# The role of situational interest in game-based learning

Antti Koskinen [1], Jake McMullen [2], Hilma Halme [2], Minna Hannula-Sormunen [2], Manuel Ninaus [3] and Kristian Kiili [1]

[1] Tampere University, Kalevantie 4, Tampere, 33100, Finland
[2] University of Turku, Turku, 20014, Finland
[3] University of Innsbruck, Innrain 52, Innsbruck, 6020, Austria

**Abstract**

Previous research has emphasized the important role of interest in education. However, only a few studies have investigated situational interest in game-based learning environments. Therefore, this study aims to clarify the role of situational interest in game-based mathematics learning by examining its relations with learning outcomes, self-efficacy, and math interest. Ninety-eight 7th-grade participants played the Number Trace rational number learning game for three 45-minute lessons. Pre-and post-tests were used to measure rational number conceptual knowledge and self-reported measures of math interest. Situational interest and self-efficacy were measured within the game environment. Results indicated that situational interest and learning outcomes were positively related. Furthermore, self-efficacy, as well as math interest, were positively related to situational interest.

**Keywords**

Situational interest, game-based learning, learning, self-efficacy, individual interest

## 1. Introduction

At the beginning of the 21st century, digital games were seen as an instructional method that could prominently change the way we see instruction [1]. Drawing from the experiences of how people interact with commercial games, it was postulated that using games designed to enhance the quality of instruction, referred to as game-based learning, would be an engaging, fun, and novel method that can respond to digital natives' learning preferences and ways of thinking [1]. In other words, digital game-based learning was argued to be an effective and interesting instructional method for students who have grown up in the digital era.

To convert requirements of the curriculum to a novel instructional environment requires extensive research, evidence-based justifications, and new assessment methods tailored to the requirements of the novel environment. During the past decades, scholars have made tremendous efforts justifying game-based learning as a prominent instructional method that could answer the needs of modern society [e.g., 2]. Supporting propositions of [1], recent meta-analyses have provided evidence that game-based learning is an effective instructional method that can add value exceeding conventional instruction [3, 4].

Although game-based learning environments are designed to trigger learners' interest, surprisingly the role and meaning of interest in game-based learning process has not been studied sufficiently yet. In fact, none of the recent reviews or meta-analyses on game-based learning have featured interest as a topic, sub-topic, or

6th International GamiFIN Conference 2022 (GamiFIN 2022), April 26-29, 2022, Finland
EMAIL: antti.koskinen@tuni.fi (A. Koskinen); jamcmu@utu.fi (J. McMullen); hilma.halme@utu.fi (H. Halme); mimarha@utu.fi; (M. Hannula-Sormunen); manuel.ninaus@uibk.ac.at (M. Ninaus); kristian.kiili@tuni.fi (K. Kiili)
ORCID: 0000-0002-9755-1057 (A. Koskinen); 0000-0002-7841-7880 (J. McMullen); 0000-0002-4357-5977 (H. Halme); 0000-0002-6106-2569 (M. Hannula-Sormunen); 0000-0002-4664-8430 (M. Ninaus); 0000-0003-2838-6892 (K. Kiili)

moderator in analysis [e.g., 2, 3, 4]. Moreover, [5] review of the theoretical foundations in gamification, serious games, and game-based learning show that only four studies were based on interest theories, whereas self-determination theory was utilized in 82 studies and flow theory in 47 studies. However, ample research evidence from studies conducted in non-game-based learning environments indicate that interest is an important motivational factor that substantially contributes to learning and motivation [e.g., 6]. Since interest can be dependent on specific environmental stimuli, it is important to examine the role of situational interest also in game-based learning as a way to advance our understanding of motivational mechanisms in game-based learning.

## 1.1. The role of interest in learning

Being interested in something is a powerful psychological state that can substantially affect learning and motivational outcomes. In fact, several motivational questionnaires, such as intrinsic motivation scales [7] and ARCS -model related scales [8], feature interest as a part of the construct. However, interest differentiates from other motivational constructs as it is always content-dependent [9, 10].

All individuals are hardwired to develop and experience interest at any age and in many contexts [11, 12]. According to prominent interest theories, interest is the outcome of an interaction between a person and environmental stimuli [13, 6]. If the interest is predominantly influenced by the interaction with specific environmental stimuli it is called situational interest [6]. Situational interest is a psychological state associated with increased attention, effort, enjoyment, and concentration while engaging with particular content [9]. In instructional settings, this state reflects the learner's interest towards for example mathematics, but also how the learning material is presented [10]. Therefore, situational interest is always enhanced by the interaction with a combination of the features of the learning environments [14]. A person’s interaction with these features is affected by past experiences that, partly, determine reactions to these features and thus experienced interest [10, 15]. In particular, past research has identified individual interest, representing an individual’s enduring trait-like interest [6], and self-efficacy, representing an individual’s beliefs of how they will perform in certain tasks [16, 17], as factors determining how interaction with the learning environment are experienced and whether situational interest is enhanced or not [18, 19]. Theoretically, the expectancy-value model of achievement choices [20] posits that expectations of success (consisting partly of self-efficacy) and subjective task value (consisting partly of individual interest) directly influence engagement with the task and, thus, how situational interest is experienced. Therefore, individual interest and self-efficacy can be seen to efficiently reflect the key factors influencing situational interest.

Previous investigations in non-game-based learning contexts found that situational interest affects the learning process by enhancing cognitive and affective components [21]. That is, enhanced situational interest can result in increased engagement [22], attention [21], persistence [21], and lead to improved learning [23]. Moreover, situational interest, if maintained, may develop into individual interest, which can have a major influence on one’s later learning experiences and outcomes [6, 11]. Although situational interest appears to be a powerful supporter of learning, its role in game-based learning environments may be more multifaceted.

## 1.2. Game-based learning and interest

Game-based learning is expected to, by design, increase students’ situational interest, as it often features several potential triggers of interest [24]. An examination based on [25] suggestions for potential triggers of interest (highlighted with italics below) shows that this claim is well supported on a theoretical level: *digital* game-based learning is a relatively *novel* instructional approach, which provides *challenge* [24], induces *emotions* [26], and provides possibilities for *group work* [27] and trying out new roles that make it possible to *identify* oneself as a character, thereby creating *ownership* [24]. In addition, digital game-based learning environments usually use incentive structures, such as stars, points, leaderboards, badges, and trophies, as well as game mechanics that can trigger and help maintain interest [24]. In fact, [28] found that, in 12 of 14 studies, students reported more interest in simulation and gaming activities than in conventional classroom activities. More recently, [29] found that students’ situational interest was higher in a game-based writing intervention group than in a non-game-based online writing environment. In addition, [30] demonstrated that game-based learning can be used to increase interest in learning mathematics. Based on these theoretical and empirical considerations, it appears that digital game-based learning is a learning environment that features several characteristics that foster interest and the unique combination of these characteristics is not usually found in other instructional environments. Accordingly, game-based learning may be an ideosyncratic learning environment regarding situational interest.

Situational interest may have similar manifestations and influences in game-based learning than in non-game learning environments. Studies have shown that interaction with the mechanics of game-based learning environments has a significant effect on situational interest. For example, manipulation of game mechanics [31] or scaffolding [32] affected situational interest. Moreover, [33] demonstrated that, in game-based math learning, individual math interest was positively related to situational interest, and [34] showed that self-efficacy is positively related to situational interest in game-based learning. However, past research shows mixed results regarding the relation between situational interest and learning in game-based learning. [35] found that situational interest was positively related to learning, but [32] found no relation between interest and learning. Moreover, [36] reported that situational interest was positively related to the post-test score, however, [37] did not find such a relation. Based on these considerations, it is important to advance our understanding of the relation between situational interest and learning in game-based learning.

## 1.3. The present study

Given the unique motivational characteristics of game-based learning environments, and the influence of environmental features on situational interest, examining the role of situational interest in game-based learning will add valuable insight into the components influencing the effectiveness of game-based learning. This study contributes to the current body of literature on game-based learning and situational interest by investigating how situational interest and learning are related and how individual math interest and self-efficacy are related to situational interest. Accordingly, three research questions are examined:

1. What is the relation between situational interest and learning in game-based math learning?

According to previous research findings situational interest can lead to enhanced engagement [22], attention [21], and persistence [21] all of which are important factors contributing to learning. In fact, results from different instructional settings, for example, computer simulation [38], problem-based learning [23], and interactive exhibitions in museums [39] suggest that situational interest and learning are positively related. However, in the game-based learning domain, the study results are mixed [35, 36, 37, 32]. As most of the research evidence suggests positive relation, we expect that situational interest and learning to be positively related in game-based math learning (H1).

2. What is the relation between situational interest and math interest in game-based math learning?

Studies conducted in different instructional settings show that individual interest is positively related to situational interest [e.g., 23, 18]. In game-based math learning, [33] found that high individual interest in math was related to high and maintained situational interest during the gameplay. Thus, we expect individual math interest and situational interest to be positively related in game-based math learning (H2).

3. What is the relation between situational interest and self-efficacy in game-based math learning?

Studies conducted in different instructional settings show that self-efficacy is generally positively related to situational interest [38]. However, [40] found contradictory results; students' initial high self-efficacy predicted a decrease in students’ situational interest. In game-based learning context, [34] found that initial mastery experience (i.e., self-efficacy) in a dancing game positively correlated with situational interest. Accordingly, we expect self-efficacy and situational interest to be positively related in game-based math learning (H3).

## 1.4. Participants

98 (49 female, 49 male) Finnish 7th grade students (M = 13,2 years, SD = 0.36) from nine schools participated in the study. The nine schools were from varying socioeconomic status (SES) areas from a city located in southern Finland. All participants had parental permission to participate

in the study. Ethical board and municipality approval were granted for this study. Only participants who had completed the pretest and finished at least two game-worlds were included in the study.

## 1.5. Description of the Number Trace -game

The Number Trace game is based on the number line estimation task, in which students estimate the spatial position of a target number on a horizontal number line (e.g., where does 3/7 locate on a number line ranging from 0 to 1) [41]. Number line-based instruction has been an effective instructional method to support conceptual rational number understanding [42, 43, 44] and it is also successfully applied in game-based learning [45, 46]. In the game, the player controls a dog on a number line and tries to find bones hidden in the ground. The location of the bones is determined by a given magnitude of a rational number (a target number). Different kinds of representations can be used as target numbers (e.g., symbolic, and non-symbolic fractions, mixed numbers, decimals, whole numbers, and equations).

The game was designed to support the development of 7th graders' rational number understanding based on the Finnish national core curriculum and theories of adaptive expertise with rational numbers [47]. Figure 1 shows three types of tasks featured in the game: i) basic number line estimation, ii) unbounded number line estimation, and iii) number line-based arithmetic tasks. The unbounded number line has no labeled endpoint, but a single unit distance (e.g., 0–1/4; see Figure 1 bottom) in addition to the start point [48]. Different combinations of rational number representations and task configurations were used to support a deep understanding of rational number properties as well as foster situational interest. For example, figure 1 shows an example of an unbounded number line estimation task that includes cross-notation (fractions and decimals) and an example of a non-symbolic addition task.

The game consisted of three game worlds, with six, seven, and eight levels, respectively. Each level consisted of ten tasks, and the students could complete each game level only once. The first game world included symbolic fraction and decimal number tasks that were designed to strengthen students' basic rational number understanding. The second game world included non-symbolic rational number estimation tasks and basic arithmetic with non-symbolic rational numbers. The third game world included mainly cross-notation tasks aimed at developing an understanding of the relation between notations.


**Figure 1:** Examples of tasks included in the game. Top: Symbolic fraction estimation task. Middle: non-symbolic addition tasks. Bottom: unbounded cross-notation number line estimation task.

The students received immediate feedback for their answers. The player lost virtual energy for inaccurate estimates and was provided emotional feedback – the dog avatar was upset. In the case of accurate estimates, students scored points based on their estimation accuracy, and emotional feedback was provided – the dog avatar was happy. Delayed feedback was provided after completing a level – students could earn one to three stars based on their performance.

To further support learning and to foster situational interest, the game provided scaffolds, and dynamic difficulty adjustment. Scaffolds were provided after inaccurate answers and several different scaffolding mechanics were utilized. For example, reduction of the fraction to the smallest common factor [35, for more details]. Both adaptive and fixed scaffolding was used. The adaptation was based on students' previous performance in similar tasks. If the game did not have enough performance data on a certain task type, fixed scaffolding was used instead. Unlike adaptive scaffolds, fixed scaffolds were always shown after an inaccurate answer and the used scaffold mechanic was the same for all students. In contrast to scaffolding, dynamic difficulty adjustment was used to provide an extra challenge to well-performing students. For example, the challenge was increased by augmenting the tasks with mathematical traps that had to be avoided (locations shown with rational numbers).

## 1.6. Measurements

The computer-based pre-and post-tests were conducted in regular classrooms by the members of the research team. The items measuring rational number understanding had a fixed time limit.

Pretest and posttest scores were calculated as the average of the correct answers. Pre-and post-tests included 34 items. Eight number line estimation tasks; four items on a 0-1 number line and four items on a 0-5 number line. Both of these featured two decimal and two fraction tasks. Students' answer was scored as correct if the accuracy was over 92% in number line 0-1, and over 90% in number line 0-5. Eight conversion tasks (convert 3/5 to a decimal number or convert 0.4 to a fraction number); four items of the fraction to decimal conversions and four items of decimal to fraction conversions. Six ordering tasks (arrange 0.5; 1/4, 5/7, 0.356 in order from smallest to largest). Twelve rational number arithmetic procedures tasks (e.g., $1/4 \times 4$; $0.5 \div 2$). The reliability for the pretest was good (Cronbach's $\alpha = .80$), and the reliability for the post-test was acceptable (Cronbach's $\alpha = .76$). The *learning* variable was calculated by subtracting the average of pretest scores (M = .53, SD = .22) from the average of post-test scores (M = .63, SD = .20).

Math interest was measured during the pretest with a scale derived from the TIMMS test [49]. The scale included nine statements about students' attitude towards learning mathematics. Reliability for the scale was high (Cronbach's $\alpha = 0.93$). The *math interest* variable was calculated as the average value of the scale items.

In-game measurement was used to assess learners' self-efficacy and situational interest during the gameplay [35, for more details]. This tool utilized core game mechanics, which presumably allowed learners to maintain game flow without interruption.

*Situational interest* was measured six times during the intervention: at the end of the 1st, 4th, 5th, 7th, 10th, and 11th game level. The students answered the question: "How interesting did you find the tasks in this game level" on a continuous scale from 0 to 5 (Figure 2). The situational interest variable was calculated as an average value of the situational interest measurements. 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 pairs of situational interest measuring points (levels 4 and 5; levels 10 and 11) that included similar tasks with respect to math content. Test-retest reliability ratings for pairs of situational interest measures were .80 and .59 (indicating good and acceptable reliability, respectively), Overall, these ratings indicate acceptable reliability considering the content-dependent nature of situational interest, and the small variation in the scale.

*Self-efficacy* was measured at the beginning of each of the two-game worlds. Students answered the question: "I will certainly perform well on the forthcoming tasks." on a continuous scale from 0 to 5. Self-efficacy was calculated as an average of the self-efficacy measurements. Test-retest reliability rating for self-efficacy was .63. This is acceptable when considering that the first measure was authored before the participants had played the game and the second when participants had experience with the demands of the game.


**Figure 2**: Utilized in-game measurement of situational interest

## 1.7. Procedure

The study was conducted in mathematics lessons during regular school days. The pre- and post-tests were administered by the members of the research team. The pretest was carried out a week before the start of the intervention and the posttest was conducted a week after the intervention. The teachers were asked not to teach rational numbers during the study. The students played the Number Trace -game for three 45-minute sessions within a two-week period.

# 2. Results

Descriptive statistics and correlations are shown in Table 1.

**Table 1**
Descriptive statistics and correlations, **< 0.05; ** < 0.01

| Variables | 1. | 2. | 3. | 4. |
|---|---|---|---|---|
| 1. Situational interest | - | | | |
| 2. Self-efficacy | .57** | - | | |
| 3. Math interest | .42** | .34** | - | |
| 4. Learning | .28* | .23* | .06 | - |
| M | 3.50 | 3.49 | 2.74 | .12 |
| SD | .88 | .95 | .71 | .11 |
| Range | 1 - 5 | 1 - 5 | 1 - 4 | 0 - 1 |
| Skewness | -.06 | -.39 | -.49 | .13 |
| Kurtosis | -.49 | .00 | -.43 | -.57 |

Table 1 shows that situational interest and learning were positively related in game-based math learning, thus H1 was confirmed. A multiple regression analysis was conducted to examine whether math interest and self-efficacy were uniquely related to situational interest. Together math interest and self-efficacy explained 38% of variance in situational interest, $F(2, 95) = 29.13$, $p < .001$. Math interest was positively related to situational interest ($\beta = .26$, $p < .05$) after controlling for self-efficacy, thus confirming H2. Self-efficacy was positively related to situational interest ($\beta = .48$, $p < .001$), after controlling for math interest, thus H3 was confirmed.

# 3. Discussion, limitations and conclusion

This study examined the relation between situational interest and learning and how individual math interest and self-efficacy relate to situational interest in game-based learning. As expected, situational interest and learning were positively related. Our results indicate a similar moderate positive relation between situational interest and learning as found previously in problem-based and experiential learning environments [23, 39]. Regarding the previous mixed results in the game-based learning context, our result supports the finding of [35] who found a positive relation between learning and situational interest. One reason for the mixed results reported in previous studies can be the differences between measurement methodologies. Similar to the present study, [35] measured situational interest within the game, while studies measuring situational interest after the game reported a non-significant relation between situational interest and learning [32, 37]. This might suggest that measuring situational interest within the game, reflects the fluctuating nature of situational interest better than post-game measurement. Future studies should examine differences between the measurement methodologies of situational interest.

Based on our results, we cannot determine if situational interest is an outcome or antecedent of learning, or both. For example, situational interest may influence learning by enhancing attention, concentration, and persistence [21, 22]. On the other hand, learning may affect situational interest, for example, by creating a positive mood that increases situational interest [19, 32]. The most plausible explanation might be that both of these arguments are true and there is a reciprocal relation between situational interest and learning.

Consistent with previous studies [18, 23, 33, 34], situational interest was positively related to both math interest and self-efficacy. However, the relation between math interest and situational interest was relatively low in the current study. This might indicate that students' math interest mainly reflects students' previous experiences of non-game-based learning environments, and it does not profoundly reflect the situational interest experienced in the game-based learning environments. On the other hand, students' individual interest mathematics in general may differ from their individual rational number interest in a particular learning context. Nevertheless, situational interest experienced in the game-based learning environments might be more related to the interestingness of the game than the instructional content itself. However, as this study does not give a direct answer for this conjecture, future studies should examine sources of situational interest more exhaustively in game-based learning.

It is important to consider the limitations of this study. The intervention was carried out in an authentic classroom setting and thus it is probable that several students did not manage to complete all the required game levels to be included in the analysis. We could not identify the reasons why some students did not manage to complete the game. However, we can assume some reasons: a) the game may have featured too many rational number tasks for the students and they may not have had the competence and persistence to complete the levels in the allocated time, b) the students' slow progress in the game may have been the result of low interest in the content, in game-based learning, or in the game genre, graphics, or user interface, c) as the intervention was carried out with computers, technological problems (bad network, updates, etc.) may have caused some students to not complete the required levels. In any case, the sample with adequate data was lower than expected. Therefore, we could not use growth curve modelling and all situational interest and self-efficacy measurements were collapsed into sum variables. This restricted our analyses but permitted us to formulate a general overview of this phenomenon with a sufficient sample size. Moreover, the study design restricted making any causal inferences. Therefore, future research should investigate the reciprocal relation between situational interest and learning.

Despite these limitations, the results of this study increase our understanding of the role of situational interest in game-based learning and thus advance our understanding of components affecting the effectiveness of game-based learning. Specifically, situational interest and learning outcomes are related in game-based learning. Furthermore, the results indicate that the relation between math interest and situational interest was relatively low. This suggests, that the game designers should not only focus on improving the mere learning outcomes of the games, but also consider how game-based learning can be utilized to spark interest in students who do not find learning of the topic otherwise interesting. For example, if we can spark students' interest in game-based math learning, this can possibly enhance their interest also in non-game-based math learning [6] and thus make students realize their full learning potential [11].

## 4. Acknowledgements

This research was funded by the Academy of Finland (grant numbers 326618, and 310338) and the Strategic Research Council (SRC) established within the Academy of Finland (grant number 336068).

## 5. References

[1] M. Prensky, Digital game-based learning, Comput. Entertain. 1 (2003) 21–21. doi:10.1145/950566.950596

[2] E. A. Boyle, T. Hainey, T. M. Connolly, G. Gray, J. Earp, M. Ott, ... & J. Pereira, J, An update to the systematic literature review of empirical evidence of the impacts and outcomes of computer games and serious games, Comput. Educ. 94 (2016) 178–192. doi:10.1016/j.compedu.2015.11.003

[3] P. Wouters, C. van Nimwegen, H. van Oostendorp & E. D. van Der Spek, A meta-analysis of the cognitive and motivational effects of serious games, J. Educ. Psychol. 105 (2013) 249–265. doi:10.1037/a0031311

[4] D. B. Clark, E. E. Tanner-Smith & S. S. Killingsworth, Digital games, design, and learning: A systematic review and meta-analysis, Rev. Educ. Res. 86 (2016) 79–122. doi:10.3102/0034654315582065

[5] J. Krath, L. Schürmann & H. F. Von Korflesch, Revealing the theoretical basis of

gamification: A systematic review and analysis of theory in research on gamification, serious games and game-based learning, Comput. Hum. Behav. 125 (2021). doi:10.1016/j.chb.2021.106963
[6] S. Hidi & K. A. Renninger, The four-phase model of interest development, Educ. Psychol. 41 (2006) 111–127. doi:10.1207/s15326985ep4102_4
[7] A. M. Isen & J. Reeve, The influence of positive affect on intrinsic and extrinsic motivation: Facilitating enjoyment of play, responsible work behavior, and self-control, Mot. & Emot. 29 (2005) 295–323. doi:10.1007/s11031-006-9019-8
[8] J. M. Keller, Development and use of the ARCS model of instructional design, J. Instruct. Develop. 10 (1987) 2–10. doi:10.1007/BF02905780
[9] P. A. O’Keefe, E. J. Horberg & I. Plante, The multifaceted role of interest in motivation and engagement, In: P. A. O’Keefe & J. M. Harackiewicz (eds.), Sci. Interest., Springer, Cham, 2017: pp. 49–67.
[10] M. Knogler, Situational interest: A proposal to enhance conceptual clarity, In: P. A. O’Keefe & J. M. Harackiewicz (eds.), Sci. Interest., Springer, Cham, 2017: pp. 109–124.
[11] K. A. Renninger & S. E. Hidi, To level the playing field, develop interest, Policy. Insigh. Behav. Brain. Sci. 7 (2020) 10–18. doi:10.1177/2372732219864705
[12] P. J. Silvia, Interest—The curious emotion, Cur. Direct. Psychol. Sci., 17 (2008) 57–60. doi:10.1111/j.1467-8721.2008.00548.x
[13] A. Krapp, An educational–psychological conceptualisation of interest, Int. J. Educ. Vocat. Guidan. 7 (2007) 5–21. doi.org:10.1007/s10775-007-9113-9
[14] M. Ainley, Interest: Knowns, unknowns, and basic processes, In: P. A. O’Keefe & J. M. Harackiewicz (eds.), Sci. Intrest., Springer, Cham, 2017: pp. 3–24.
[15] A.M. Durik, C. S. Hulleman, & J. M. Harackiewicz, J. M, One size fits some: Instructional enhancements to promote interest, Intr. Math. Sci. Learn. (2015) 49–62.
[16] A. Bandura, Self-efficacy: toward a unifying theory of behavioral change, Psychol. review 84 191 (1977). doi:10.1037/0033-295X.84.2.191
[17] F. Pajares & D. H. Schunk, Self-beliefs and school success: Self-efficacy, self-concept, and school achievement, In: R. J. Riding & S. G. Rayner (Eds.), Self percep. Ablex Publishing, 2001: pp. 239–266.
[18] A. Tapola, M. Veermans & M. Niemivirta, Predictors and outcomes of situational interest during a science learning task, Instruct. Sci. 41 (2013) 1047–1064. doi:10.1007/s11251-013-9273-6
[19] P. J. Silvia, Self-efficacy and interest: Experimental studies of optimal incompetence, J Voc. Behav. 62 (2003) 237–249. doi:10.1016/S0001-8791(02)00013-1
[20] J. S. Eccles & A. Wigfield, From expectancy-value theory to situated expectancy-value theory: A developmental, social cognitive, and sociocultural perspective on motivation, Contemp. Educ. Psychol. 61 (2020). doi:10.1016/j.cedpsych.2020.101859
[21] M. Ainley, S. Hidi & D. Berndorff, Interest, learning, and the psychological processes that mediate their relationship, J. educ. psychol. 94 (2002) 545–561. doi:10.1037/0022-0663.94.3.545
[22] J. C. Y. Sun & R. Rueda, Situational interest, computer self-efficacy and self-regulation: Their impact on student engagement in distance education, Brit. J. Educ. Tech. 43 (2012) 191–204. doi:10.1111/j.1467-8535.2010.01157.x
[23] J. I. Rotgans & H. G. Schmidt, How individual interest influences situational interest and how both are related to knowledge acquisition: A microanalytical investigation, J. Educ. Res. 111 (2018) 530–540. doi:10.1080/00220671.2017.1310710
[24] J. L. Plass, B. D. Homer, & C. K. Kinzer, Foundations of game-based learning, Educat. Psychol. *50* (2015) 258–283. doi:10.1080/00461520.2015.1122533
[25] K. A. Renninger, J. E. Bachrach & S. E. Hidi, Triggering and maintaining interest in early phases of interest development, Learn. Cult. Soc. Interac. 23 (2019). doi:10.1016/j.lcsi.2018.11.007
[26] M. Ninaus, S. Greipl, K. Kiili, A. Lindstedt, S Huber, E. Klein, ... & K. Moeller, Increased emotional engagement in game-based learning–A machine learning approach on facial emotion detection data, Comput. Educ. 142 (2019). doi:10.1016/j.compedu.2019.103641
[27] H. Y. Sung & G. J. Hwang, A collaborative game-based learning approach to improving students' learning performance in science

courses, Comput. Educ. 63 (2013) 43–51. doi:10.1016/j.compedu.2012.11.019
[28] J. M. Randel, B. A. Morris, C. D. Wetze & B. V. Whitehill, The effectiveness of games for educational purposes: A review of recent research, Simul. Gaming. 23 (1992) 261–276. doi:10.1177/1046878192233001
[29] C. C. Liao, W. C. Chang & T. W. Chan, The effects of participation, performance, and interest in a game-based writing environment, J. Comp. Assist. Learn. 34 (2018) 211–222. doi:10.1111/jcal.12233
[30] L. D. Pratama & W. Setyaningrum, Game-Based Learning: The effects on student cognitive and affective aspects. J. Phys.: Conf. Ser. 1097 (2018). doi:10.1088/1742-6596/1097/1/012123
[31] J. L. Plass, B. D. Homer, E. O. Hayward, J. Frye, T. T. Huang, M. Biles, ... & K. Perlin, K. The effect of learning mechanics design on learning outcomes in a computer-based geometry game, in: E-learn. Games. Train. Educ. Health. Sports. 2012: pp. 65–71.
[32] C. H. Chen & V. Law, Scaffolding individual and collaborative game-based learning in learning performance and intrinsic motivation, Comput. Hum. Behav. 55 (2016) 1201–1212. doi:10.1016/j.chb.2015.03.010
[33] G. Rodríguez-Aflecht, T. Jaakkola, N. Pongsakdi, M. Hannula-Sormunen, B. Brezovszky & E. Lehtinen, The development of situational interest during a digital mathematics game, J. Comput. Assist. Learn. 34 (2018) 259–268. doi:10.1111/jcal.12239
[34] C. Huang & Z. Gao, Associations between students' situational interest, mastery experiences, and physical activity levels in an interactive dance game, Psychol. Health Med. 18 (2013) 233–241. doi:10.1080/13548506.2012.712703
[35] K. Kiili, A. Lindstedt, A. Koskinen, H. Halme, M. Ninaus & J. McMullen, Flow Experience and Situational Interest in Game-Based Learning: Cousins or Identical Twins, I. J. Ser. Games. 8 (2021) 93–114. doi:10.17083/ijsg.v8i3.462
[36] J. L. Nietfeld, L. R. Shores & K. F. Hoffmann, Self-regulation and gender within a game-based learning environment, J. Educ. Psychol. 106 (2014).
[37] J. L. Plass, P. A. O'Keefe, B. D. Homer, J. Case, E. O. Hayward, M. Stein & K. Perlin, The impact of individual, competitive, and collaborative mathematics game play on learning, performance, and motivation, J. Educ. Psychol. 105 (2013). doi:10.1037/a0032688
[38] M. Niemivirta & A. Tapola, Self-efficacy, interest, and task performance: Within-task changes, mutual relationships, and predictive effects, Z. Pädagog. Psychol. 21 (2007) 241–250. doi:10.1024/1010-0652.21.3.241
[39] M. P. Vainikainen, H. Salmi & H. Thuneberg, Situational interest and learning in a science center mathematics exhibition, J. Res. STEM Educ. 1 (2015) 15–29. doi:10.51355/jstem.2015.6
[40] K. Nuutila, A. Tapola, H. Tuominen, S. Kupiainen, A. Pásztor & M. Niemivirta, Reciprocal Predictions Between Interest, Self-Efficacy, and Performance During a Task, Front. Educ. 5 (2020) 36–49. doi:10.3389/feduc.2020.00036
[41] R. S. Siegler & J. E. Opfer, The development of numerical estimation: Evidence for multiple representations of numerical quantity, Psychol. Sci. 14 (2003) 237–250. doi:10.1111/1467-9280.02438
[42] R. S. Siegler, Magnitude knowledge: The common core of numerical development, Develop. Sci. 19 (2016) 341–361. doi:10.1111/desc.12395
[43] D. W. Braithwaite & R. S. Siegler, Putting fractions together. J. Educ. Psychol. 113 (2020) 556–571.doi:10.1037/edu0000477
[44] S. M. Wortha, J. Bloechle, M. Ninaus, K. Kiili, A. Lindstedt, J. Bahnmueller, M.Korbinian, & E. Klein, Neurofunctional plasticity in fraction learning: an fMRI training study, Trends. Neurosci. Educ. 21 (2020). doi:10.1016/j.tine.2020.100141
[45] K. Kiili, K. Moeller, & M. Ninaus, Evaluating the effectiveness of a game-based rational number training-In-game metrics as learning indicators, Comput. Educ. 120 (2018) 13–28. doi:10.1016/j.compedu.2018.01.012
[46] M. M. Riconscente, Results from a controlled study of the iPad fractions game Motion Math, Games. Cult. 8 (2013) 186–214. doi:10.1177/1555412013496894
[47] J. McMullen, M. M. Hannula-Sormunen, E. Lehtinen & R. S. Siegler, Distinguishing adaptive from routine expertise with rational number arithmetic, Learn. Instruct. 68 (2020). doi:10.1016/j.learninstruc.2020.101347
[48] S. Jung, S. Roesch, E. Klein, T. Dackermann, J. Heller & K. Moeller, K, The strategy matters: Bounded and unbounded

number line estimation in secondary school children, Cogn. Develop. 53 (2020). doi:10.1016/j.cogdev.2019.100839
[49] I.V. S. Mullis, M. O. Martin, P. Foy, & M. Hooper, M, TIMSS 2015 International Results in Mathematics. Retrieved from Boston College, TIMSS & PIRLS International Study Center website: http://timssandpirls.bc.edu/timss2015/international-results/ (2016).