Flow Experience and Situational Interest in Game-Based Learning: Cousins or Identical Twins

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Abstract

While game-based learning seems to be an effective instructional approach, the underlying learning and engagement mechanisms of games are still poorly understood. In the current study, we investigated to what extent flow experience and situational interest are different indicators of engagement in game-based learning. Fifty-two Finnish 5th graders played a game on fractions at home during COVID-19 enforced distance learning. Flow and situational interest measures were embedded directly into the game environment. Results revealed that although flow experience and situational interest constructs share similar components, they also differ. In particular, regression analysis indicated that situational interest is mostly related to immersive aspects of flow. Moreover, learning gains achieved by playing the game and situational interest were positively related – a relation not found with flow. Although flow was not related to learning gains, it seems to be a more competence-oriented construct than situational interest as it was positively correlated with in-game performance. The design of the game successfully supported weaker students with adaptive scaffolds and in-game self-reporting measures worked well. Taken together, even though situational interest and flow share similar components, both constructs are important for multifaceted assessment of engagement in game-based learning. Theoretical and practical implications for engagement research and game design are discussed.

Keywords: *Engagement, Flow experience, Situational interest, Game-based learning, Adaptive scaffolding, Fractions;*

1 Introduction

In recent years, the use of game elements in learning environments has increased remarkably [1]. A growing body of evidence indicates that game-based instruction can be more effective than conventional instruction [2]–[5]. However, regardless of continuously increasing scientific outputs, the underlying mechanisms of successful game-based learning are still poorly understood [6], [7]. This might partly explain the finding of a meta-analysis by Wouters and colleagues [2], according to which, game-based learning is not experienced to be more motivating than conventional instructional methods. It has been argued that the intrinsic appeal of games can be explained by their ability to satisfy basic psychological needs for competence, autonomy, and relatedness [8]. However, this cannot be taken for granted and therefore game-based learning designers have a unique concern to ensure the quality of playing experience [9] and maintain pedagogical objectives [10], [11]. In other words, game-based learning solutions need to be well designed to facilitate learning, motivation, and engagement.

Although some researchers tend to use the terms “engagement” and “motivation” interchangeably, these terms should not be considered as totally parallel. According to Russell, Ainley, and Frydenberg [12], “Motivation is about energy and direction, the reasons for behavior, why we do what we do.” whereas “Engagement describes energy in action, the connection between person and activity.”. In line with this, Schwartz and Plass [13, pp. 55] have proposed that "Engagement in games is the active and focused investment of effort in a game environment". As research has shown that highly engaged learners are more likely to learn more than disengaged learners [14], the evaluation of engagement is an important part of educational game design. Unfortunately, the field of game-based learning lacks a definitional agreement of the constructs that can be used to measure engagement and motivational aspects [15], [16]. To contribute to discussions about appropriate engagement measures in game-based learning, this paper focuses on flow experience [17], [18] and situational interest constructs [19], [20], [21] that have been used to measure the quality of learning experience. That is, we seek to examine these constructs as proxies of engagement, their associations, and potential areas of distinction in the context of an adaptive math game. In other words, the purpose of the present study is to shed light on to what extent flow experience and situational interest are in fact different terms for engagement in game-based learning or if they really do represent different takes on engagement and learning. Furthermore, as engagement is a highly dynamic, fluctuating, and context-dependent construct [22], we considered ways to measure situational engagement without disturbing the playing experience. The knowledge gained from our investigation will inform subsequent research on engagement in game-based learning and the design of situational engagement measures.

In the following, we will first provide a brief overview on engagement and its theoretical relationship to flow and situational interest, before we consider game design principles grounded on these constructs. After that we shortly review game-based math learning studies that have focused on flow and situational interest. Based on this theoretical framing we end the introduction with a short overview of the present study including the laid hypotheses.

1.1 Flow and situational interest as measures of engagement

Boekaerts [23] has pointed out that the literature on engagement is quite diverse and researchers approach engagement in various ways. In line with this, Eccles [24] has concluded that engagement is an elusive, emergent, and multifaceted concept that is hard to measure and complex to theorize. Nevertheless, there is increasing agreement that student engagement consists of behavioral, emotional, and cognitive dimensions [14], [25], [26]. Behavioral engagement can be defined in terms of consistency of effort, participation, attendance, and other desired academic behaviors; Cognitive engagement in terms of investment in learning, depth of processing, and/or the use of self-regulated metacognitive strategies; Emotional engagement in terms of learners' affect and emotions in learning environments, such as interest, boredom, or anxiety. Although some researchers link interest to emotional engagement and motivation to cognitive engagement, motivation literature usually considers interest as a subset of motivation [27]. Consistently, Ainley [27] has stated that at its simplest form, interest is a core psychological process energizing and directing students’ interaction with certain activities in the learning environment.

The concept of flow provides an integrated view of engagement that includes all the dimensions described above (cf. [24]) and is one of the most popular constructs to describe playing experience [17], [28]. Flow often discussed in the context of intrinsic motivation [29] – refers to optimal experience, where a goal directed activity is so pleasant that a person wants to perform it again and again without being concerned with what he will get out of it [30]. The experience of flow is beneficial in learning as it can be considered as a reward that motivates individuals to increase their competence [31]. “The state of flow is characterized by a combination of several specific aspects, namely, (1) concentration, (2) a merging of action and awareness, (3) reduced self-consciousness, (4) a sense of control, (5) a transformation of time, and (6) an experience of the activity as intrinsically rewarding" [32, pp. 52]. Rooted in flow theory, student engagement has been conceptualized as the heightened, simultaneous experience of concentration, interest, and enjoyment [26], [33]. Previous research has proposed that flow theory provides a solid foundation for analyzing and designing engagement in educational and serious games [17], [18]. Furthermore, in the context of educational game design, challenge-skill balance, clear goals, immediate and cognitive feedback, sense of control, and playability are identified as flow antecedents that should be carefully considered when designing game-based learning environments [7].

Situational interest is another motivational construct that may partly reflect and explain students' engagement in game-based learning. Situational interest refers to attentional and emotional reactions that occur at a relatively limited or defined point in time and are caused by some feature(s) in the instruction itself [34]. If the situational interest triggered by the game can be maintained for a longer period of time, it may eventually develop into individual interest, a relatively enduring tendency to reengage with similar activities or content over time. The literature on situational interest has identified enjoyment, interest, focus/concentration, and feeling entertained in response to a triggering event as main components of situational interest [35]. Furthermore, a growing body of literature suggests that increased situational interest may positively affect attention, cognitive processing, and persistence [36] and thus lead to increased engagement [37] and individual interest.

Despite several similarities between situational interest and flow, there are also clear differences. For example, fluent performance and sense of control are integral components of flow experience, whereas these are not essential characteristics of situational interest. Furthermore, clear goals and immediate feedback are important antecedents for flow [4], but these components are not clearly emphasized in situational interest research. Nevertheless, in general, both interest and flow theory focus on explaining the reasons for engagement [29]. Although flow and situational interest clearly share characteristics with engagement, Boekaerts [23] has argued that it is important to differentiate these constructs from engagement as engagement refers to all types of student interactions with the learning material and contextual factors. However, flow and situational interest can be seen as a specific form of engagement that emerges in the situation. In fact, Eccles [24] points out that some researchers consider engagement as a moment-to-moment, state-like construct and some as a more stable, trait-like construct that changes gradually over a longer time period. Flow theory is well aligned with the state view and flow state is sometimes considered also as a peak experience. Similarly, situational interest refers to the state-like interest that interaction with the environment activates [38]. As game-based learning environments are rich and dynamic in nature, the state-based approach fits well to investigate engagement in games. Thus, although flow experience and situational interest provide only a somewhat limited view on certain aspects of engagement, in line with previous research [16, 24], we use these constructs as strong proxies to measure engagement in a game-based learning environment. Next, we will consider how flow and situational interest inform the design of game-based learning environments.

1.1.1 Design principles for learning and engagement

Engagement in learning activities arises from reciprocal interaction between learners and a learning environment [39]. Scholars have found that learning environment(s) that feature fun, challenge, and utilize computers may increase situational interest [40]. Interestingly, these same concepts are often mentioned as scholars describe features that make game-based learning an engaging and effective instructional approach. Kiili *et al.* [17] emphasize that subjective experience cannot be directly designed – instead only the context, for example, the game-based learning environment, from which the experience and engagement arouse can be designed.

Several theoretical models and frameworks grounded on flow theory have been proposed for evaluating games [41] and for designing engagement for educational games

[17]. For example, Sweetser and Wyeth [41] proposed a GameFlow model for evaluating enjoyment in games. Although the GameFlow model distinguishes several elements and criteria for achieving enjoyment in games, it does not provide an adequate foundation to design game-based learning environments. The flow framework for educational games [17] extends the GameFlow model and provides also a means to optimize engagement and learning outcomes. Therefore, we use this framework and cognitive theory of game-based learning [42] to consider design principles for supporting learning and engagement in game-based learning environments. Particularly, we focus on design aspects that are relevant in the light of the game that was developed for the present study.

With respect to flow theory, clear goals, feedback, and learning tasks that are balanced for players' skills are important prerequisites of engagement and enjoyment [4]. The goals of the game should be clear and direct the player's attention to the learning objectives of the game. If the learning objectives are not intrinsically integrated with gameplay [10], the game may fail to produce educationally effective experiences. The feedback that the game provides should be tied to learning objectives and inform the player about progression toward the goals. Both immediate and cognitive feedback should be provided. The immediate feedback keeps the player focused on the tasks and helps the player to perceive the consequences of his or her actions. On the other hand, the aim of cognitive feedback is to stimulate the player to reflect on his experiences and facilitate generative processing [42], i.e. making sense of the learning content. For example, elaborated feedback and scaffolding could be used to support sense-making. Overall, game designers should ensure that the game provides a well-balanced combination of both interesting game features maintaining the motivation for generative processing and effective instructional features directing the player's attention to the essential content of the game without overloading players' cognitive capacity. It is important to recognize that players' interest may decrease as the novelty of the game-based learning environment fades [43]. One way to overcome this effect is to utilize an adequate set of different game mechanics to repeatedly foster situational interest [9], [44], [45]. However, game mechanics should be intrinsically integrated with the learning content of the game [10].

Challenge-skill balance is theoretically the most important aspect of flow. According to Kiili *et al.* [17] the aim of an educational game design is to provide the players with challenges that are balanced according to their competence levels to maximize engagement and learning outcomes. The authors presented an extended three-channel model of flow that explains the dynamics of challenge-skill balance and provides means to design dynamic difficulty adjustment systems for games (Figure 1). The model shows that flow is a linear channel where both P1 and P4 represent situations where skills and challenges are in balance and player experiences flow. If the challenges provided by the game are too easy the player tends to feel bored (P2) and, in contrast, if the challenges are too difficult, the player tends to feel anxiety (P3). Although both P1 and P4 situations can be equally enjoyable, P4 is more complex because the challenges involved and skills required are greater. Flow is not a stable state, because occasionally the player tends to either experience boredom or anxiety, which may motivate the player to strive for the flow state to experience enjoyment again. For instance, when feeling anxious, the player might be motivated to, for example, train certain skills to perform better in the game. In contrast, a bored player might select more challenging tasks or goals in the game. This dynamic characteristic explains why flow inducing activities tend to lead to growth and discovery. However, players are not always self-directed in this reflective process or the game environment does not provide means for players to adjust challenge-skill balance. In such situations, players need external support to achieve the flow state. Thus, the extended three-channel model of flow includes a zone of proximal development [46], which refers to the difference between what a player can do without help and what he or she can do when support is provided. That is, the flow zone can be extended by providing appropriate support for the player when the required challenge exceeds the player's skills. Scaffolding is one example of instructional support that has been successfully utilized in game-based learning [47]. Scaffolding refers to support provided during the learning processes to assist a learner in achieving something that would be hard or even impossible without assistance [48]. That is, scaffolding temporarily reduces the demands of the task to facilitate learning. This requires constant assessment of player's competencies; for an overview, see [49] and providing just the right amount of support so that the player still has to do the majority of the work to obtain the preset goals of the game. Taken together, game developers should implement dynamic difficulty adjustment systems [7] into the games to facilitate engagement and learning.

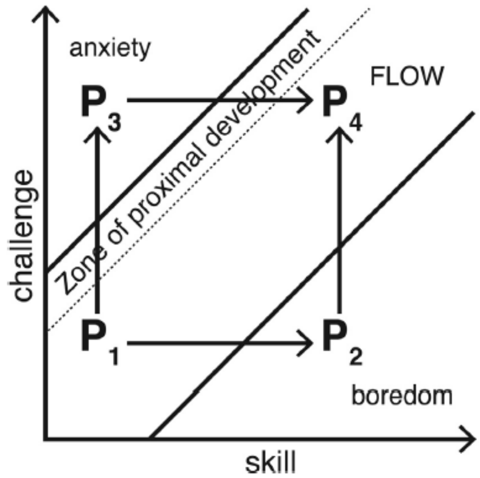

Figure 1. *The extended three channel model of flow*

Recent research is in line with the theoretical considerations presented above as results suggest that learning environments that utilize adaptive features can be more effective than non-adaptive learning environments; for reviews, see [50], [51]. Adaptive game features might be particularly useful in challenging topics such as fractions – the learning domain of the present study. Adaptive game features might also engage and support students that have negative feelings about the learning domain, such as students with higher math anxiety. Math anxiety is known to reduce mathematics performance already at the primary school level [52]–[54]. Especially the intrusive thoughts that students experience while they are anxious tax unnecessarily their working memory [55], [56], which may undermine learning. Thus, game-based learning environments that allow graceful failure – failure as an expected and intended design choice by providing a safe virtual environment [9] – have a potential to engage also math-anxious students as they do not feel continuous external pressure in the learning environment. Thus, on a theoretical level, graceful failure might be a relevant antecedent for the loss of self-consciousness aspect of flow. This means that during flow a player is totally focused on playing the game and is able to forget all unpleasant things. Thus, there is no room for self-scrutiny and a player can totally ignore what others may think of him or her. Such a state of mind is very engaging and facilitates exploratory behavior.

1.1.2 Measuring engagement in game-based learning

In addition to problems to define engagement, it has been acknowledged that the measurement of engagement is challenging. Although innovative approaches to measure engagement have emerged recently [57], for an overview, see [58], in this paper, we focus on self-reports that are still the most commonly used engagement measure [59] regarding also assessment of flow experience [15] and situational interest [59].

Although measures that are based on intrinsic motivation theories (e.g., flow and self-determination theory) are widely used to study engagement in game-based learning, some scholars have also attempted to ground engagement measures on interest theories. These attempts are in line with calls to incorporate more situational measures into game-based learning research. For example, situational interest has been used in comparing engagement levels that game-based instruction and more conventional instruction produce [61] as well as comparing interest levels that different game mechanics [44] and playing approaches [62] induce. Surprisingly, in these studies, situational interest was measured only once after the playing treatment, and thus the results do not reflect the situational engagement adequately. However, some scholars have attempted to better capture the fluctuating nature of situational interest by administering one situational interest item several times during the game playing sessions – sometimes referred to as microanalytic assessment [63], [64]. As an example, Rodríguez-Aflecht *et al.* [43] measured situational interest in Number Navigation Game by using a statement (“I like this game” on a Likert scale of 1 to 5) after each game level. They decided to use one item scale to avoid disrupting players' engagement in the playing activity. Split-half reliability analyses indicated that the one item approach worked well. They found out that situational interest decreased over time when students played the game. They also reported that game-based learning was not unequivocally motivating as it did not trigger situational interest for every student, or it triggered, but the game did not maintain it. In general, their data collection approach resembles the Experience Sampling Method (ESM) that is very common in flow research and allows exploring flow experience patterns [65]. Ronimus and colleagues [66] also measured engagement with one item due to participants' young age. They used the same Likert scale statement several times to measure how much the players enjoyed playing the game.

Nevertheless, a systematic literature review on flow in game-based learning revealed that in all included studies flow questionnaires were administered only once after the gameplay session, and thus none of the studies utilized the experience sampling method [15]. However, in a recent study, flow experience was measured at two time points during a math game intervention and the results indicated that the level of flow decreased towards the end of the intervention [67] showing a similar trend as in the above discussed situational interest study [43]. Nevertheless, the study also revealed that the success or the failure in the immediate game level played before the flow questionnaire did not distort the answering. This may indicate that other qualities of the experience influence the level of flow more than just the recent success in the game. On the other hand, the use of the experience sampling method has been criticized, as the repeated answering to long flow questionnaires may break down the flow state during the playing session and decrease the validity of the measurement [15]. Thus, non-disturbing ways to administrate flow measures are called for, especially with younger children who may be less able to easily access their own experiences either after playing or with external assessment instruments.

Although several scales have been used to measure flow experience in game-based learning [15], in the present study we use the Flow Short Scale [68], because it has been successfully used in several game-based learning studies in the mathematics domain [66 67], [69], [70] and in some studies, its subscales, fluency of performance and absorption by activity, are analyzed [69], [70] allowing a more fine-grained basis for examining the relation between flow experience and situational interest. For instance, Ninaus *et al.* [70] found a game-based version of a math task as compared to its non-game-based equivalent to achieve higher scores on fluency of the performance subscale. No difference was found on absorption by activity subscale.

1.2 Present study

The use of games in education is often justified in terms of their potential to enhance learning by engaging players [13]. In contrast, previous research has shown that in the big picture, game-based instruction is not (always) more engaging than conventional instruction [2]. One possible reason for this lack is that previously used engagement measures may not properly capture engagement in games. As well, poor instructional design of games may disturb the playing experience. In the present study, we applied powerful game design principles, grounded in interest and flow theories, to design a math game that includes adaptive scaffolding and then used this game to investigate player engagement and learning gains. We used flow experience (post-game assessment) and situational interest (in-game assessment) as engagement measures. The primary goal of the present study was to examine whether flow experience and situational interest are just different terms reflecting the same mechanisms behind engagement in game-based learning or if they really grasp different takes on certain aspects of engagement. In line with this, we also considered the feasibility to use flow and situational interest constructs as proxies of engagement in the context of playing a math game. The secondary goal was to evaluate the implementation of the game and examine the relation between engagement, game performance, and learning gains that the game produces.

To the best of our knowledge, the relation between situational interest and flow experience have not been directly examined in a game-based learning context yet. In addition, there is limited understanding of the relation of these engagement constructs with game performance and learning gains in a math game context – a limitation of the literature we also address. Nor is it known how other relevant background variables, namely math anxiety and prior knowledge, are related to situational interest and flow experience in a game-based learning environment including adaptive features. With the present study, we aim to reduce the above-mentioned gaps in the literature by testing the following five hypotheses and deepening the achieved understanding through exploratory analyses.

(H1) As flow experience and situational interest constructs share several common characteristics, we expected that flow experience and situational interest have a positive relation. (H2) As flow experience should be associated with high in-game performance [67 68], we expected that in-game performance and the level of flow are positively related. (H3) As situational interest has been linked to enhanced performance [71], [72], we expected that also in-game performance and situational interest are positively related. Based on previous research on flow [15] and situational interest [73], we expected that both (H4) flow and (H5) situational interest are positively related to learning gains.

In addition to these hypotheses, we also carried out preliminary analysis examining the effectiveness of the scaffolding mechanism, in order to confirm that the game experience of the participants was not harmed by poor alignment of challenge and skills. Additional exploratory analyses examined the relation of math anxiety with flow experience and situational interest. Despite evidence suggesting that the effects of math anxiety on performance are mediated by contextual factors [74], we do not know of any previous studies examining the relation of math anxiety with flow and situational interest in game-based mathematics learning. Therefore, we investigated these relations in an exploratory fashion. In addition, exploratory analyses were conducted to examine the relation of prior knowledge with situational interest and flow experience.

2 Method

2.1 Participants

This study included 52 fifth-grade students (age M=11.3, SD=.449; male n=28, female n=24) from eight schools located in the city of Helsinki, Finland. The study was approved by the ethical board of the city of Helsinki and all students had parental permission. Originally, over 200 students started the study, but as the study was conducted in spring 2020, the COVID-19 pandemic, unfortunately, forced the schools into a lockdown, which greatly affected our data gathering and participant inclusion criteria.

2.2 Description of the game

We used our math game research environment, an extended version of the Semideus number line game engine [5], to create a Number Trace fraction game for this study. The math game research environment allows the creation of web-based math games that can include a variety of different kind of number line-based tasks and instructional features, and supports collection of both behavioral and self-reported data. The mathematical content (fractions) was intrinsically integrated with the game mechanics. That is, the core mechanic of the game is based on a number line estimation, which requires users to indicate the position of a given number on a horizontal line with only its endpoints specified (e.g. where goes 4/5 on a number line ranging from 0-1). Ample research indicates that the number line estimation task can be used to assess, as well as train, students' understanding of number magnitude; for a review, see [75]. Positive learning outcomes using number line game mechanics have been reported previously. See for example a systematic review of rational number games [10].

In the game, the player controls a dog character and tries to locate bones hidden in the forest. The location of the bone is displayed as a symbolic fraction, a visual representation, or a mixed number. The player has to estimate the location and walk the dog to it. On some tasks, the walking was replaced with sequential jumping where the jump length is fixed to some mathematically meaningful sequence (usually a unit fraction of the task). For example, if the estimated value is 3/7, the dog would need three jumps (3 * 1/7) to move from the left side of the number line to the bone. Some tasks also included enemies that had to be avoided or destroyed. The number line ranged either from 0 to 1 or from 0 to 5. The different fraction presentations, number line ranges, jumping movement, and enemies not only broadened the offered learning content but also provided new features over the course of the play to freshen up the game and to repeatedly catch and foster situational interest. Further, the animal characters and the storyline were used to facilitate immersion in the game.

The game provided clear goals to the player and contained several feedback mechanisms. On the task level, the player's goal was to locate bones as accurately as possible. For inaccurate estimates (i.e., estimates more than ±8% away from the correct location) the player lost virtual energy. The 8% accuracy threshold was determined based on our previous studies in Finland [5], [76]. If the player ran out of energy, the level ended and had to be replayed. The player had two attempts on each task. When the player estimated a target fraction accurately enough he found the bone and earned points. The number of earned points depended on estimation accuracy. Moreover, after successful estimation or after the second inaccurate estimation attempt, the correct location of the bone was shown with a green marker on the number line. Additionally, the estimation accuracy percentage was shown. Figure 2 shows examples of positive and negative feedback provided for the player. In each game level, the player could earn 1-3 stars that were also based on playing performance: one star for completing the level, one star for locating enough bones, and one star for completing the level within the energy loss limit. Thus, both immediate and delayed feedback was provided and goals of the game directed players' attention to fraction magnitudes.

Figure 2. *On the left: Positive feedback after successful estimation. On the right: Negative feedback after unsuccessful estimation.*

The game recorded players playing performance and formed a competence model of each player. The competence model was used to provide adaptive scaffolding for struggling players. The aim of scaffolding was to balance the challenge level of the game to the skills of the weaker players and facilitate generative processing. The adaptive scaffolding was based on competencies in three categories: proper fractions, improper fractions, and mixed numbers. The competence level was the mean of the player's five most recent estimations in previous game levels on the tasks relevant to each category. Only five estimations were used in the competence calculations as we wanted the competence level to respond fast enough to students' performance. Different scaffolds were triggered to assist the player based on the competence levels relevant to the task at hand. That is, if the competence model indicated that the player had had severe difficulties in similar tasks earlier in previous levels (for example, if the estimation accuracy was less than 80%; rules varied depending on the task types), the player was assisted immediately at the beginning of the task. On the other hand, if the player had had minor difficulties with tasks dealing with the same competence (for example, if the mean estimation accuracy was less than 80-90%; rules varied depending on the task types), scaffolds were provided only if the initial answer (first attempt) was incorrect. Furthermore, the scaffolds were often new features and were designed to also catch and maintain players' interest in the game.

The scaffolds included in the game:

- Shows the improper fraction as a mixed number. For example: 5/2 → 2 ½
- Shows the fraction number as a pie graph to provide visual representation.
- Subtracts the fraction to the smallest common factor. For example: 4/8 → 1/2
- Summons birds to divide the number line into equal sections based on the denominator of the fraction to be estimated. For example: 3/8 → divide into eight sections
- Summons worms to visualize improper fractions or mixed numbers (see Figure 3).
- Activates the jumping shoes for jump movement (see Figure 3).

Figure 3. *On the left: An example of a proper fraction task in which a "jumping shoes" scaffold has been activated. On the right: An example of a mixed number task in which a "Worms" scaffold has been activated.*

The used game engine allowed us to implement in-game questionnaires (self-report measures). Instead of a basic number line estimation task, a question or a statement is provided to the player. Figure 4 shows examples of situational interest and flow experience measures used in the present study. The answer is given using the core number line mechanic, but this time the exact value is clearly visible above the dog, so the player knows exactly what he/she is about to answer the question. The number line range defines the used answer scale. For example, a range from 1 to 5 means that the question has a continuous scale from 1 to 5 with the range definitions, "Completely disagree" and "Completely agree", shown in the text bubble.

Figure 4. *On the left: A task used to measure situational interest. The answer is given on a continuous scale from 1 to 5 with the exact value shown. On the right: A task from the flow questionnaire level.*

2.3 Measures

Pretest and posttest. We had planned to administer both pretest and posttest using a browser-based, non-gamified platform, developed by the authors. But since we could not administer the posttest due to Covid related school lockdown, we had to form an "ad-hoc pretest" and an "ad-hoc posttest". The pretest was conducted with the browser-based platform as planned and the test included several task types. However, to align the pretest with the posttest, only the fraction estimation tasks of the original test were used as a final pretest. The test contained eight number line estimation items (3/5, 3/7, 10/37, 2/3 for number line ranging from 0 to 1 and 22/7, 9/2, 2½, 1⅔ for number line ranging from 0 to 5). The student estimated the location of a fraction by dragging a marker on a number line. Students' pretest score was determined by their fraction estimation accuracies (i.e. how closely they estimated the value to the true location of the magnitude). For the posttest score, the estimation accuracies from the tasks on game levels 12 and 14 were used as those levels contained similar tasks to the pretest (proper fractions, improper fractions, and mixed numbers) with the same ratio. The answers affected by scaffolds (0.2% of all answers) were excluded. Although the digital pretest and the game-based posttest are not entirely comparable, they can be used as test measures as previous studies have shown that the game-based number line estimation performance correlates strongly with the paper-based number line estimation performance [5], [76]. Kiili and Ketamo [5] also found out that the game did not favor frequent gamers over casual or non-gamers performance-wise.

Math anxiety was measured with three items created by the authors that were derived from other popular math anxiety questionnaires [77] but were intentionally rephrased to measure fraction related anxiety as part of the prior knowledge test: "I get anxious when I think about fraction tasks", "I am worried that I will not learn fractions" "While doing fraction tasks, I cannot think clearly" with a scale ranging from 1 to 5 (disagree to agree).

Flow experience was measured with a slightly modified version of the Flow Short Scale [68] using a total of 10 items (6 items for fluency of performance subscale; 4 items for absorption by activity subscale). The statements were changed to past tense and revised the activity to refer to game playing (see Appendix A). Furthermore, the answering was done on a continuous scale ranging from 1 to 7 (completely disagree to completely agree) instead of the Likert scale used in the original scale (1 = Not at all; 4 = Partly; 7 = Very much).

Situational interest was measured at the end of six levels with a question "The tasks of this game level were interesting" with a continuous scale ranging from 1 to 5 (i.e. completely disagree to completely agree). The use of a single-item scale is justifiable as i) a previous study [43] demonstrated that single-item scale can be a valid approach to measure situational interest without disturbing playing experience, ii) one well operationalized item can yield better information than multiple, poorly operationalized items [78] and iii) single-item scales may be advantageous because respondents may resent being asked questions that appear to be repetitions [79].

Game performance in the Number Trace game was measured using the estimation accuracy percent of the initial answer on each task in levels 10-18 (see procedure). If the student answered incorrectly, the game offered another attempt, but the latter answer was not taken into account in the game performance measurement.

Scaffold count was calculated by tracking the number of tasks, where the student was scaffolded.

2.4 Procedure

The teachers were supposed to hold five lessons (45 minutes each) within a four-week period, in which the students would complete the pretest, play the Number Trace game and complete the posttest. During this period, the teachers were instructed not to teach fractions in any other way. But, as mentioned, school lockdowns interrupted the intervention, which forced us to re-evaluate our participant inclusion criteria for the study. Some teachers decided not to continue playing, but with the classes that continued the playing at home, we faced another issue: as different classes had progressed at different schedules, there were some variations on how far the students had progressed on the game content before the lockdown that we had to take into account in defining participation inclusion criteria.

Students were selected for the study based on the following criteria (figure 5). First, every student had to have completed the pretest at school. Second, we decided that we will analyze data only from such game levels that all participants have played either at school or at home as the playing context, such as surroundings, and interaction with teacher and peers, affect engagement. Based on this criterion, we finally included students that had played the levels 10-18 and the subsequent flow questionnaire level at home. Levels 19-24 were excluded because too few of the included students managed to complete them. Further, also the planned posttest was excluded as we could not administer it during the school lockdown. Each level contained 10 fraction estimation tasks, meaning that the game performance data from 90 tasks were analyzed in the present study.

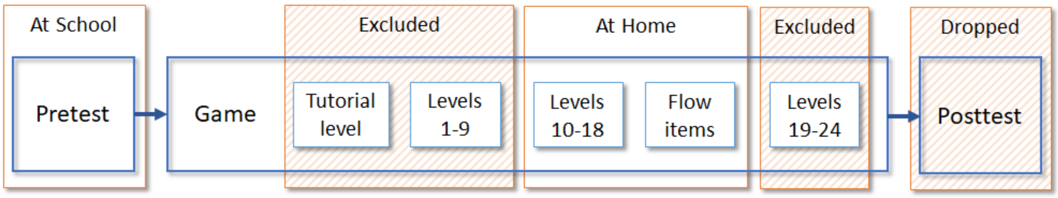

Figure 5. *The planned procedure of the study, which was interrupted by distance learning due to COVID-19. The parts marked with "Excluded" were not included in the data used in the study.*

Situational interest was measured in levels 10, 13, and 16 using an in-game question (see section 2.3). After level 18, the students completed a level that included the modified Flow Short Scale items. The flow level started with one training item, which was excluded from analyses. The training item was used to remind students how to answer the in-game questionnaire items, and to clarify that tasks of the flow level are different from previous levels including fraction tasks.

2.5 Analyses

Anomalies, such as answering patterns and too short answering durations were explored from the self-reports data. As a result, we identified two students, who both had very short answering durations (all answers less than two seconds) in the flow questionnaire items, and all their answers were at the default value (i.e. where the answering marker was when the task first appeared on the screen). Thus, these students were omitted from analyses.

Overall, the data was normally distributed except in case of math anxiety. On a continuous scale from 1 to 5 (low to high anxiety), about 70% of the answers were less than 2 and only about 10% were 3 or higher showing that students did not generally experience high math anxiety. Therefore, the data can be considered skewed (M = 1.74, SD = .87, skewness = 1.75, kurtosis = 3.56). Thus, we run both Pearson's and Spearman's correlation analyses to study relationships between different variables. A forced-entry multiple regression analyses were run to determine how subscales of flow predict/explain situational interest.

The learning gain was computed by subtracting the pretest score from the posttest score and a paired-samples t-test to examine the learning gains. The effect size (Cohen's d) was calculated to evaluate the magnitude of the learning gains.

The reliability of flow experience and math anxiety scales was examined with Cronbach's alpha. Test-retest approach (Spearman's rank correlation coefficient) was used to evaluate the reliability of the repeated one item situational interest measure. The reliability of situational interest was evaluated based on two situational interest measuring points (levels 7 and 13) that included exactly the same tasks with respect to math content and game mechanics (only the playing context may have varied: home or school).

3 Results

The descriptive statistics for the measured variables and reliabilities of the used scales are listed in Table 1 and correlations between variables in Table 2. The flow experience and its subscales, as well as math anxiety scale had at least acceptable internal consistency, as determined by a Cronbach's alpha of .76-.87 [80]. Test-retest reliability for situational interest ratings was .56. This is acceptable when considering the fluctuating nature of situational interest and the assumption that learning gains between the measuring points may have affected players' situational interest.

Table 1. *Descriptive statistics and reliabilities of scales.*

	Mean	SD	Median	Scale (reliability)
Flow Experience	4.42	1.21	4.37	1-7 (α = .87)
Fluency of Performance	4.72	1.23	4.85	1-7 (α = .85)
Absorption by Activity	3.87	1.52	4.04	1-7 (α = .76)
Situational Interest	3.36	1.08	3.55	1-5 (α = .77)
Math Anxiety	1.74	0.87	1.48	1-5 (α = .76)
Game Performance	93.90	2.04	93.90	0-100%
Pretest (Pior Knowledge)	84.30	7.18	83.50	0-100%
Posttest	92.10	3.15	92.70	0-100%
Learning Gains	7.72	6.36	9.02	0-100%
Scaffold Count	5.85	6.07	4.00	0-60

Table 2. *Correlations (Pearson's r †) between the measured variables.*

	1	2	3	4	5	6	7	8
1 Flow Experience	1							
2 Situational Interest	.41 **	1						
3 Math Anxiety	.08	-.004	1					
4 Game Performance	.34 *	.02	.05	1				
5 Pretest (Prior Knowledge)	.05	-.38 **	-.28 *	.43 **	1			
6 Posttest	.29 *	.05	-.20	.72 ***	.46 ***	1		
7 Learning Gains	.08	.45 ***	.22	-.13	-.90 ***	-.03	1	
8 Scaffold Count	-.18	.07	.22	-.66 ***	-.53 ***	-.71 ***	.24	1

Note. * p < .05, ** p < .01, *** p < .001

† The same analysis with Spearman's correlation did not change the results substantially

3.1 *Game performance indicators and learning gains*

Students performed very well in the game, as the mean estimation accuracy (i.e. game performance) was 93.9%. The best performing players completed the analyzed part of the game play (levels 10-18) without seeing any scaffolds, while the most struggling student received scaffolds on 23 tasks (M = 5.85, SD = 6.07). As designed for, the adaptive scaffolding system provided more scaffolds to students with weaker prior knowledge as indicated by the medium negative correlation ($r = -.53$, $p < .001$) between scaffold count and prior knowledge (pretest). The large negative correlation ($r = -.66$, $p < .001$) between scaffold count and in-game performance was also expected as the scaffolds were targeted for low-performing players.

A paired-samples t-test was conducted to compare estimation accuracy in the pretest and in the posttest. The accuracy was significantly higher in the posttest (M = 92.1, SD = 3.15) than in the pretest (M = 84.3, SD = 7.18), $t(51) = 8.75$, $p < .001$, $d = 1.21$. The increased estimation accuracy (i.e. learning gains) had a large negative correlation with prior knowledge ($r = -.90$, $p < .001$). This shows that the students with the most room for improvement (that is, their starting estimation skills were low) also improved the most.

3.2 *Relation of flow experience and situational interest in game-based learning*

In line with Hypothesis 1, we found that flow experience was related to situational interest, $r = .41$, $p = .002$. In order to get a deeper understanding of this relation, we ran a multiple regression analysis with situational interest as a dependent variable and the two subscales of flow – fluency of performance and absorption by activity – as predictors. The results of the forced-entry multiple regression [$F(2,49) = 9.15$, $p < .001$; adjusted $R_2 = .24$] indicated that absorption by activity (standardized Beta = 0.59, $p < .001$) explained 27.2% of the variance. Fluency of performance, however, did not account for a unique part of the variance in situational interest (standardized Beta = -0.13, $p = .41$). The correlation between the subscales was large ($r = .60$, $p < .001$), which is consistent with [12].

In line with Hypothesis 2, we found a correlation, albeit only a small one, between experienced flow and in-game performance ($r = .34$, $p = .015$). This suggests that the students with better in-game performance had a higher experience of flow. Contrary to Hypotheses 3, situational interest did not correlate with in-game performance. The data did not support Hypotheses 4 either, as flow experience did not correlate with learning gains ($r = .08$, $p = .56$). However, in line with Hypothesis 5, situational interest did correlate positively with learning gains ($r = .45$, $p < .001$). Finally, we explored the relation between prior knowledge and engagement. We found a small negative correlation between prior knowledge and situational interest ($r = -.38$, $p = .006$), but it did not correlate with flow experience ($r = .05$, $p = .713$).

In order to shed more light on relation between flow experience and situational interest we explored the relation between math anxiety and these engagement measures.

Interestingly, math anxiety did not correlate either with flow experience ($r = .08$, $p = .574$) or situational interest ($r = -.004$, $p = .98$) suggesting that both flow and situational interest are independent of math anxiety.

4 Discussion

Player experience is crucial in games and game-based learning. For instance, if players do not enjoy the game, they will not play the game at all or they will play the game only superficially without investing cognitive resources to consider the challenges and the content of the game deeply enough, i.e. they are not fully engaged with the gameplay. The purpose of the current study was to investigate the relation of two engagement measures, flow experience and situational interest, in the game-based learning context. To deepen the understanding, we examined the relation of these engagement measures with learning gains, in-game performance, and math anxiety. On practical terms, this work considers the feasibility to use these constructs as engagement measures in game-based learning research and demonstrates that the core game mechanics can be used to embed self-report measures smoothly into the games. In the following, results will be discussed in more detail.

4.1 The relation between flow and situational interest

In general, the measures of engagement used in the present study at least partially aligned with one another. That is, in line with Hypothesis 1, we found a positive relationship between flow experience and situational interest, indicating that these constructs share common or similar components. Importantly, a more detailed analysis revealed that the flow subscale, absorption by activity, explained variation in situational interest, while the fluency of the performance subscale did not contribute to it. However, only about one-quarter of variance in situational interest was explained by flow experience suggesting that the two constructs are fairly independent. This suggests that future game-based learning studies, at least the ones including scaffolding features, should measure both situational interest and flow experience to achieve more comprehensive view on players' engagement. On the other hand, we suggest that researchers should consider forming new scales that combine items from both flow experience and situational interest constructs.

4.1.1 Engagement and competence

The relation between used engagement constructs and competence was explored through a number of analyses in the present study. Our results suggest that prior knowledge, game performance, and learning outcomes have varying relations with flow experience and situational interest. In particular, the flow construct appears to align more closely with competence and performance levels than situational interest. As expected in Hypothesis 2, we found that students who performed better in the game also experienced more flow, which is in line with previous research [68]. This would support the use of adaptive scaffolds as they may help the students with less competence to perform better and thus, presumably, experience higher flow as well. In contrast, contrary to Hypothesis 3, in-game performance was not related to situational interest. In fact, this might partly explain why fluency of the performance subscale did not predict situational interest. On the other hand, this is understandable as students' average in-game performance was very high (estimation accuracy of 94%) and some studies have shown that perceived knowledge gaps may increase situational interest [64], [81]. Thus, accumulated learning (i.e. increased in-game performance) may have decreased some students' situational interest, which may partly explain why situational interest did not correlate with in-game performance.

The complexities of the relations between prior knowledge and engagement further suggest that flow is the more competence-oriented construct in comparison to situational interest. In line with previous research [64], [81], prior knowledge and situational interest in the game were negatively related. Thus, although flow was not related to prior knowledge, it seems that flow is a more competence-oriented construct than situational interest. These results mirror previous findings that knowledge accumulation tends to be inversely related to situational interest. Further, a perceived lack of knowledge may be what leads to situational interest, which in turn leads to learning. This suggests that immediate feedback, including negative feedback, is a crucial feature of designing games for engagement, as these indications of knowledge gaps may help trigger and maintain situational interest, at least for students with low enough prior knowledge. In other words, presumably, very competent students did not have a strong enough thirst for knowledge as the game may have been too easy for them and thus their situational interest were at a lower level. In that sense, the adaptive scaffolding system did not serve these students well and an adaptive difficulty adjustment system should be implemented to increase challenge and engagement also for more competent students.

Importantly, situational interest appears to be the more relevant construct when considering learning outcomes, in comparison to flow experience. Contrary to Hypothesis 4, flow experience did not correlate with learning gains while students played the game. This may be that those who had higher prior knowledge, which was negatively correlated with learning gains in the present study, may have also been somewhat likely to have more flow-like experiences during their playing. This is in line with the competence-orientation of flow mentioned previously. In line with this, and the previous discussion of situational interest and knowledge gaps, Hypothesis 5 indeed was confirmed, as learning gains and situational interest were related.

4.1.2 Engagement and math anxiety

Students' prior math anxiety level was not related to either flow experience or situational interest. This might suggest that players can be engaged with the game independent of their level of math anxiety. Hopefully, this finding opens a new research branch for the engagement research field as we are not aware of any other studies in which these relations were investigated. However, in one related study, Wang *et al.* [82] found that students' math anxiety level decreased after gamified math instruction and this reduction was positively related with flow experience. Altogether, these results provide some preliminary evidence that game-based math learning can be a promising instructional approach for math-anxious students. However, due to small sample size and skewed distribution of math anxiety - i.e. overall low math anxiety, which, in fact, is common in Finland among the age group of the sample [84] – these results need to be interpreted cautiously and more research with more robust research designs should be conducted.

4.2 Game design considerations

In the current study, learning analytics of the game was successfully used to identify students that needed assistance. Consequently, weaker students were scaffolded, which balanced the game's challenge for them. As mentioned, students with lower prior knowledge experienced higher situational interest, which we, in addition to lack of knowledge, attribute to the additional game mechanics offered to them through adaptive scaffolding. Likely, the used scaffold mechanics have triggered situational interest in players as they may have perceived the scaffolds as novel and personally relevant events that have also helped them to identify the existing knowledge gaps. The downside of scaffolding is that it only supports students who need assistance. We would argue that flow and situational interest could have been facilitated with adaptive features that consider also the needs of well-performing students. In the current implementation, better-performing students missed some of the game features as the scaffolds were not shown to them. This could be compensated by including features that increase the difficulty such as dynamic adjustment of the required estimation accuracy threshold, extra enemies to make playing harder, or ways to increase the mathematical difficulty. For example, one of the scaffolds subtracts the fraction number to the lowest common factor. This could be reversed by expanding the original fraction number into "larger" and more difficult factors. With respect to better-performing students, the increased difficulty would probably facilitate flow as the challenge would be better balanced with skills, and the novel features and possibly aroused knowledge gaps would facilitate also situational interest. Consequently, game designers need to also consider how engagement can be fostered in well-performing or even gifted students.

4.3 Measuring engagement

We used in-game questions to measure flow experience and situational interest. Moreover, measuring situational interest was based on a microanalytical approach as the construct was measured several times during playing [64], [65] with single item. The study demonstrated that we managed to successfully utilize the game's core mechanics to embed self-report items into the game. The answering was fluid and did not distract the students or disrupt the playing experience. Only answers of two students had to be removed from the analyses, as they were clearly invalid. That is, the results suggest that such in-game self-report measures do not encourage careless responding. In fact, our approach was an effective way to collect the students' experiences during gameplay as answering the questions was mandatory in order to progress in the game. Our microanalytic and in-game approach works well to measure situational interest, as it allows an easy and non-distracting way to collect repeated measures providing more exhaustive insights into what happens during the gameplay compared to common before or after game measurement approaches.

As flow and situational interest were acquired directly in the game environment using the same mechanics as the learning mechanics, we might suggest that this approach constitutes a more valid assessment than typical post-hoc and paper-based tools. However, the effect of in-game vs. out-game assessment needs to be investigated in dedicated studies. Nevertheless, it seems apparent that assessments of an environment taking place within the tested environment should produce more valid results. Moreover, measuring the same (state) construct multiple times also allows for more fine-grained analyses by, for instance, temporal and dynamic fluctuations (for a comprehensive review on process measures in game-based learning [49]. Finally, we call for endeavors to develop even shorter flow scales than Flow Short Scale that could be more easily and non-intrusively embedded into games with respect to the microanalytical approach. On the other hand, also the development of new scales that combine items from flow experience and situational interest should be considered.

4.4 Limitations

The limitations of this study revolve much around the pandemic-enforced school lockdowns, which altered the research design quite a bit from the original. First of all, it greatly reduced the sample size (N=52), reducing the statistical power of the study. It also forced us to exclude some early game levels from our analyses that complicate the interpretation of the results. We were also unable to conduct the planned posttest, so we had to evaluate learning gains by comparing the estimation accuracy of the pretest to an "ad-hoc posttest", i.e. estimation accuracy of the selected levels of the game. This comparison indicated that playing the Number Trace game significantly improved students' conceptual fraction knowledge. The students with lower prior knowledge profited most as they had the most room for improvement. However, the large improvement needs to be interpreted cautiously as the tasks of the pretest and the game was not entirely comparable, although previous studies [5], [76] offer some evidence that the used game mechanisms offer comparable data. Further, the lack of a proper posttest also meant that we could not include a control group in the analyses. Even though we did manage the difference in playing surroundings by making sure that the measured game content was not played partly at school and partly at home, but only at home, we expect that there were variations in students' home surroundings. Things like distractions, technical issues, or parental help during the play might have affected the results, but on the other hand, the current results have high ecological validity as the study wasn't conducted in a lab or controlled setting.

One possible objection against our findings may be that situational interest, as operationalized in our study, does not comprehensively represent situational interest construct as envisioned in the literature. If true, this would impair our findings. However, when developing our single-item situational interest scale, we tried to select such a wording that best corresponds to the main characteristics of situational interest. Thus, we grounded our operationalization directly on the core aspect of situational interest (being interested in something) that only indirectly reflects other aspects of situational interest, namely enjoyment and attention. Nevertheless, there is no reason to believe that our situational interest scale was not about situational interest as our operationalization closely matches the definition of situational interest. However, we suggest that the convergent validity of the used single-item situational interest scale needs to be examined in future studies to ensure its validity. This would especially be fruitful with examining other dimensions of engagement beyond situational interest and flow experience.

5 Conclusion and future directions

The current study advances the game-based learning field by shedding light on the unaddressed relationship between situational interest and flow experience, and on the feasibility to use these as engagement measures. The results indicated that although flow and situational interest constructs are positively related, they are not identical twins but more like cousins. The present study showed that the immersive aspects of flow experience, rather than the competence-related aspects, are associated with situational interest. Although flow appears to be more related to actual game performance, situational interest seems to relate to learning gains. Further, unlike flow, situational interest seems to be inversely related to knowledge accumulation and is triggered by a perceived lack of knowledge. Thus, dynamic difficulty adjustment, adaptive scaffolding, and adaptive feedback provide tools for game designers to facilitate both situational interest and flow experience.

On the practical side, as both flow and situational interest aim to explain why people engage in activities, they are useful measures for game design that can be used to evaluate playing experience and engagement as well as the quality of game-based learning environments. The achieved understandings can guide game designers and researchers in the evaluation of engagement and help to develop games that are more likely to generate robust educational results, such as increased engagement and learning gains. Further, the results provide some validation for the proposed use of the game's core mechanics to collect self-reported playing experience data within the game.

Future research should focus on generalizing these preliminary results in different kinds of game-based learning environments, and more exhaustively investigate to what extent situational interest and flow experience explain engagement. Additionally, more research is needed to create robust methods to capture the highly dynamic, fluctuating, and context-dependent nature of engagement without disturbing the playing experience. The micro-analytic assessment approaches, taking advantage of the game's core game mechanics, could provide means for this.

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Appendix

Appendix A. *Modified Flow Short Scale items.*

	Question	Fluency of performance	Absorption by activity
1	The game provided just the right amount of challenge.		x
2	My thoughts/activities ran fluidly and smoothly.	x	
3	I didn’t notice time passing.		x
4	I could concentrate on playing.	x	
5	My mind was completely clear.	x	
6	I was totally absorbed in playing.		x
7	The right thoughts/movements occurred of their own accord.	x	
8	I knew what I had to do in the game.	x	
9	I felt that I had everything under control.	x	
10	I was completely lost in thought.		x