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Does the emotional design of scaffolds enhance learning and motivational outcomes in game-based learning?

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Abstract

Background: In recent years, the importance of emotions in learning has been increasingly recognized. Applying emotional design to induce positive emotions has been considered a means to enhance the instructional effectiveness of digital learning environments. However, only a few studies have examined the specific effects of emotional design in game-based learning.

Objectives: This quasi-experimental study utilized a value-added research approach to investigate whether emotional design applied to scaffolding in a game-based learning environment improves learning and motivational outcomes more than emotionally neutral scaffolding.

Methods: A total of 138 participants, mean age of 11.5 ($SD = 0.73$) participated in the study. A total of 68 participants played the base version of a fraction learning game (Number Trace), where scaffolding was provided with emotionally neutral mathematical notations, and 70 participants played the value-added version of the game using emotionally designed animated scaffolding agents. Pre-and post-tests were used to measure conceptual fraction knowledge and self-reported measures of situational interest and situational self-efficacy to evaluate motivational outcomes.

Results and Conclusions: Our results indicate that the emotional design applied to scaffolds can improve the educational value of a game-based learning environment by enhancing players' situational interest and situational self-efficacy. However, although the intervention improved the participants' conceptual fraction knowledge, there was no significant difference between the scaffolding conditions in participants' learning outcomes.

Takeaways: The results suggest that emotional design can increase the educational impact of game-based learning by promoting the development of interest, as well as improving self-efficacy.

KEYWORDS

emotional design, fraction learning, game-based learning, scaffolding, self-efficacy, situational interest

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1 | INTRODUCTION

1.1 | Objective and rationale of the research

Consider an instructional scenario in which a student struggles to estimate fraction magnitudes well. A teacher notices this and draws different graphical hints on the whiteboard. Some of these hints trigger students' interest and help them make better sense of fraction magnitudes. This study considers a similar scaffolding scenario within a digital game-based learning context. Scaffolding refers to support provided during learning processes to assist a student in attaining such a level of understanding that would be impossible to achieve without assistance (Wood et al., 1976). In this study, we investigate the instructional and motivational impact of scaffolds that a math game provides to struggling students. Like a teacher, the game can provide scaffolds in different ways. Thus, we seek to better understand how the implementation of scaffolding affects learning and motivational outcomes.

The utilization of scaffolding features in digital learning environments can substantially improve learning (Belland et al., 2017; Kim et al., 2018). However, only a few studies have considered the effects of the representations used in scaffolds, although this can have a major effect on learning (Quintana et al., 2004). In contrast, research on the instructional value of pedagogical agents recognized and underscored the aesthetic design of agents as one of the main factors that affect learning and motivational outcomes (Martha & Santoso, 2019). In this study, we extended the emotional design of the game-based learning environment to the scaffolding system of the game by presenting the emotionally neutral notation scaffolds with emotionally designed animated scaffolding agents. In particular, the goal is to examine whether fractions are learned better when scaffolds are presented with emotionally designed animated scaffolding agents or with emotionally neutral abstract mathematical notations. The rationale for focusing on learning fractions is that understanding fractions has a major role in students' future success in mathematics (Siegler et al., 2012), fractions are generally difficult to learn (e.g., Tian & Siegler, 2017), and at-risk students are in danger of falling behind in fraction learning (e.g., Resnick et al., 2016). Furthermore, fraction competence contributes to the building of students' domain-specific self-concept, and thus affects, for example, math anxiety and math interest.

1.2 | Theoretical background

1.2.1 | Game-based learning

Educators have long been interested in exploiting play and games in learning (Gee, 2003). During the last few decades, the number of empirical studies investigating the effectiveness and motivational aspects of digital instructional games has increased dramatically (Boyle et al., 2016). In recent scientific literature, such digital learning solutions are usually referred to as serious games or game-based learning (Wouters & Van Oostendorp, 2017). According to Plass et al. (2020), game-based learning refers to a learning task that is redesigned to make the basic task more interesting, meaningful and ultimately more effective for learning. Hence, game-based learning environments utilize various game mechanics, aesthetic design elements, narrative elements, representations of instructional content and incentive systems to catch attention, trigger interest, provide meaningfulness and support deep processing of the instructional material (Plass et al., 2015). Moreover, utilization and implementation of these elements should rely on sound pedagogical practices that exploit the possibilities that modern digital technologies can provide (e.g., Kiili et al., 2015). Recent meta-analyses have provided evidence that a combination of the above-mentioned elements results in more effective learning environments than conventional learning approaches in general as well as for learning mathematics (e.g., Clark et al., 2016; Sailer & Homner, 2020; Wouters et al., 2013). However, the game's design significantly affects its instructional effectiveness (Clark et al., 2016; Wouters & Van Oostendorp, 2013). For example, game-based learning environments that include instructional support (e.g., scaffolding and self-explanation) are more effective than game environments without instructional support (Wouters & Van Oostendorp, 2013). This finding may partly explain Wouters et al. (2013) finding that game-based learning is not more motivating than conventional instructional methods, as poorly implemented instructional support can harm motivation (e.g., Azevedo & Bernard, 1995).

1.2.2 | Scaffolding and scaffolding agents

Wood et al. (1976) first used the metaphor of instructional scaffolding to describe how parents and teachers provide dynamic support for learners. In general, scaffolding has two aims: (a) to increase situational competence(s) so that otherwise unattainable goal(s) can be obtained (e.g., Belland, 2017; Wood et al., 1976) and hence by doing so (b) increase performance on future tasks so that previously unattainable goals can be obtained without external support (e.g., Belland, 2017; Reiser, 2004). This requires that an instructor constantly assesses learners' competencies and evaluates learners' needs in comparison to task requirements, and adjusts the provided support accordingly (e.g., Belland, 2017). Therefore, instructional scaffolding is a constantly developing, situationally dependent instruction process that involves adding and fading of the given support as needed. In digital game-based learning, this requires that the given support is adapted according to the students' competence(s) and task requirements.

Syntheses of past results has shown that including instructional scaffolding in digital learning environments can substantially improve learning (Belland et al., 2017; Kim et al., 2018). Digital game-based learning provides a prominent context for implementing scaffolding in a computer-based learning environment. In digital game-based learning, scaffolding can, for example, be utilized to focus attention (Kao et al., 2017), enhance self-regulation (Sun et al., 2018) and lower the perceived demands of the task (Hung et al., 2014). Results of a meta-analysis indicated that games including scaffolding significantly improved learning outcomes when compared to games without

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scaffolding (Wouters & Van Oostendorp, 2013). In addition, Clark et al. (2016) found that scaffolding in a game-based learning environment had the highest impact when it featured intelligent agents or when adaptation was based on past performance. One explanation for these results is that scaffolding facilitates players' engagement by allowing them to train content at an appropriate challenge level (Kiili et al., 2014).

For this study, we developed animated scaffolding agents that offer appropriate support based on the students' competence levels and the cognitive requirements of the fraction tasks of the used game. Animated scaffolding agents are animated non-player characters designed to increase the situational competence(s) of struggling students and, hence, increase their future performance in similar situations. These animated scaffolding agents share similarities with traditional, usually more or less human-like, pedagogical agents. Like pedagogical agents, animated scaffolding agents are designed to fulfil pedagogical goals in digital learning environments (Gulz et al., 2011; Haake & Gulz, 2009). However, unlike traditional pedagogical agents that often rely on social agency theory (Atkinson et al., 2005; Martha & Santoso, 2019), animated scaffolding agents are not designed to be human-like to offer social cues and trigger social responses. Instead, animated scaffolding agents are designed to support the cognitive performance of struggling players and enhance motivational outcomes through emotional design.

The foundation of emotional design is based on well-supported propositions. First, emotions are inherently motivational and interconnected with cognition (Izard, 2009; Pekrun & Stephens, 2010; Plass & Kaplan, 2016). Second, by applying emotional design to digital instructional materials, it is possible to induce positive emotions (Ninaus et al., 2019; Plass et al., 2014; Plass et al., 2020; Um et al., 2012). In fact, research findings have suggested that if instructional material induces positive emotions, it can enhance basic cognitive mechanics, such as attention (Park et al., 2015), memory (Madan et al., 2019) and perception (Izard, 2009). This can lead to increased learning (Brom et al., 2018; Loderer et al., 2020; Pekrun, 2006; Um et al., 2012), motivation (Erez & Isen, 2002; Loderer et al., 2020), situational interest (Endres et al., 2020), self-efficacy (Usher & Pajares, 2008) and even improve executive functions that are crucial for learning and development (Homer et al., 2019). In digital learning environments, positive emotions can be induced by altering the representation of information (Plass et al., 2015). Initial emotional design research has identified that the use of round shapes, warm colours and game character expressions can be used to induce positive emotions (Brom et al., 2018; Homer et al., 2019; Plass et al., 2014; Plass et al., 2020; Um et al., 2012). Therefore, the effectiveness of a game-based learning environment will, at least to a degree, depend on its emotional design.

1.3 | Present study

This quasi-experimental study utilized a value-added research design in which the learning outcomes of a group that plays the base version of a game are compared to the learning outcomes of a group that plays the same game with one feature added (e.g., Mayer, 2019). In the present study, we extended the emotional design of the game-based learning environment (a base game) to the game's scaffolding system by presenting the emotionally neutral abstract scaffolds with emotionally designed animated scaffolding agents. The added value of this extension was examined regarding the learning and motivational outcomes. Three hypotheses are examined: (1) the learning hypothesis, (2) the interest hypothesis, and (3) the competence belief hypothesis.

Hypothesis 1. *Learning hypothesis: According to past research findings, the use of round shapes, warm colours and game character expressions can be used to induce positive emotions in digital learning environments (Homer et al., 2019; Plass et al., 2014; Um et al., 2012). Positive emotions can enhance basic cognitive mechanisms, such as attention (Park et al., 2015), memory (Madan et al., 2019) and perception (Izard, 2009), all of which are important factors contributing to learning. This proposition is supported by findings of studies conducted using digital learning environments (Mayer & Estrella, 2014; Plass et al., 2014; Um et al., 2012) and game-based learning environments (Homer et al., 2019), showing that emotional design that induces positive emotions enhances learning. Accordingly, we expect that learning with animated scaffolding agents will enhance learning outcomes when compared to learning with abstract mathematical notation scaffolds.*

Hypothesis 2. *Interest hypothesis: Situational interest refers to an affective response that occurs at a relatively limited or defined point in time and is caused by some feature(s) in instruction (Ainley, 2017; Knogler, 2017). That is, something in the instruction catches the learner's attention and triggers interest. In general, relatively little is known about which instructional features trigger interest (Renninger et al., 2019), and even less is known about how emotional design can be utilized to trigger interest. However, it can be assumed that emotionally loaded instruction can catch learners' attention and increase situational interest more efficiently than emotionally neutral instruction (Endres et al., 2020). Furthermore, induced positive emotions can enhance the enjoyment of learning and hence potentially foster situational interest (Pekrun et al., 2007). Initial research conducted in digital learning environments partly supports these claims by showing that induced positive emotions can elevate levels of interest (Endres et al., 2020; Plass et al., 2015; Um et al., 2012). In contrast, however, Park et al. (2015) did not find such an effect in their study. Despite somewhat contradictory initial results, we expect that learning with animated scaffolding agents will enhance situational interest when compared to learning with abstract mathematical notation scaffolds.*

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Hypothesis 3. *Competence belief hypothesis: Self-efficacy represents an individual's beliefs about how they will perform in certain tasks (Bandura, 1977; Pajares & Schunk, 2001). As self-efficacy is partly constructed by emotional states, it is possible to increase self-efficacy by inducing positive emotions (Usher & Pajares, 2008). Moreover, by utilizing emotional design, it is possible to lower anxiety (Loderer et al., 2020), which is often related to low self-efficacy (Akin & Kurbanoglu, 2011). Furthermore, a positive emotional state and lowered anxiety influence the interpretation of one's own experience and thus further increase self-efficacy in future tasks requiring similar competencies (Usher & Pajares, 2008). Therefore, we expect that learning with animated scaffolding agents will increase self-efficacy when compared to learning with abstract mathematical notation scaffolds.*

2 | METHOD

2.1 | Participants and design

The sample comprised 138 participants: 62 boys and 59 girls, and 17 who refused to report their gender. The participants were between 10 and 13 years old ($M = 11.5$; $SD = 0.73$; (27) 4th, (109) 5th and (2) 6th graders). The participants were from classes that the teacher registered to participate in the study. The participants were from schools located in varying socioeconomic status areas in two southern Finland cities. Participants were assigned to play one of two implementations of the Number Trace game: the base version or the extended version. The random assignment between the conditions was conducted at the classroom level. A total of 68 students were assigned to the condition with mathematical notation scaffolding (base version) and 70 students to the condition with animated scaffolding agents (extended version).

The study complies with the national legal and ethical requirements, including the ethical guidelines of the Finnish National Board on Research Integrity, legislation for the protection of privacy, and the EU General Data Protection Regulation (GDPR). Local school authorities approved the study. Parents and participants were informed about the study (purpose of the study, procedure, materials, data-gathering methods and data management). A possibility to prevent the child's participation in the research was provided for parents or carers. Participation was voluntary and participants had the right to refuse to participate at any time without consequences.

2.2 | Game-based learning stimuli

The Number Trace math game research environment (Greipl et al., 2021; Kiili et al., 2018) was used to create game-based learning materials for this study. The Number Trace game research environment is designed for producing number-line-based math instruction for research and learning purposes. The produced games can be played with a web browser. The environment—and its predecessor, Semideus—has been previously successfully utilized in several studies focusing on enhancing understanding of rational number learning and game-based learning (e.g., Koskinen et al., 2022; Ninaus et al., 2017).

The materials comprised two Number Trace game versions – a base version and an extended version. Both versions of the games utilize the same overall design principles (Table 1), but in the extended version, the mathematical notation scaffolds were replaced with emotionally designed animated pedagogical agents. The mathematical content of the game versions was identical and designed to support the development of 4th–6th graders' conceptual fraction knowledge. Conceptual fraction understanding refers to understanding the properties of fractions, including magnitudes (e.g., 3/5 is greater than ½), and fraction notation expressions (e.g., ¾ = 6/8) (e.g., Bailey et al., 2015). The learning objective of this study was to develop students' conceptual fraction understanding of mixed number and improper fraction magnitudes according to the guidelines of the Finnish national core curriculum.

Next, we present the design of the base version of the game, followed by a description of the extended version in which the mathematical notation scaffolds were replaced with emotionally designed animated pedagogical agents (see details of the extended version from Section 2.2.4).

2.2.1 | Description of the base game

As shown in Figure 1, Number Trace is a platform type of game designed to support the development of conceptual fraction number knowledge. The game was built around estimating and comparing fraction magnitudes on a number line. Several studies have shown that estimating fraction magnitudes on a number line is an effective and engaging instructional approach for learning fractions (e.g., Braithwaite & Siegler, 2021; Kim et al., 2018; Riconscente, 2013), and yielding better learning results than regular school instruction (e.g., Fuchs et al., 2016).

In the game, the player controls a dog on a number line and tries to locate bones hidden in the ground by estimating the given target fractions. Figure 1 shows two kinds of number line estimation tasks used: (I) the basic number line estimation task (e.g., Siegler & Opfer, 2003), where players estimate the spatial position of a target number on a horizontal number line with only its start and endpoint specified (e.g., where does 8/4 go on a number line ranging from 0 to 3; Figure. 1 left column), and (II) the unbounded number line estimation tasks (e.g., Cohen & Blanc-Goldhammer, 2011), where players estimate the spatial position of a target number on a horizontal number line based on the start point and one given number on the number line (e.g., where does 4/4 go on a number line starting from 0, location of 1/2 is shown on the number line, but the endpoint is hidden from the player; Figure 1 right column). The use of number line estimation as a core game mechanic is based on ample previous research

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TABLE 1 Summarisation of major game design principles and their implementation

Principle	Description (D)	Implementation	Game research foundation
Focus	Game targets well-specified learning objectives (knowledge/skill)	Focus is on fraction magnitudes on a number line.	Kiili 2005; Kiili et al., 2019; Parong et al., 2020
Practice and intrinsic integration	Game provides tasks that are meaningfully integrated to the game world to repeatedly train the targeted knowledge or skills.	The core game mechanic is based on locating bones (estimating given magnitudes) accurately on number lines.	Habgood & Ainsworth, 2011; Kiili et al., 2015; Kiili et al., 2019; Parong et al., 2020; Plass et al., 2015; Walkington, 2021
Variation	Game allows training/learning in various contexts.	Includes both basic and unbounded number line estimation tasks. The range of the number line is varied.	Parong et al., 2020
Clear goals	Game provides clear and achievable goals that follow learning objectives.	In each level, the player can achieve 1–3 stars based on the playing performance.	Garris et al., 2002; Kiili et al., 2014
Feedback	Game provides immediate and embedded feedback on execution of targeted learning objectives.	Immediate feedback: The dog is happy, and points are received when estimated accurately enough; The dog is unhappy and virtual energy is lost when estimated inaccurately. Delayed feedback: Achieved stars; Bonus points based on remained energy level.	Erhel & Jamet, 2013; Kiili et al., 2014
Learning analytics and tracking	Game keeps track of players' performance.	Game records player's competence on improper fractions and mixed numbers.	Kiili et al., 2019; Plass et al., 2015; Shute & Rahimi, 2017
In-game learning support	Provides hints and support for players when needed.	Scaffolding is provided after inaccurate estimations (wrong answers) by adding guiding landmarks on the number line. The level of scaffolding support is based on learning analytics.	Ke, 2016; Kiili et al., 2014: Kiili et al., 2019
Emotional design	Game includes features that aim to induce emotions that support deep cognitive processing leading to strong learning outcomes.	Rounded shapes, warm colours and game character expressions are used.	Ninaus et al., 2019; Plass et al., 2020

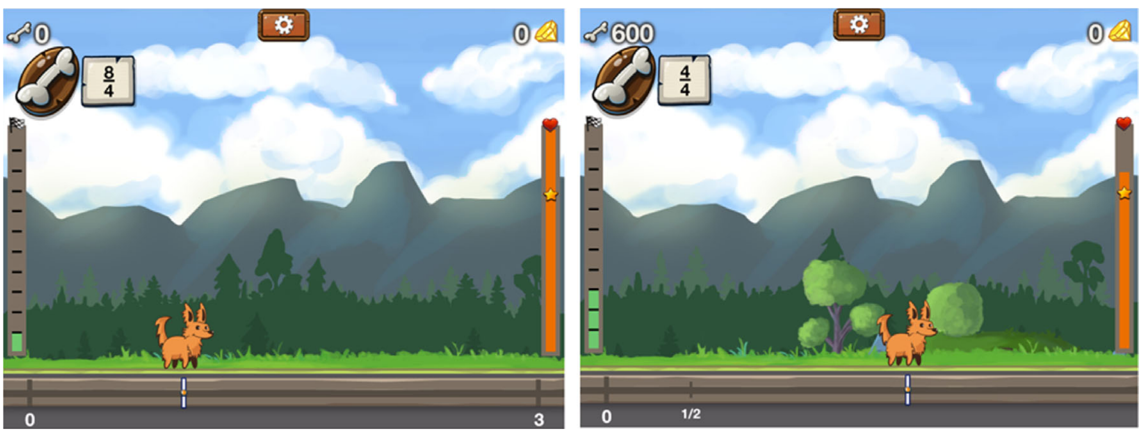

FIGURE 1 On the left side is a basic number line estimation task and on the right side is an unbounded number line estimation task. The left top corner in both pictures shows the (target) fraction being estimated, and above it shows the points (bones) acquired by the player. The unbounded task on the right has a hatch mark pointing where ½ is on the number line. The bar on the left shows progress in the level, and the bar on the right shows the remaining energy.

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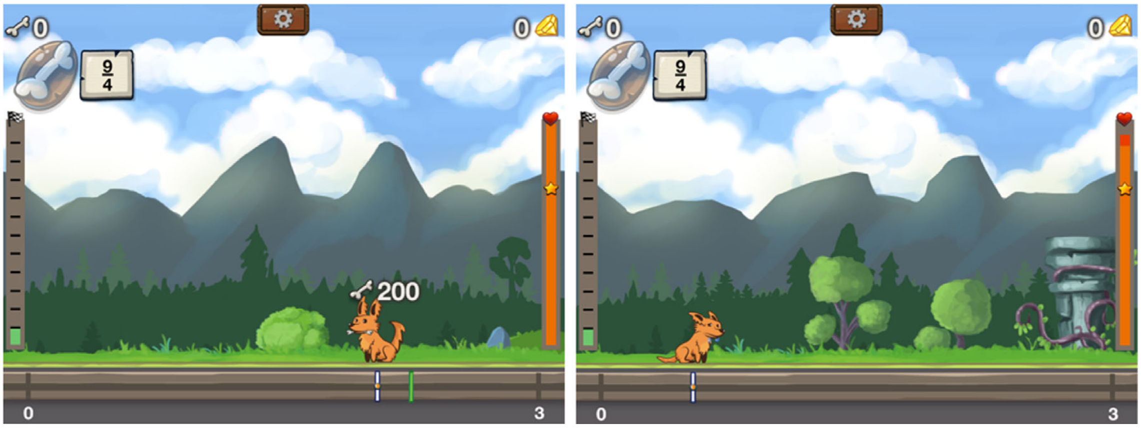

FIGURE 2 Immediate positive feedback after a correct answer (left); immediate negative feedback after an incorrect answer (right).

demonstrating that it is an effective instructional mechanic in game-based fraction learning (e.g., Braithwaite & Siegler, 2021; Kim et al., 2018).

Table 1 summarizes the major theoretical design principles and frameworks that informed the design of Number Trace and shows how these principles were applied in the game. These principles and frameworks were implemented according to the integrated design framework of game-based and playful learning (Plass et al., 2015) to form coherent learning and playing experience for the participants.

As emphasized in several of the frameworks used, feedback is one of the key elements affecting engagement, interest and learning. Therefore, various feedback mechanics were implemented in Number Trace. Figure 2 shows the mechanics of how immediate positive and negative feedback was implemented in the game. After a correct answer (estimation accuracy of at least 92%), the player receives bones as points, the correct location of the target fraction is shown on the number line, and the dog looks happy. In contrast, after the wrong answer, the dog is sad; the player loses energy and does not get points. After the wrong answer, the player has a second attempt featuring scaffolding. Moreover, after finishing all the tasks of a game level, the player receives delayed feedback as 1–3 stars depending on the success on the level.

2.2.2 | Level structure and progression

The game comprised nine levels. Players had to complete the levels in a predetermined order. Each level contained 10 estimation tasks, and the levels could be completed only once to ensure that each participant received the same amount of instruction. Altogether, the game included 38 improper fractions (i.e., fractions where the numerator is greater than the denominator e.g., 8/4) estimation tasks on bounded number lines, 27 mixed number (e.g., $2\frac{1}{2}$) estimation tasks on bounded number lines and 25 improper fraction estimation tasks on unbounded number lines, making a total of 90 tasks. The first level of the game (10 tasks) was introductory and explained the idea of mixed numbers, improper fractions and utilized scaffolding mechanism. The game emphasized slightly more improper fraction instruction, as past research has shown that they tend to be harder to learn than mixed numbers (Tian et al., 2021). The relatively small number of tasks was expected to significantly improve participants' fraction number understanding, as previous studies have suggested that even short game-based number line interventions can result in substantial learning gains (e.g., Fazio et al., 2016). The player had two attempts in every task to get the correct answer before the game automatically advanced to the next task.

2.2.3 | Implementation of scaffolding

Of the 90 estimation tasks, 80 featured scaffolding. Scaffolding was shown to the player if the player's first response was incorrect for a given task. Estimations more than ±8% away from the correct location (estimation accuracy below 92%) resulted in an incorrect trial and activated scaffolding. This threshold was chosen to ensure that the participants received sufficient scaffolding. Previous studies have suggested that most primary school students initially do not reach an estimation accuracy of over 90% in improper fraction estimation tasks (Tian et al., 2021). Moreover, this threshold ensured that most players were appropriately challenged throughout the game.

The scaffolds were designed to develop participants' conceptual fraction understanding by drawing their attention to the relational nature of fractions, especially in highlighting the role of the denominator as a splitting mechanism and the role of the numerator as the number of denominators that make up the magnitude. Two main types of scaffolds were included. Figure 3 (left column) shows an example of a multilevel partition scaffold, where the number line was marked with whole number, hatch marks and unit-fraction ($\frac{1}{3}$ in the example) hatch marks. This scaffold illustrates that each whole number part of the number line can be divided into three equal-sized units. Further, it tries to promote a strategy to use these units to form an improper fraction on the number line – in the current example 8/3 ($\frac{1}{3} + \frac{1}{3} + \frac{1}{3} + \frac{1}{3} + \frac{1}{3} + \frac{1}{3} + \frac{1}{3} + \frac{1}{3} = 8/3$ or $8 \times \frac{1}{3} = 8/3$). Further, it also provides a means to use a mixed number strategy in

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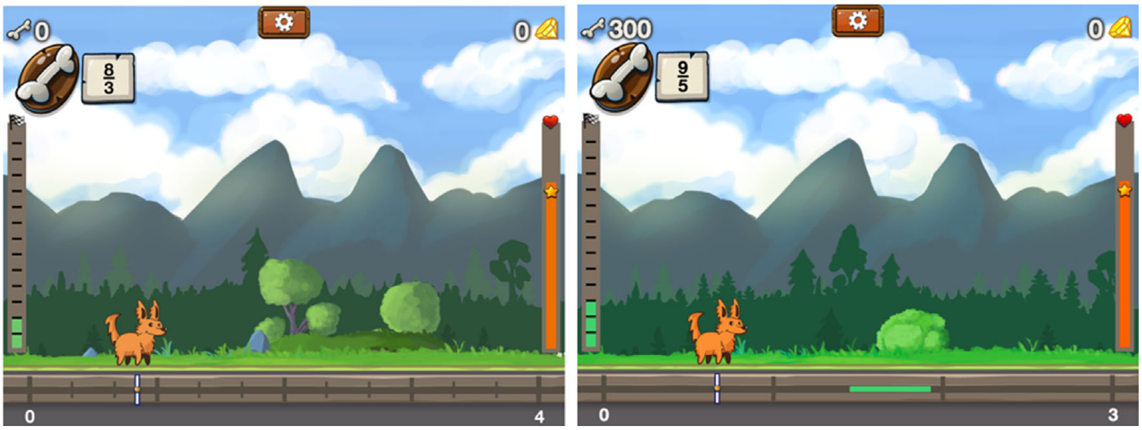

FIGURE 3 Scaffolds presented with mathematical notations

estimation (e.g., transforming 8/3 to 2⅔). Figure 3 (right column) shows an example of a whole number partition scaffold that visually decreases the estimation area. In this kind of scaffold, each whole number on a line was marked with a hatch mark. According to Siegler and Thompson (2014), whole number landmarks increase the encoding of improper fractions (i.e., fractions larger than 1). In addition, a certain area of the number line was highlighted with a green bar, indicating an approximate area (16% of the number line) where the target fraction was located. The bar's location was randomized such that the whole bar was not within the required accuracy threshold. That is, the correct position was not at the midpoint of the green bar, and students who selected random locations on the area of the bar gave easily wrong answers to the task. With this randomisation, we aimed to counteract mindless answers in the highlighted area.

Half of the scaffolds were fixed, meaning that all players received the same scaffold after a wrong answer. The other half of the scaffolds were adaptive. Adaptive scaffolding was implemented so that the player's estimation accuracy in previous tasks defined which one of these three scaffolds was provided to the player if the first response was incorrect. The thresholds of the different scaffolding levels were based on the previous research (Tian et al., 2021; McMullen et al., 2020), suggesting that estimation accuracy 90%–92% requires only minor support, estimation accuracy between 70% and 90% requires average support and estimation accuracy below 70% requires most support. Figure 4 shows an example of a task that includes three possible scaffolding levels.

2.2.4 | Description of the extended game version

The extended version of the Number Trace game was identical to the base version, except for the visual implementation of scaffolding. The mathematical notation scaffolds of the base version were substituted with animated scaffolding agents in the form of worms and a dog friend. Emotional design to induce positive emotions was applied to the visual appearance of these agents: they were roundly shaped, cute and had happy facial expressions, and the worms were presented in a bright green colour. In addition, the worms were animated to roll in from the left side of the screen and rolled out to the right after the task was completed. The rolling animations of the worms were only decorative entrance and exit effects and thus, the animations did not disturb the perception of the mathematical information that they presented. Figure 5 (left column) shows an implementation example of a multilevel partition scaffold when worms were used. In this kind of scaffold, each worm comprises several parts that correspond to the unit-fraction hatch marks of the base version. For example, in Figure 5 (left column), each worm is divided into three equal-size units ($1/3 + 1/3 + 1/3 = 1$ worm), as the denominator of the target fraction is three. Figure 5 (right column) shows an implementation example of the whole number partition scaffold with a decreased estimation area when animated agents were used. In this scaffold, the worm characters replaced the whole number hatch marks (each worm corresponds to a whole), and a dog character replaced the green bar. That is, the dog sniffed around the same sized area as highlighted with a green bar in the base version, thus showing an approximate location of the target fraction.

2.3 | Measures

All data were gathered within the game-based learning environment.

2.3.1 | Pre-questionnaire

The pre-questionnaire used a similar interface used in the instructional part of the game. However, instead of estimating fraction magnitudes, the participants answered questions using the same number-line-based mechanics on a continuous scale. Moreover, smiley faces were added besides the numbers on the number line as well as decimal numbers to aid participants' self-evaluation (Figure 6). Naturally, participants did not receive corrective feedback; however, they received a fixed number of points for their answers.

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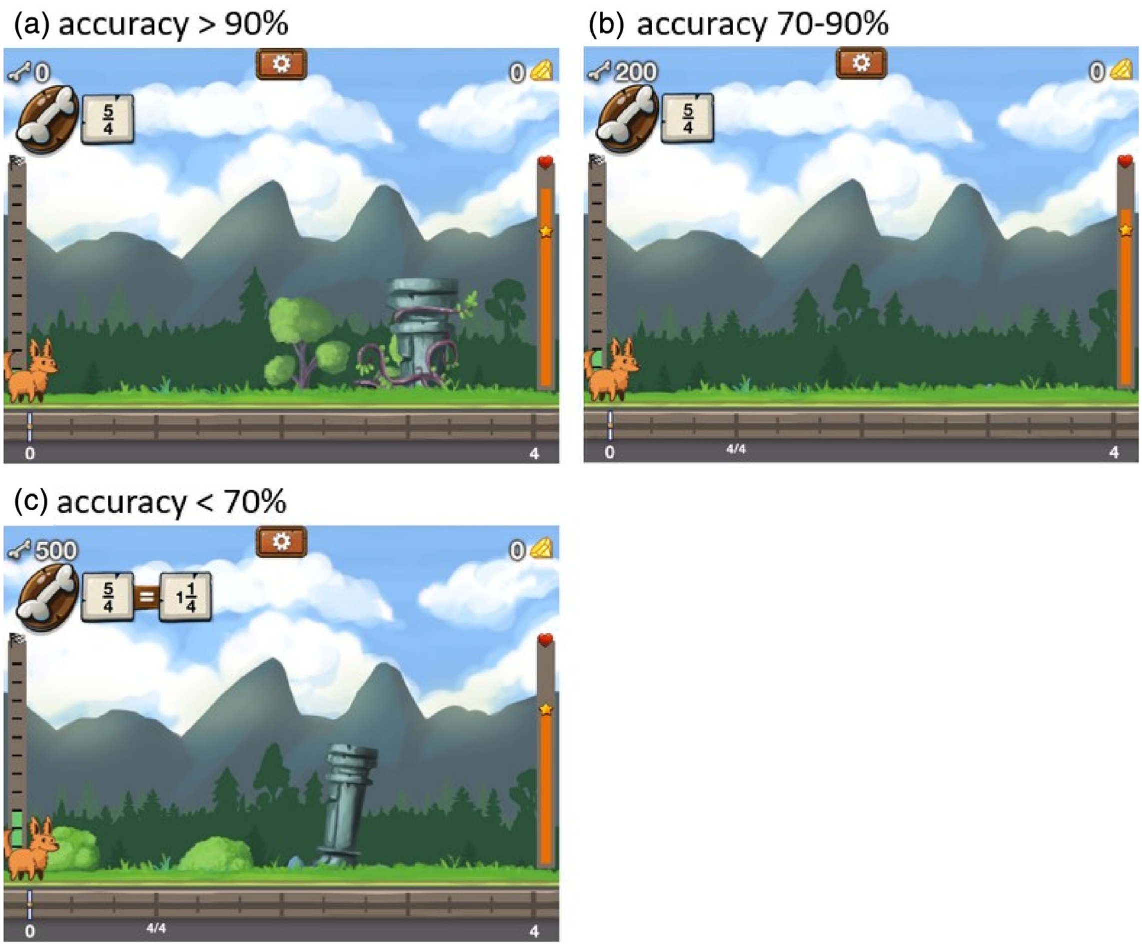

FIGURE 4 Example of scaffolds with different support levels. (a) Least support: Whole number hatch marks supplemented with unit hatch marks; (b) average support: Whole number hatch marks supplemented with unit hatch marks and the nearest whole number hatch mark labelled in a fraction format; (c) Most support: Same as average support, but the target fraction was also shown as a mixed number or with approximation area.

FIGURE 5 Scaffolds presented with animated agents

1. Math interest was measured with three statements about participants' attitudes towards learning mathematics (e.g., "I like learning mathematics") with a continuous scale from one (completely disagree) to five (completely agree). Reliability for the scale was excellent (Cronbach's $\alpha = 0.93$). The math interest construct was calculated as the average value of the scale items.

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2. Fraction interest was measured with one statement (i.e., "I like learning fractions") with a continuous scale from one (completely disagree) to five (completely agree).
3. Fraction self-efficacy was measured with one statement (i.e., "I am certain that I will do well on fraction tasks") on a continuous scale from one (completely disagree) to five (completely agree).
4. Liking of playing educational math games was measured with one statement (i.e., "I like playing educational math games") on a continuous scale from one (completely disagree) to five (completely agree).

2.3.2 | Pre-and post-test

Participants concluded the pre-and post-test using a similar interface that was used in the instructional part of the game (see Figure 1). However, there was a maximum time of 45 seconds per test item; participants were shown a timer indicating the remaining time. Participants had only one attempt at each item.

To assess the intervention's learning effect, we developed two parallel versions of a test to measure conceptual fraction knowledge, representing the participants' understanding of mixed number magnitudes and fraction magnitudes. Therefore, we created difficulty-and magnitude-matched tests A and B (Table 2). These tests served both pre-and post-test. That is, participants (n = 69) who were randomly assigned to conduct test A as a pre-test conducted test B as a post-test; similarly, participants who conducted test B as a pre-test (n = 69) conducted test A as a post-test. Test assignment was randomized within conditions. Pre-and post-tests were conducted either on a number line that went from 0 to 5 or from 0 to 2.5. Neither of these number line ranges was used in the instructional content of the intervention. Thus, this would effectively capture if the learning effects from the game would generalize to other number line lengths, indicating a better transfer of learning and a developed understanding of the concepts learned through the game. To determine whether participants' performance on tests A and B was equivalent before the intervention, an independent sample's t-test was conducted. The analysis indicated that there was no difference between tests A and B [$t(136) = 0.07$, $p = 0.95$].

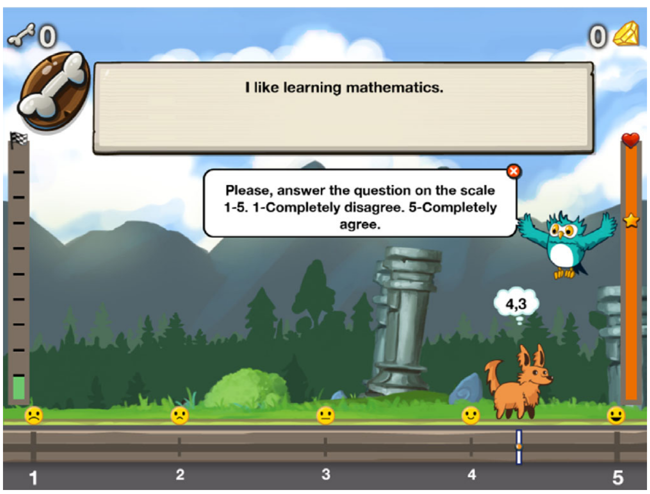

FIGURE 6 A sample of math interest item of the pre-questionnaire.

Tests A and B comprised 17 items (Table 2). The division of different pre-and post-test items was designed to correspond with the number of different tasks students conducted in the game. The tests comprised the following items:

1. Estimation of improper fraction magnitudes (8 items). Participants had to indicate the correct position of a target number (e.g., 3/2) in the number line from 0 to 5. Each item was scored as correct or incorrect (±8% estimation error as a limit).
2. Estimation of mixed number magnitudes (4 items). Participants had to indicate the correct position of a target number (e.g., 3 3/4) in the number line from 0 to 5. Each item was scored as correct or incorrect (±8% estimation error as a limit).
3. Comparison of improper fractions (5 items). Participants had to indicate which of two fractions was the larger/smaller one (e.g., 8/3 vs. 6/2) on an unbounded number line from 0 to 5 (3 items) and on a number line from 0 to 2.5 (2 items). Each item was scored as correct or incorrect (comparison was done correctly).

Pre-and post-test scores were calculated as an average of correct answers. Both tests had acceptable reliability (pre-test Cronbach's $\alpha = 0.69$; post-test Cronbach's $\alpha = 0.77$).

2.3.3 | In-game measurements and metrics

In-game self-report measures were used to assess the participants' situational self-efficacy and situational interest. The in-game

TABLE 2 Items of tests A and B

	Estimation of improper fraction magnitudes								Estimation of mixed number magnitudes			
Test A	**3/2**	**7/2**	**14/3**	**5/4**	**9/3**	**2/5**	**4/1**	**7/3**	**3 3/4**	**4 1/8**	**1 1/5**	**2 2/6**
Test B	4/3	9/2	12/3	6/5	10/3	4/5	3/1	5/2	3 1/4	4 1/5	1 1/6	2 2/8

	Comparison of improper fractions				
Test A	**8/3 vs. 6/2**	**3/2 vs. 5/5**	**5/4 vs. 9/6**	**8/2 vs. 8/4**	**9/4 vs. 5/4**
Test B	9/4 vs. 6/2	3/2 vs. 4/4	4/3 vs. 9/6	8/4 vs. 8/2	9/5 vs. 6/5

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FIGURE 7 In-game measurement of situational interest

measurements utilized a similar interface that was used in the instructional part of the game to minimize the risk of breaking the game flow (Figure 7). That is, instead of estimating fraction magnitudes, participants answered questions using the same number-line based mechanic. Situational interest and self-efficacy were assessed three times during the instruction: at the 2nd, 5th and 9th game level. These measurement points were determined to measure participants' situational interest and situational self-efficacy at the beginning, at the middle, and at the end of the study, thus comprehensively reflecting participants' motivational states during the gameplay. Situational interest was measured at the end of these game levels and situational self-efficacy after the third task of the above-mentioned game levels.

1. Situational interest was measured with one statement: "Tasks on this game level were really interesting" on a continuous scale from one (completely disagree) to five (completely agree). Situational interest assessment with one item is not unusual, which agrees with previous studies (e.g., Rodríguez-Aflecht et al., 2018). The situational interest variable was calculated as an average value of the situational interest measurements across the three-game levels and had acceptable reliability, with Cronbach's $\alpha = 0.79$.
2. Situational self-efficacy was measured with one statement: "I will certainly perform well on the tasks of this game level." on a continuous scale from one (completely disagree) to five (completely agree). The situational self-efficacy variable was calculated as an average of the situational self-efficacy measurements across the three-game levels and had acceptable reliability, with Cronbach's $\alpha = 0.79$.

In-game metrics were used to measure how much and what kind of scaffolding (i.e., fixed and adaptive) participants received. The amount of scaffolding variable was calculated as the sum of the number of adaptive and fixed scaffolds that the students received.

2.4 | Procedure

This study was conducted in regular school classes during regular school days and was administered mainly by classroom teachers.[1] Before the intervention, the teachers were provided with clear guidance about the research and procedures of the study. Table 3 shows the structure of the study. First, the participants logged into an online game-based learning environment with their personal passwords. After logging in, participants conducted nine onboarding tasks (i.e., step-by-step instruction) to become familiar with the game mechanics. This was followed by two tasks, ensuring that the participants had mastered core game mechanics. After this onboarding phase, participants started the pre-questionnaire and pre-test. They were instructed not to discuss their answers with other participants. After completing the pre-test, the participants began with the instructional content of the game. During playing, the participants could proceed at their own pace and discuss with each other if they had technical problems with the game. After finishing the game, participants completed the post-test. With this naturalistic study design, we aimed for strong ecological validity.

3 | RESULTS

3.1 | Descriptive statistics

Table 4 shows the descriptive statistics and zero-order correlations. Overall performance levels and motivational responses were in line with previous research involving students of the same age as those participating in this study (e.g., McMullen et al., 2020; Riconscente, 2013). Table 4 shows that there were not any anomaly zero-order correlations between the variables. Furthermore, Table 4 shows that the data was normally distributed and thus allowed the utilization of parametric statistical analyses.

3.2 | Condition equivalence

T-tests and $\chi 2$ tests were conducted to determine whether participants in the two scaffolding conditions (animated agent vs. mathematical notation) had any pre-existing differences. Participants in the two conditions did not differ on age [$t(136) = 1.80$, $p = 0.73$], pre-test score [$t(136) = 0.10$, $p = 0.60$], fraction self-efficacy [$t(136) = 0.68$, $p = 0.50$], math interest [$t(136) = 1.00$, $p = 0.32$], fraction interest [$t(136) = 0.68$, $p = 0.36$] or liking of playing educational math games [$t(136) = 0.72$, $p = 0.47$] (Table 5). Further, the number of scaffolds received by both groups did not significantly differ [$t(136) = 0.52$, $p = 0.60$] (Table 5). A $\chi 2$ test revealed that the animated agents (boys $n = 30$; girls $n = 35$) and mathematical notations (boys $n = 32$; girls $n = 24$) conditions did not differ significantly in the proportion of boys and girls, $\chi 2\ (1) = 1.45$, $p = 0.23$. Based on these results, we concluded that random assignment produced conditions that were equivalent to these basic characteristics.

[1]One of the authors supported the teachers in conducting the study in one classroom

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TABLE 3 Structure of the study

Onboarding	Pre-instruction measurements	Instruction	Post-instruction measurements
Nine tasks instructing game mechanics. Two tasks validating mastering of the core game mechanics.	Eight improper fraction magnitudes estimation items. Four mixed number magnitude estimation items Five comparison of improper fraction items. Three items measuring math interest. One item measuring fraction interest. One item measuring fraction self-efficacy. One item measuring the liking of playing educational math games.	38 improper fraction tasks. 27 mixed-number tasks. 25 improper unbounded comparison tasks. Three items measuring situational interest. Three items measuring situational self-efficacy.	Eight improper fraction magnitudes estimation items. Four mixed number magnitude estimation items. Five comparison of improper fraction items.

TABLE 4 Descriptive statistics and zero-order correlations

	1.	2.	3.	4.	5.	6.	7.	8.	9.
1. Pre-test score	1								
2. Post-test score	0.68**	1							
3. Math liking	−0.08	−0.16	1						
4. Fraction interest	−0.17*	−0.22*	0.77**	1					
5. Fraction self-efficacy	−0.21*	−0.16	0.61**	0.64**	1				
6. Liking of math games	−0.07	−0.08	0.51**	0.44**	0.34**	1			
7.Situational interest	−0.03	−0.11	0.51**	0.49**	0.35**	0.30**	1		
8.Situational self-efficacy	−0.01	−0.09	0.54**	0.45**	0.44**	0.30**	0.58**	1	
9. Number of scaffolding	−0.14	−0.26**	−0.21*	−0.12	−0.26**	−0.15	−0.10	−0.34**	1
Theoretical range	0–1	0–1	1–5	1–5	1–5	1–5	1–5	1–5	0–80
M	0.36	0.52	3.66	3.35	3.68	4.16	3.13	3.22	36.67
SD	0.19	0.22	1.15	1.25	1.10	1.02	1.14	1.04	11.42
Skewness	0.90	0.35	−0.72	−0.46	−0.74	−1.32	−0.16	−0.31	−0.35
Kurtosis	0.19	−0.83	−0.39	−0.76	−1.16	1.30	−0.90	−0.52	−0.55

Note: Correlation (**) is significant at the 0.01 level (2-tailed); Correlation (*) is significant at the 0.05 level (2-tailed).

TABLE 5 Means and *SD*s of animated agents and mathematical notations conditions age, pre-test score, post-test score, fraction self-efficacy, fraction interest, math interest, liking of playing educational math games, and the number of scaffolding received

Condition		Age	Pre-test score	Post-test score	Fraction self-efficacy	Fraction interest	Math interest	Liking of math games	Number of scaffolding
Agent	M	11.46	0.37	0.52	3.62	3.32	3.76	4.10	36.17
	SD	0.67	0.20	0.23	1.16	1.27	1.19	0.98	11.15
Notation	M	11.50	0.35	0.51	3.75	3.38	3.57	4.22	37.19
	SD	0.78	0.18	0.22	1.04	1.24	1.11	1.06	11.76

3.3 | Learning outcomes

We conducted a two-way repeated measures ANOVA with pre-and post-test as a repeated within-subject factor and condition (animated agents vs. mathematical notations condition) as a between-subject factor to test whether participants' conceptual fraction knowledge improved more when scaffolding was provided with animated scaffolding agents than with mathematical notation (Hypothesis 1). There was a main effect of the measurement point [$F(1, 136) = 119, 38$, $p < 0.001$, $\eta 2p = 0.47$]. Estimated marginal means showed that the post-test scores ($M = 0.52$, $SE = 0.02$) exceeded the pre-test scores ($M = 0.36$, $SE = 0.02$), indicating that all participants improved their conceptual fraction knowledge while playing the game (Figure 8). However, there was no statistically significant interaction effect of

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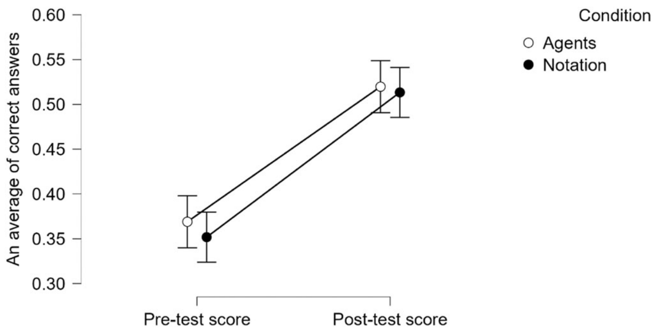

FIGURE 8 Estimated marginal means of two-way repeated measures ANOVA.

measurement point and condition nor a significant main effect of condition ($F(1, 136) = 0.13$, $p = 0.72$). This indicates that there were no significant differences between the conditions in the improvement of conceptual fraction knowledge [$F(1, 136) = 0.14$, $p = 0.71$]. Thus, the emotional design applied to animated scaffolding agents ($M = 0.44$, $SE = 0.02$) did not enhance learning more than scaffolding presented with abstract mathematical notations ($M = 0.43$, $SE = 0.02$) (Figure 8). Thus, Hypothesis 1 was rejected.

3.4 | Motivational outcomes

A one-way ANCOVA was conducted to compare the level of situational interest between the conditions while controlling for pre-intervention fraction interest. After controlling for pre-intervention fraction interest [$F(1, 135) = 45.19$, $p < 0.001$ $\eta 2p = 0.25$], there was a statistically significant difference in mean situational interest between the conditions [$F(1, 135) = 5.81$, $p = 0.017$, $\eta 2p = 0.04$]. Comparing the estimated marginal means showed that participants in the agent condition reported higher situational interest ($M = 3.33$, $SE = 0.12$) than in the notation condition ($M = 2.92$, $SE = 0.12$). That is, emotional design applied to animated scaffolding agents enhanced participants' situational interest more than scaffolding presented with abstract mathematical notations; thus, Hypothesis 2 was confirmed (Figure 9).

Another one-way ANCOVA was conducted to compare the level of situational fraction self-efficacy between the conditions while controlling for pre-intervention fraction self-efficacy. After controlling for pre-intervention fraction self-efficacy [$F(1, 135) = 35.45$, $p < 0.001$, $\eta 2p = 0.20$], there was a statistically significant difference in mean situational fraction self-efficacy between the conditions [$F(1, 135) = 8.10$, $p = 0.005$, $\eta 2p = 0.06$]. Comparing the estimated marginal means showed that participants in the agent condition reported higher self-efficacy ($M = 3.43$, $SE = 0.11$) than in the notation condition ($M = 2.99$, $SE = 0.12$). That is, emotional design applied to animated scaffolding agents enhanced participants' situational fraction self-efficacy more than scaffolding presented with abstract mathematical notations; thus, Hypothesis 3 was confirmed (Figure 10).

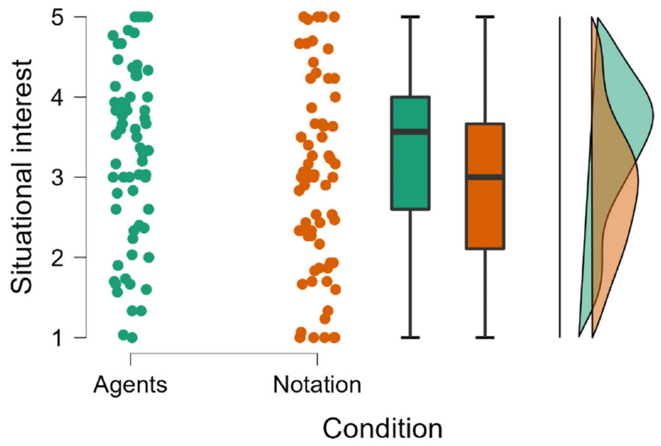

FIGURE 9 Estimated marginal means of one-way ANCOVA on participants' situational interest while controlling for pre-intervention fraction interest.

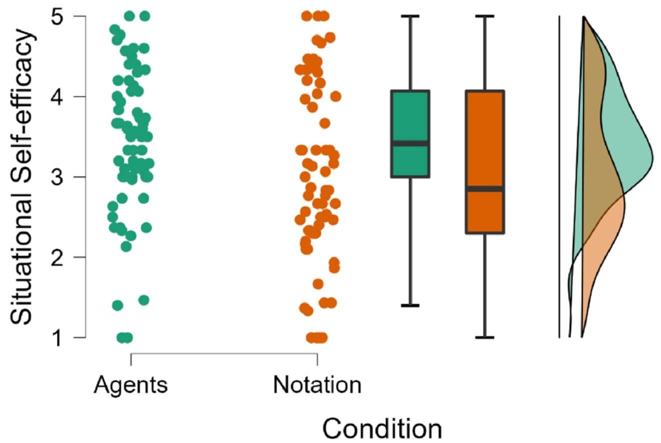

FIGURE 10 Estimated marginal means of one-way ANCOVA on participants' situational self-efficacy while controlling for pre-intervention fraction self-efficacy.

4 | DISCUSSION

This quasi-experimental study utilized a value-added research approach to provide novel insights into how emotional design applied to scaffolding affects students' learning, situational interest and situational self-efficacy. While the intervention improved the participants' conceptual fraction knowledge, we did not identify any differential learning effects between the scaffolding conditions. However, we found that participants in the animated agent scaffolding condition reported increased situational self-efficacy and situational interest compared to participants in the mathematical notation condition. In the following section, we will discuss these results extensively.

4.1 | Learning outcomes

Contrary to our expectations, the results indicated that emotional design applied to animated scaffolding agents did not improve

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learning more than scaffolding presented with emotionally neutral mathematical notations. This result contrasts past findings showing that emotional design enhances learning outcomes in digital learning environments (Mayer & Estrella, 2014; Plass et al., 2014; Um et al., 2012). Although we expected that emotional design would improve learning, we may have overlooked the cumulative effect of the overall visual and instructional design of the base version game, which already utilized factors of emotional design (see Table 1). The overall learning effect of the intervention shows that the base version of the game was effective in fraction instruction; thus, it is not surprising that no further learning differences between the two conditions were found in this relatively short intervention. In fact, the base version of the game utilized number line-based instruction and scaffolding, both of which have been found to enhance learning outcomes in game-based learning (e.g., Clark et al., 2016; Kiili et al., 2018). Furthermore, the visual design of the base version game featured several positive emotion-inducing features, such as the main game character offering emotionally rich immediate feedback. This may have diminished the potential additional beneficial learning effects of the emotionally designed animated scaffolding agents. Interestingly, Homer et al. (2019) had a similar feedback design in their emotional design game-based learning intervention, in which they detected a significant learning effect. However, the overall visual design of their base game did not feature as many emotion-inducing visual elements as was included in the base version of the current game. Mayer and Estrella (2014) state that emotional design elements can prime and sustain improved cognitive processing by directing attention to important instructional features. Therefore, these contradictory results can partly be explained by the overall varying degrees of the richness of the emotional design. Based on our results, we argue that adding emotionally designed elements to an already emotionally rich learning environment does not always lead to desired attentional behaviour and enhance essential cognitive processing.

Another viable explanation for the lack of positive learning effects could be that the scaffolding in both conditions used partitioning of the number line as the main instructional approach. As the scaffolding of the base version already highlighted important aspects of fraction instruction, it is possible that the emotional design of partitioning did not further direct players' attention to these essential instructional aspects. On the other hand, it is also possible that some participants may have had difficulties interpreting the mathematical instruction that the animated scaffolding agents were designed to provide. For example, the constantly moving playing companion dog may have distracted some participants more than the equivalent scaffold in the abstract mathematical notation condition: the static green bar on the number line. In these situations, the processing of animated scaffolding agents may have required extraneous cognitive resources, diminishing resources allocated for essential processing of instructional content (e.g., Sweller, 2020) and thus hindered learning. However, as we did not find any learning differences between the two conditions, this alternative interpretation is unlikely.

4.2 | Motivational outcomes

As expected, emotional design applied to scaffolding presentation significantly increased participants' situational interest compared with abstract mathematical notation while controlling pre-intervention fraction interest. This result follows previous findings suggesting that emotional design in digital learning environments increases students' interest (e.g., Endres et al., 2020; Um et al., 2012). According to interest theories, situational interest is triggered and maintained by interactions with feature(s) in instruction (Ainley, 2017; Knogler, 2017). That is, in our intervention, interaction with the worms and the companion dog appears to have enhanced situational interest. One possible reason why these scaffolding agents triggered situational interest is that they were designed to have anthropomorphic features (e.g., smiling faces). In addition, the animated movement of the worm and playing companion dog together with their appealing design may have increased general liking of the game, which has resulted in enhanced situational interest.

Moreover, the results of this study show that the emotional design applied to the representation of scaffolds significantly increased the participants' situational fraction self-efficacy. This finding provides additional support for the claim that self-efficacy is partly constructed by emotional states (Usher & Pajares, 2008). This study demonstrated that even relatively low exposure to emotional design in the form of animated agents can enhance participants' situational self-efficacy. One possible explanation for the improved self-efficacy is that the participants did not feel anxious and incompetent regarding failures. That is, the utilization of animated scaffolding agents may have hindered the negative effects of making mistakes by providing positive emotion-inducing support after the incorrect answer, thus enforcing game-based learning environments' capability to support players' feelings of graceful failure (e.g., Plass et al., 2015). The importance of this finding is magnified by the suggestion that self-efficacy is partly constructed by the interpretation of one's own experience (Usher & Pajares, 2008).

The found improvements in situational interest and situational self-efficacy are important as the improved motivational states contribute to the development of one's domain-specific self-concept (e.g., Eccles & Wigfield, 2020). Furthermore, according to situated expectancy-value theory (Eccles & Wigfield, 2020), the improvement of these motivational states positively influences engagement with the learning material.

5 | LIMITATIONS AND FUTURE STUDIES

The major limitation of this study is that it utilized convenience sampling. The sample consisted of students whose teacher registered their classes for the study. Thus, we did not have full control over the representativeness of the sample. However, the participating classes were from varying socioeconomic status areas in southern Finland. We decided to include participants from three grades. This was done, as all the included class levels are learning fractions and previous

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research shows that conceptual fraction understanding between these three grades does not differ much (e.g., Resnick et al., 2016). Furthermore, research suggests that the response to emotional design is similar within the included age groups (Brom et al., 2018). Because of these limitations, one should exercise caution when generalizing current results. Future studies should consider utilizing probability sampling techniques within one grade level.

The design of the study aimed at high ecological validity; therefore, we lack a full understanding of the exact procedures that were used in the classroom. Before the study, we provided clear guidance to the teachers describing the desired procedures, but these were not controlled. Moreover, as the study was conducted during regular school days, general schooling issues (e.g., National holidays, teachers' sickness, etc.) may have resulted in some participants not having sufficient time to complete the required tasks. Nonetheless, it is reasonable to assume that there have not been any systematic unwanted practices, which could have jeopardized the validity of the results.

As the focus of this study was to investigate how emotional design affects learning and motivational outcomes, we did not include direct measurements of emotions. Thus, the results of this study do not directly contribute to the discussion of how emotions are related to learning and motivation. The utilization of a value-added research approach allowed us to compare the instructional effectiveness of the base version of the game to the extended game version in which emotional design was applied to scaffolding. As the design of the base version was not emotionally neutral and emotional design was applied only to the subsidiary part of the game, our results should be carefully interpreted. That is, our findings do not directly advance our understanding of the general benefits of emotional design but reveal the effects of adding emotional design to certain instructional elements included in the game. In fact, we strongly encourage scholars to investigate the effects of adding emotional design elements to emotionally designed game-based learning environments to detect possible saturation threshold(s) of the effectiveness of the emotional design. These studies could benefit from, for instance, utilizing physiological process measures (for an overview, see Nebel & Ninaus, 2019), such as eye-tracking (e.g., Ninaus et al., 2020; Park et al., 2015), facial expression detection (e.g., Ninaus et al., 2019), or even think-aloud methods (e.g., Stark et al., 2018) to more deeply understand how learners perceive and process emotionally enhanced digital instruction.

6 | CONCLUSION

This study provides an example of how adopting a value-added research approach can advance our understanding of the effects of emotional design on scaffolding. In this study, we examined how extending the emotional design of the game-based learning environment to the game's scaffolding system affects learning and motivational outcomes. The results of this study indicate that, indeed, emotional design applied to scaffolds can improve the educational value of a game-based learning environment by enhancing players' motivational outcomes, that is, situational interest and situational self-efficacy. Nevertheless, we did not find further evidence that the emotional design of scaffolding results in enhanced learning if the game-based learning environment already uses emotional design features. However, the intervention significantly improved the participants' fraction understanding, providing further support for utilizing number line-based instruction and scaffolding in game-based fraction learning.

These results imply that the possible added value of emotional design may depend on its implementation. That is, the benefits of adding new emotionally designed elements to a game-based learning environment may be strongly related to the emotional richness of the environment. Therefore, future game-based learning studies examining the effectiveness of emotional design should carefully consider the design differences of the compared game versions regarding how emotionally rich they are. Overall, this study provided important insights and considerations for designing such studies and demonstrated how emotional design can be used to improve motivational outcomes in game-based learning.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

PEER REVIEW

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DATA AVAILABILITY STATEMENT

Data available on request from the authors.

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