al., 2005; Van de Pol et al., 2014).

Whole-class scaffolding. Whole-class scaffolding is conducted at the beginning of the gameplay phase, mainly when the teacher finds that the majority of students are experiencing difficulties with similar kinds of problems while playing the digital game. For instance, the teacher may ask the students to pause the game and show them how to analyze and solve common types of arithmetic problems (Study I; see Sun, Ruokamo, et al., 2021). To ensure that whole-class scaffolding in the gameplay phase is provided to and benefits every student who needs it, I suggest that the teacher use technological tools, such as a smartboard and a slide projector, to demonstrate the puzzles in the digital game.

Whole-class scaffolding in the gameplay phase enables congruity between students' experience levels and conceptual understanding (Sun, Ruokamo, et al., 2021). As the students become more familiar with the gaming process, their problem-solving approaches and control over the learning process improve (Chen & Law, 2016; Sun, Ruokamo, et al., 2021).

One-to-one scaffolding. When a student is unable to solve a problem independently, the teacher provides one-to-one scaffolding (Sun, Ruokamo, et al., 2021). In the gameplay phase, one-to-one scaffolding is contingent support that is adaptive to individual students' needs. Therefore, one-to-one scaffolding is consistent with the findings of Van de Pol et al. (2010) and Belland et al. (2013), who indicated that scaffolding is a dynamic intervention in which the support provided by the teacher is contingent and should depend on the situation and the student's responses at the time.

Contingent support includes guidance, feedback, encouragement, and intervention (Sun et al., 2023; Van de Pol et al., 2011; Van de Pol & Elbers, 2013). The provision of individualized adaptive support based on students' learning engagement is essential for the development of conceptual knowledge; it also influences students' emotions and activates their ability to explore solutions independently (Chi et al., 2001; Sun et al., 2023; Van de Pol et al., 2011).

Fading and Transfer of responsibility. When contingent support is offered and results in students' improved performance and understanding, the teacher can then withdraw and decrease the level of support provided (Van de Pol et al., 2010, 2012). This fading of support subsequently leads to the transfer of responsibility from the teacher to the students, enabling the students to independently regulate and conduct learning activities in the digital game-based mathematics classroom (Sun, Ruokamo, et al., 2021; Van de Pol et al., 2010).

According to Van de Pol et al. (2010), scaffolding is an interactive process that requires the active participation of the teacher as well as students. Therefore, I suggest that teachers use various whole-class and one-to-one scaffolding approaches based on diagnosing students' existing and current understanding in the specific phase of the digital game-based learning process (Studies I and III; see Sun, Ruokamo, et al., 2021; Sun et al., 2023). In the proposed pedagogical model, teacher scaffolding provided in the digital game-based mathematics classroom can help students build links between their mathematics knowledge and the knowledge gained through the game (Barzilai & Blau, 2014; Rienties et al., 2012). Moreover, scaffolding makes learning more accessible to students, which positively influences their emotions toward learning and increases their persistence (Barzilai & Blau, 2014; Chen & Law, 2016).

5.2.2 Students' Learning Activities

In the pedagogical model, students' learning activities during gameplay are influenced and defined by collaboration and engagement, which directly lead to learning outcomes in the expectation phase. These elements were derived from the research process and the results of the three studies previously described (Studies I–III).

Collaboration. Collaboration is one of the elements in the pedagogical model (Study II; see Sun et al., 2022). Tomasello (2016) stated that students are more motivated to understand and solve problems in collaborative contexts. They tend to prefer collaborating with their peers over working alone, which leads to harder work and greater persistence when solving problems (Roschelle & Teasley, 1995; Tomasello, 2016).

During the digital game-based learning process, the teacher can encourage students to collaborate with their peers to solve puzzles (Study II; see Sun et al., 2022). Digital gameplay creates a learning situation with potential effects on students' interactions with their peers and cognition of their peers' work (Baek & Touati, 2020; Lehtinen, 2003; Lipponen et al., 2018). When students play digital games collaboratively, negotiate ideas, and attempt to convince their peers about specific task details, they are motivated to reflect on, understand, and form perceptions about their playing behaviors (Baek & Touati, 2020; Diniz dos Santos et al., 2019; Kiili, Lainema, et al., 2014; Tomasello, 2016). Furthermore, student collaboration during gameplay is conducive to sharing strategies and domain knowledge, co-constructing knowledge, and completing learning tasks by providing and receiving peer support (Chang & Hwang, 2017; Kiili, Perttula, et al., 2014; Lehtinen, 2003). Constructive peer interactions, which are embedded within gameplay, stimulate students' emotional engagement and enable them to form positive relationships with their peers and teacher as well as instruct and monitor one another's actions using different strategies (Baek & Touati, 2020; Chounta, 2019; Danby et al., 2018; Kiili, 2010).

In the proposed pedagogical model, collaboration plays an important role in enhancing individual students' learning activities and knowledge construction in mathematics. As a feasible instructional approach, student collaboration—which includes mutual participation, interaction, negotiation, and joint decision-making (Khoo, 2016; Lipponen et al., 2018; Roschelle & Teasley, 1995; Tomasello, 2016)—is one of the crucial elements for sustaining students' engagement in digital game-based mathematics learning.

Engagement. The element of engagement was added to the pedagogical model because of its importance in promoting students' learning activities and attaining the expected outcomes of digital game-based learning (Studies II and III; see Sun et al., 2022; Sun et al., 2023). Generally, engagement refers to an individual's participation in and behavioral, emotional, and cognitive responses to an activity (Fredricks et al., 2004; Fredricks & McColskey, 2012; Renninger & Bachrach, 2015). According to Kiili et al. (2012), engaged students generally show "sustained behavioural and cognitive involvement in activities accompanied by a positive emotional tone" (p. 80).

The pedagogical model highlights the three dimensions of student engagement, which are closely associated with teacher scaffolding, peer collaboration, and digital games in the learning process (Study II; see Sun et al., 2022). When students are behaviorally, emotionally, and cognitively engaged in the digital game-based learning process, they perceive the digital game as fun, which activates their interest in exploring it further, and their relationships with their teacher and peers are of high quality (Abdul Jabbar & Felicia, 2015; Lam et al., 2012; Sun et al., 2022). Progress in engagement is a principal element that helps students effectively cope with frustration in the learning process and leads to the development of learning outcomes (Guthrie et al., 2012; Lam et al., 2012; Skinner & Pitzer, 2012). Therefore, an increase in the three dimensions of engagement leads to students experiencing enjoyment, putting effort into learning, and using deep processing strategies to understand domain knowledge in mathematics and develop their arithmetic skills (Lam et al., 2012; Pekrun & Linnenbrink-Garcia, 2012; Sun et al., 2022).

5.3 Expectation

The gameplay phase is followed by the expectation phase. The outcomes of digital game-based learning are multifaceted and can indicate whether the game offered students an effective learning experience. Domain-specific knowledge and skills as well as transferable knowledge and skills are the expected learning outcomes in the proposed pedagogical model.

Since a digital game was used in the present study, number sense and arithmetic skills were the domain-specific knowledge and skills included in the pedagogical model (Studies I and II; see Sun, Ruokamo, et al., 2021; Sun et al., 2022). The game Wuzzit Trouble consists of three levels that range from basic to complex. The basic level offers valued practice problems that can enhance students' number sense, while the complex level requires students to solve integer arithmetic problems utilizing algebraic and algorithmic thinking, which can enhance their arithmetic skills. The integration of teacher scaffolding, peer collaboration, and Wuzzit Trouble in the present study's learning process provided an opportunity to reinforce students' number sense and algebraic and algorithmic thinking techniques, in line with the goals of the mathematics curriculum in primary education. Therefore, the teacher should establish a well-formulated classroom context to address students' needs based on their work levels as well as use mixed approaches linking digital games with other instructional strategies (Callaghan et al., 2018; Pekrun & Linnenbrink-Garcia, 2012).

Problem-solving and critical thinking skills are the transferable knowledge and skills included in the pedagogical model (Studies I–III; see Sun, Ruokamo, et al., 2021; Sun et al., 2022; Sun et al., 2023). Collaboration in the process of digital game-based learning requires students to interact with their peers, negotiate for turns, dispute different perspectives, and attempt to convince one another. Peer collaboration enables students to co-construct domain knowledge and improve their critical-thinking skills so that they can find the best ways to solve arithmetic problems and succeed in the game world (Chang & Hwang, 2017; Nebel et al., 2017; Tomasello, 2016). Moreover, the digital game-based learning environment has the potential to influence students' transferable knowledge and skills. The interactive multimodal features of digital games are beneficial for facilitating students' problem-solving and critical thinking skills. For example, most of the integer arithmetic problems in Wuzzit Trouble have more than one solution, so students were required to think carefully and determine the best problem-solving strategy to release Wuzzits with fewer rotations, thereby earning more stars and points (Pope & Mangram, 2015; Sun, Ruokamo, et al., 2021). In addition, teacher scaffolding not only helps students gain conceptual knowledge and improve their arithmetic skills but also gives them the opportunity to efficiently proceed with and control their problem-solving process during digital game-based learning (Barzilai & Blau, 2014; Waiyakoon et al., 2015).

As the pedagogical model shows, teacher scaffolding and peer collaboration in the process of digital game-based learning can help foster and develop students' problem-solving and critical thinking skills. The ability to transfer and generalize knowledge and skills allows students to apply what they have learned in one context to another, and digital game-based learning is desirable because it helps students improve this ability. Considering this, I suggest that the teacher uses gameplay elements (i.e., funny, playful, interactive, and competitive elements) to design various tasks and activities for the digital game-based learning process. This would activate students' potential to think critically when solving problems as well as transfer their knowledge and skills to different contexts.

Due to the flexible nature of the pedagogical model, not all elements mentioned above need to be involved in a digital game-based learning process, and there may also be additional elements. Some elements may also be changed; for example, the learning outcome of domain-specific knowledge depends on the selection and use of digital games. Overall, the pedagogical model for digital game-based learning can be applied to mathematics classrooms and to determine which knowledge and skills need to be developed at the primary education level. The pedagogical model thus ensures that a complete, practical approach to teaching and learning is adopted. With the support of the pedagogical model, the teacher can design digital game-based learning process and flexibly use teacher scaffolding approaches, giving students the opportunity to achieve the expected outcomes of the learning activities.

The pedagogical model in this dissertation was designed for educators and teachers who do or will utilize digital game-based learning in their classrooms. The aim is to give them suitable ideas about and perceptions of digital game-based learning. The pedagogical model can also be used by researchers and designers of digital games to examine the effectiveness of digital game-based learning in primary mathematics education and develop additional learning approaches that would benefit the process. Designers may also refer to the pedagogical model when designing new digital games for primary mathematics.

6 DISCUSSION AND CONCLUSIONS

This final chapter presents a discussion and evaluation of the main findings and methodological considerations of the study. It provides information on the ethical guidelines followed for this research, the practical implications of the study, and directions for future research.

6.1 Summary of the Research Results

The main purpose of this study was to understand teaching and learning in digital game-based learning and provide valuable insights to facilitate primary mathematics education with digital game-based learning. The specific aim was to develop a pedagogical model that would elucidate appropriate ways of applying digital game-based learning in the mathematics classroom in primary education. The pedagogical model designed in this study can be used by mathematics teachers and educational practitioners to create an innovative learning environment to support students' learning activities in primary mathematics education. Learning theories, theoretical insights into game-based teaching and learning, and the studies undertaken as part of this research have contributed to the design of the pedagogical model. At the start of the study, the following research question was formulated:

What kinds of scaffolding strategies do teachers implement in digital game-based learning and what are students' gaming and mathematics learning experiences in collaborative digital game-based learning classrooms in which teacher scaffolding is provided?

The design process involved collecting different kinds of data on the perspectives and learning experiences of students, teachers' teaching approaches in digital game-based primary mathematics classrooms, and the selected articles. In Study I, the teacher scaffolding provided in digital game-based learning classrooms and their effects on students' perceptions of learning were explored. In Study II, students' engagement in collaborative digital gameplay was measured, and the associated factors impacting the three dimensions of engagement in mathematics learning were investigated. In Study III, I searched for and analyzed relevant research articles and provided evidence of the teacher scaffolding strategies used in different stages of game-based learning and their correlative influence on students' learning.

The main outcome of this study is a pedagogical model for digital game-based learning in primary mathematics education, with the interrelationships among the elements being the central features of the model. According to the findings of the studies undertaken for this dissertation and previous research on game-based learning, the relationships among the three phases are conditional and are therefore indicated by one-way arrows in the pedagogical model. According to the pedagogical model, the teacher begins their role by deciding which teaching methods to use, and these then influence students' digital game-based learning activities (Chen & Law, 2016; Haataja et al., 2019; Sun et al., 2018). Accordingly, the relationships between the teacher and students in the orientation and gameplay phases direct the students' learning outcomes in the expectation phase (Barzilai & Blau, 2014; Muhonen et al., 2016). While the relationships that occur in the various phases are not new discoveries, the phases in the pedagogical model can optimize students' mathematics learning, particularly in primary education. In addition, the pedagogical model emphasizes the importance of the teacher, especially for scaffolding in various phases of the digital game-based learning process, in promoting students' learning activities and achieving the expected learning outcomes as well as for further developing primary mathematics education.

In addition to developing a pedagogical model for digital game-based learning, the present study helps extend our understanding of the current pedagogical uses of digital game-based learning. The research findings indicate that the educational use of digital games is viewed as a "disruptive educational practice" (Del Moral Pérez et al., 2018, p. 31). It is commonly recognized that the design of a game-based learning classroom is an effective means of activating students' learning activities and impacting their learning outcomes and social skills (Gros, 2007; Hosťovecký & Novák, 2017; Hsu & Wang, 2018; Lipponen et al., 2018; Meletiou-Mavrotheris & Prodromou, 2016). In particular, the research provides evidence that students' learning outcomes are influenced positively in a digital game-based learning classroom (Studies I–III). The design of such a classroom also emphasizes the teaching approaches required in this novel learning context (Studies I–III). It underlines students' perceptions of learning mathematics using a digital game (Study I) and the associated factors that can benefit the three dimensions of engagement in digital game-based learning (Study II). The main results of the research are shown in Table 6.

Table 6
Summary of the Research Results

Study	Main research results
Study I	• Different teacher scaffolding approaches in a digital game-based learning process, such as whole-class and one-to-one scaffolding, can be used to support the development of students' domain-specific knowledge and arithmetic skills.
Study II	• The behavioral, emotional, and cognitive dimensions of engagement are conceptualized as multifaceted constructs and can be influenced in the classroom context, which involves teacher support, peer collaboration, and task characteristics. • Achieving learning outcomes can improve students' engagement, while progress in the three dimensions of engagement is a critical element that leads to the development of learning outcomes.
Study III	• Different teacher scaffolding strategies are implemented in teacher–student interactions during the orientation and gameplay stages and have a correlative influence on students' learning in primary education.
Studies I and III	• Teacher scaffolding provided in the orientation stage helps students become familiar with the game and gaming process as well as understand the learning activity. • Teacher scaffolding provided in the gameplay stage has a positive effect on students' knowledge connection and acquisition.
Studies I–III	• Teacher scaffolding provided in a game-based learning classroom can stimulate students' enjoyment and engagement in learning.

Table 6 summarizes the main results of the three studies. In general, the pedagogical model designed for the use of digital games in mathematics education can take various forms and be viewed as a popular platform that provides students with opportunities to explore, motivating them to learn in different ways. Furthermore, the elements included in the pedagogical model can be effective instructional strategies to help students obtain knowledge and skills so as to maximize their potential within the ZPD (Cai et al., 2022; Palinscar & Brown, 1984). Considering this, I not only needed to establish these novel learning contexts but also embed the necessary teaching approaches and theories within them to design a suitable pedagogical model (Barzilai & Blau, 2014; Chen & Law, 2016; Kangas et al., 2017; Waiyakoon et al., 2015). Although this study is not focused on developing a coherent theory of digital game-based learning, it takes a step toward a more coherent understanding of digital game-based learning by providing an educational standpoint on the issue. For example, with the help of teacher scaffolding in digital game-based learning, it is probably easier for students— especially for those with poor self-regulation and with limited cognitive abilities—to learn via games (Barzilai & Blau, 2014; Bell & Gresalfi, 2017; Cai et al., 2022; Hou et al., 2022; Rienties et al., 2012). In addition, issues that have not been broadly examined in previous studies in this field, such as whole-class scaffolding and the three dimensions of engagement, are investigated in the present study. The findings help answer the question of how the use of digital games can be incorporated into a pedagogical model for digital game-based learning in primary mathematics education.

It is generally more helpful to design flexible structures than establish rules that are applicable to a particular situation and may not work in others. The findings of this study can be of value to mathematics teachers, educational practitioners, researchers, and designers in education. As noted, the pedagogical model provides a general framework that can facilitate the generation of new ideas and considerations to discover appropriate approaches for the successful integration of digital games into mathematics teaching and learning process. The approaches do not contribute only to teaching and learning in the digital game-based environment; they provide a theoretical foundation and a set of workable principles that can guide teachers' pedagogical thinking and activities in a variety of contexts (Kangas et al., 2017; Sun et al., 2023; Sun, Chen, et al., 2021). In sum, this study gathered information about teaching and learning in digital game-based learning environment from multiple perspectives, which led to the design of a pedagogical model for digital game-based learning that can be used to enhance mathematics learning in primary education.

6.2 Evaluation and Methodological Considerations of the Study

The findings of this study add to the understanding of how digital games can be used in the educational context. The pedagogical model designed in the study is the result of work from previous studies—namely, two case studies, an SLR, and a DBR cycle. However, the pedagogical model was not designed in collaboration with teachers or educational practitioners, so there were shortcomings in the application of the DBR approach. As a researcher, I anticipated following the DBR approach in all cases, but I could not arrange codesigning sessions because of time constraints. Therefore, the pedagogical model is primarily based on data from the case studies. The coordination of resources and efforts is important to ensure successful collaboration in a DBR (Collins et al., 2004; McKenney & Reeves, 2013; Wang & Hannafin, 2005). With this in mind, I motivated and supported the participating mathematics teachers' use of digital games in their classrooms and provided appropriate strategies and suggestions when problems occurred in practical situations. Communication and interaction with the mathematics teachers had a significant effect on our collaboration in the DBR cycle, which impacted the implementation of the experiments and design of the pedagogical model. As previously mentioned, I designed the model with the help of other researchers in an iterative manner, as required for the DBR approach (Barab & Squire, 2004; Cobb et al., 2003; Wang & Hannafin, 2005), and previous studies provided helpful knowledge and perspectives for the design and development of the pedagogical model (Barab & Squire, 2004; Collins et al., 2004).

Although the design process was short of a joint design event, multiple perspectives were considered as the research progressed—one of the strengths of the study. The research gave me the opportunity to collaborate with educational practitioners and teachers who were interested in the research topic and in implementing the experiments at their respective primary schools. This collaboration ensured that the experiments proceeded smoothly, and thus played a critical role in the design of the pedagogical model. I can attest that the perspectives of the teachers and students who participated in this study were considered when designing the model. Moreover, I discussed the model in depth with the other researchers and will test and refine it further in the future.

Another strong feature of this study was the use of different kinds of triangulation—theoretical, methodological, data, and researcher (Denzin, 1978). The selection of theories and methods was based on the aims of the various studies considered, which ensured their validity. The first study was qualitative in nature, and the second involved mixed methods, with the qualitative method being dominant. The third study was an SLR that involved synthesizing previous studies to gain knowledge about the different teacher scaffolding strategies implemented in teacher–student interactions and their correlative influence on students' learning (Borrego et al., 2014; Petticrew & Roberts, 2006). Although a large number of studies in the field of digital game-based learning have used quantitative methods to measure and compare participants' learning results, I believe that qualitative research is needed to capture participants' perspectives and develop a comprehensive understanding of digital game-based learning in educational fields (Collins et al., 2004).

The use of various research methods and the inclusion of both students and teachers helped me obtain a substantial amount of data, while both qualitative and quantitative methods were applied to analyse the data to guarantee the reliability of the studies. In addition, the presence of the researcher during the experiments was helpful in large classrooms and for teachers with limited or no experience in using digital games for teaching. Therefore, as a researcher, it was necessary for me to use multiple approaches to measure teaching and learning activities.

One limitation of this study was the variation in the student participants' ages between the first and second studies. This is because the selection of students was based on the decisions of the participating primary schools. For Study I, the primary schools in Beijing assessed the digital game and decided that fourth and fifth graders should participate in the experiments; for Study II, the primary school in Shanghai chose second graders as participants. As the researcher, I trusted the participating schools' assessments and respected their opinions (Wang & Hannafin, 2005). Furthermore, the experimental period was not long enough for the quantitative method in Study II; however, a longer experiment did not seem feasible at the participating primary school. The students and teacher participated in the experiment during their regularly scheduled mathematics class periods and had a limited amount of time to use the digital game in the classroom. To compensate for this limitation, the qualitative data were dominant in this study.

The present study was conducted at four primary schools in two cities in China. On the one hand, this was a strength, since I had the opportunity to experience and observe different teaching environment; on the other, it was a weakness, since regional differences among the primary schools were inevitable. Therefore, the relevant issues faced by the participating primary schools had to be carefully considered at the start of the collaboration. Collaboration with other researchers, such as local researchers, facilitates meaningful changes in practical contexts and "help[s] refine the key components of an intervention" in the DBR cycle (Design-Based Research Collective, 2003, p. 6; Zheng, 2015). This kind of collaboration was beneficial in establishing the reliability and validity of the present study.

Despite its limitations, this study adds to the literature on designing digital game-based learning classroom. Its most important contribution is a pedagogical model for digital game-based learning that can help teachers and students in primary mathematics education. As a researcher, I objectively observed the classes and considered the participants' perspectives, making interpretations based on my educational background. Furthermore, the evaluation of this dissertation was not the only time this study was examined and assessed. The three studies were assessed multiple times, with constructive comments and feedback provided by anonymous reviewers associated with the journals to which I submitted the manuscripts, supervisors and other Ph.D. candidates of the graduate school in which I am involved, conference committees and participants, and other researchers in my research community. All these people and their contributions have had an important influence on the overall quality of this dissertation.

6.3 Ethical Considerations

The ethical guidelines of the Finnish Advisory Board on Research Integrity (2012) were followed for the present study. Since the participants of Studies I and II were children, the ethical considerations needed to be emphasized (Dalli & Te One, 2012; Einarsdóttir, 2007). Informed consent, interaction, and the protection of confidentiality are key ethical issues when conducting research with children (Dalli

& Te One, 2012; Einarsdóttir, 2007) and must be considered regardless of the kinds of research methods employed (Dalli & Te One, 2012).

Although written informed consent was not obtained for Study I, the school headmasters informed the students' parents about the experiment and their children's participation through a parents' meeting. In the case of Study II, I attended a parents' meeting held at the primary school and informed the parents about the study and their children's participation. Written informed consent was obtained from the school and the parents before the experiment was conducted. The informed consent form included information about the study purpose, the data collection methods, the schedule for the experiments, and a declaration that the identities of the children would not be disclosed. With regard to the ethical principles of autonomy and self-determination, each participant was informed of the activities that would be conducted during the two studies. They understood that their participation was voluntary and that they were free to withdraw from the research at any time (Einarsdóttir, 2007).

The interviews were conducted in a space (reading room, music room) close to the children's classrooms, enabling them to participate easily. A relaxed atmosphere was created during the interviews to increase the interactions between the children and me. Elaborative questions were used to encourage the respondents to reflect on their experiences and express themselves freely, and it was emphasized that there were no right or wrong answers. I also paid attention to the children's facial expressions and gestures during the interviews to determine whether they were stressed and took appropriate measures to comfort them if needed. When the surveys were administered, the children were told to answer the questions on their own and that their names and responses would be anonymized. During the classroom observations, I remained at the back of the classroom to avoid causing any discomfort to the children.

To guarantee confidentiality throughout the data collection and analytical processes and to protect the children's identity, the data for Studies I and II were coded (e.g., Student 1, Student 2, etc.). To guarantee the children's privacy, I stored the data on a password-protected mobile hard drive that only I could access.

6.4 Implications and Future Directions

A variety of theoretical perspectives were combined in this study to produce a pedagogical model for digital game-based mathematics learning. The pedagogical model indicates that the teacher scaffolding (Sun, Ruokamo, et al., 2021; Sun et al., 2023; Van de Pol et al., 2010, 2012; Wood et al., 1976) should be implemented and addressed in digital game-based learning to support mathematics learning and teaching. Furthermore, the model was developed using the perspectives of collaboration (Dillenbourg, 1999; Johnson et al., 2007; Terenzini et al., 2001; Tomasello, 2016; Vygotsky, 1978) and engagement (Fredricks et al., 2004; Fredricks & McColskey, 2012; Guthrie et al., 2012), thereby providing a theoretical foundation for teachers' pedagogical thinking and daily teaching approaches. Learning via digital games may be considered beneficial to students, but certain challenges are yet to be addressed. For example, technological difficulties and time management issues were not fully addressed in Studies I and II but are significant factors in digital game-based learning (Bell & Gresalfi, 2017; Chen & Law, 2016; Kirriemuir & McFarlane, 2003; Watson et al., 2011). Furthermore, although teaching scaffolding in the orientation and gameplay phases is important, teachers should also develop competencies related to digital game integration.

This study has several implications for the design of digital game-based learning classroom for primary mathematics education. More research is needed to determine the best digital games for improving students' mathematics learning and learning experiences. The most beneficial ways of influencing students' educational experiences, attaining expected learning outcomes, and ultimately improving students' subject knowledge and perceptions of primary mathematics education need to be identified. Insights in these areas would help in determining the optimal design for a digital game-based learning classroom. In addition, the educational use of digital games needs to be elaborated in detail.

The proposed pedagogical model covers the following three phases: orientation, gameplay, and expectation. The elements involved in each phase of the digital game-based learning process are valuable and should be explored in depth. Future studies could pursue interesting and meaningful directions, such as determining whether additional scaffolding approaches in digital games facilitate learning and how the proposed pedagogical model can be applied by teachers in different educational contexts and for other school subjects to satisfy various student demands and needs. As Van de Pol et al. (2010) noted, scaffolding is an interactive process that depends on the active participation of both teachers and students.

Teachers play a major role in digital game-based learning classroom, a point emphasized in Studies I–III. Although there are different perspectives on digital game-based teaching and learning (e.g., whether it negatively affects students' learning; Broza & Barzilai, 2011; Charsky & Ressler, 2011), this can be solved in practice by designing appropriate teacher scaffolding strategies for the digital game-based learning process, positively influencing students' learning activities (Sun, Ruokamo, et al., 2021; Sun et al., 2023). In the future, it would be interesting to investigate additional scaffolding approaches and determine which scaffolding characteristics positively impact students' digital game-based learning (Sun, Chen, et al., 2021; Sun, Ruokamo, et al., 2021). This would enable the determination of pedagogical approaches that are favorable in digital game-based learning classroom and the identification of methods that are relevant to students' learning activities and perceptions.

The pedagogical model for digital game-based learning was designed based on the experiments conducted at different primary schools in China (Studies I and II), so the research findings have implications for the Chinese context of primary mathematics education. How can we effectively implement digital game-based learning in large classrooms? How can we ensure that every student is actively and sustainably involved in the process of digital game-based learning? These questions are related to the important role of the teacher, which was emphasized in the three studies. In a digital game-based learning classroom, the teacher needs to exercise sensitivity and consciously consider and emphasize students' individuality in the orientation and gameplay phases. In addition, it is also important for teachers to create friendly and comfortable learning environment by employing classroom management strategies, since this impacts not only the success of the scaffolding approaches used but also the entire learning process (Sun, Ruokamo et al., 2021; Sun et al., 2023).

The pedagogical model proposed in this dissertation needs further research. Besides conducting additional research iterations with the educational practitioners and teachers involved from the start (Barab & Squire, 2004; Wang & Hannafin, 2005), teacher training focusing on the pedagogical model and its use should be provided. Mathematics teachers may decide how to use the pedagogical model in practice and the alterations needed for its application in the classroom. Communication between the researcher and mathematics teachers should be maintained at all times. Codesigning sessions and further data analysis can lead to the development of a relatively ideal pedagogical model. The pedagogical model and methods that best support teachers and improve students' learning activities in mathematics can also be determined. Comparing various game-based learning models would be meaningful for identifying the ones beneficial for students' learning activities and outcomes in mathematics.

In this study, I focused on designing a pedagogical model to support digital game-based teaching and learning in mathematics classroom. Future research may focus on exploring different classroom contexts associated with mathematics as well as other subject areas to enhance students' learning activities and meet a variety of student needs and demands. Furthermore, researchers may examine the transfer of this pedagogical model to different primary educational contexts and thereby assess whether the design can work as expected in different social and cultural contexts. The use of digital game-based learning at school and at home should be investigated further to identify other elements associated with primary students' mathematics learning.

This research has various practical implications. First, Although I sought to follow the principles of DBR, the actual research context made this impossible, since various obligations and heavy workloads limited the time and availability of the educational practitioners and mathematics teachers. Therefore, the pedagogical model could not be co-created and joint planning was limited. Using various methods to collaborate and interact with educational practitioners and teachers would ensure that they can flexibly contribute to the research process in the future. Furthermore, as a researcher interested in digital game-based learning in mathematics education, I need to improve the design of the classroom experiments so that the tasks can be carried out more effectively. The practical implications of using the pedagogical model in mathematics classroom should be explored more deeply to ensure its success.

Although further evidence and additional research are required, the process of designing game-based learning classroom in the present study revealed some features and elements that can add to the educational use of digital games. The limitations of this study and negative experiences associated with digital game-based learning need to be carefully considered in future research to explore this topical issue in a more careful, critical, and in-depth manner. I aim to follow this approach and ultimately answer the question of how digital games can be optimally harnessed for game-based learning in an educational context. The DBR method will help me accomplish this task. Meanwhile, the theoretical perspectives and issues highlighted in this study can be used to further develop digital game-based learning. This would make mathematics learning relevant and meaningful for primary school students, improve students' learning activities, and enhance students' perceptions of primary mathematics education.

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