Received: 7 August 2023 | Revised: 5 January 2024 | Accepted: 3 March 2024
DOI: 10.1111/jcal.12971

ORIGINAL ARTICLE

Journal of Computer Assisted Learning WILEY

Mindfulness in a digital math learning game: Insights from two randomized controlled trials

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Funding information
Hungarian National Research, Development and Innovation Office, Grant/Award Number: OTKA–PD–138723; National Science Foundation, Grant/Award Number: #DRL-1661121

Abstract

Background: Mindfulness practices enhance executive function skills and academic achievement, spurring interest in integrating mindfulness interventions into education. Embedding mindfulness practice into a digital math game may provide a low-cost, scalable way to induce mindfulness and boost game-based learning, yet this approach remains unexplored.

Objectives: We investigated the learning benefits of integrating mindfulness exercises in a digital math learning game and examined how students' trait mindfulness might moderate the outcomes.

Methods: Two classroom studies were conducted with 404 5th and 6th grade students from six public schools in the U.S. ($n_{\text{Study 1}} = 227$, $n_{\text{Study 2}} = 177$). The two randomized controlled experiments assigned students to one of the three conditions: passive control (playing the digital learning game *Decimal Point*), story-enriched active control, or mindfulness-enriched condition. Trait mindfulness, learning gains, and in-game problem-solving (including problem-solving duration, error count and correctness after reminder) were assessed. Study 2 included a manipulation check to better understand the effects of the mindfulness intervention.

Results: Findings showed no significant differences in learning gains, problem-solving duration or error count among the conditions. Students' trait mindfulness did not moderate these outcomes. Mindfulness reminders in the mindfulness-enriched game led to more correct answers after errors than jokes in the story-enriched game. Study 2 revealed that we failed to induce higher state mindfulness through the mindfulness inductions.

Conclusions: Mindfulness prompts could be especially beneficial for students experiencing frustration during gameplay, warranting more exploration for digital game-based instruction. We highlight barriers and future directions for fostering mindfulness through computer-based instruction in classrooms.

KEYWORDS

digital learning games, elementary education, mathematics, mindfulness, randomized controlled trial

1 | INTRODUCTION

In recent years researchers and educational practitioners have increasingly turned their attention towards digital games as productive learning environments. It has been argued that digital learning games offer students opportunities to acquire new knowledge and skills in a fun and self-directed way while encouraging them to develop positive attitudes and competency beliefs related to curricular content and school subjects (Gee, 2008; McLaren & Nguyen, 2023; Plass et al., 2015; Weisberg et al., 2016). Digital game environments are seen as particularly well-suited to math learning, which is a subject often viewed by students as frustrating and difficult to learn (Deng et al., 2020; Geist, 2010; Hussein et al., 2021; McLaren et al., 2017; Sun et al., 2021). Meta-analytic evidence suggests that digital game-based math interventions conducted in K-12 settings contribute to higher learning gains than traditional instructional approaches (e.g., Tokac et al., 2019). Yet, game-based learning does not always guarantee better math outcomes, (Hussein et al., 2021; Mayer, 2019), and mixed results have been found in the areas of knowledge acquisition (e.g., Wouters et al., 2017), perceptual and cognitive skills (e.g., Kiili & Ketamo, 2017), and affective, motivational and behaviour change (e.g., Kim et al., 2017). How digital games may lead to improved mathematical learning remains an important focus of digital game-based learning research.

Executive function (EF) skills are an important set of domain-general skills for math—and, arguably, for playing digital games (Cragg & Gilmore, 2014). EF skills enable non-automatic, goal-directed behaviour and include the cognitive aspects of self-regulation, including working memory, inhibitory control and cognitive flexibility. One of the most promising types of interventions to foster EF skills in children is mindfulness-based programs (for meta-analytic evidence see Takacs & Kassai, 2019).

The primary objective of this paper is to present the results of two randomized control trials investigating the feasibility and benefits of incorporating mindfulness exercises into a digital math game. By exploring the potential for mindfulness-enriched digital games to foster students' EF skills, we sought to advance our understanding of effective strategies for improving mathematical learning. Additionally, we aimed to examine whether the impact of the interventions varies based on students' trait mindfulness levels, given that prior work has suggested mindfulness inductions might be especially beneficial for participants with higher trait mindfulness who are more receptive to this technique (de Sousa et al., 2021; Laurent et al., 2015; Nagy et al., 2023).

Previous studies have identified various learning design features, such as feedback and opportunities for self-explanation or reflection, that enhance the effectiveness of math digital learning games (Wouters & Oostendorp, 2017). The present research builds on this past work and represents a pioneering effort to investigate the feasibility and outcomes of embedding mindfulness inductions into such games.

1.1 | Math achievement and executive function skills

EF skills comprise working memory, inhibitory control and cognitive flexibility and are strongly related to math performance (Mazzocco & Kover, 2007) and math problem-solving (Cragg & Gilmore, 2014). For example, students often have to manage multiple goals while executing sub-goal processes, which can strain working memory. They must retrieve and apply appropriate strategies, which requires cognitive flexibility, while maintaining focus and inhibiting extraneous information, which requires effective inhibitory control (Cragg & Gilmore, 2014). Prior research has found that EF skills moderate the relation between math skills in kindergarten and 5th grade, such that those with lower math skills in early childhood are more likely to catch up with their higher-performing peers by 5th grade if they have high EF skills (Ribner et al., 2017). Other studies suggest that the bidirectional relation between EF and math skills in preschool becomes unidirectional once students enter kindergarten, with only EF predicting math skills (Schmitt et al., 2017). Although a causal relation between EF and math learning has not been clearly established, learning theories hypothesize that bolstering components of EF should improve students' capacity to learn new math skills and practice applying those skills flexibly across problems (Clements et al., 2016).

1.2 | Mindfulness and its relationship to executive function skills and learning

Mindfulness refers to a state of focused attention to the present without judgement. Originating from Buddhist traditions (Sharf, 2015), mindfulness-based programs have become popular resources both in clinical and educational settings (Zenner et al., 2014). Such programs have been shown to offer a variety of benefits for students, including reducing stress (Dunning et al., 2019, 2022; Zenner et al., 2014), supporting self-regulation and addressing inattentive and hyperactive symptoms (Vekety et al., 2021). Mindfulness-based interventions have also been shown to help students with attention skills (Dunning et al., 2019, 2022) and to support EF skills (Dunning et al., 2019, 2022), especially working memory capacity and inhibitory control (Takacs & Kassai, 2019).

Mindfulness-based intervention programmes consist of multiple sessions and are designed to have a lasting impact on participants' trait mindfulness. Alternatively, brief mindfulness inductions have been used in laboratory experiments to induce a state of mindfulness that lasts only for a short time. These experiments have shown that short inductions can reduce negative affect (Schumer et al., 2018) and increase the regulation of negative affect (Leyland et al., 2019) and cognition (Gill et al., 2020) in adults. Furthermore, Weger et al. (2012) found that a brief mindfulness exercise mitigated the effects of induced stereotype threat in female college students and thus contributed to improved math performance. Although research with children in this area is limited, it holds promise. Notably, brief inductions appear to effectively induce a state of mindfulness in pre-adolescent children (Carsley & Heath, 2019) and have been shown to reduce test anxiety (Carsley & Heath, 2019), alleviate rumination (Hilt & Pollak, 2012) and enhance a sense of calmness (Nadler et al., 2017). Concerning the effects of short mindfulness inductions on EF skills, some studies with younger, preschool-aged children failed to show significant effects (Leyland et al., 2018; Lim & Qu, 2017). In contrast, another study focusing on children with attention deficit hyperactivity disorder demonstrated immediate, moderate-to-large effects on EF skills (Bigelow et al., 2021). Therefore, beginning math practice sessions with short mindfulness inductions and embedding short mindfulness prompts within math practice might enhance students' EF skills and thus contribute to increased math learning.

The mechanisms underlying the potential benefits of mindfulness practice on children's EF skills and learning involve both direct and indirect processes (Zelazo & Lyons, 2012). In the context of math learning, mindfulness inductions may directly impact EF skills by increasing working memory capacity, improving attention regulation and enhancing cognitive flexibility. Specifically, students are likely to pay closer attention and engage more deeply with math learning materials when they possess a larger working memory capacity, enhanced capability to inhibit distractors and increased flexibility in approaching problems from different perspectives. Additionally, mindfulness practice may also enhance EF skills indirectly by reducing math anxiety, which can consume working memory and reduce inhibitory control and cognitive flexibility (Bellinger et al., 2015; Samuel & Warner, 2021).

These findings align with emerging evidence demonstrating the beneficial effects of mindfulness-based interventions for learning and academic performance (Dunning, 2023; Verhaeghen, 2023). However, some previous experiments using brief mindfulness inductions with adults found benefits only for participants with higher levels of trait mindfulness (de Sousa et al., 2021; Laurent et al., 2015; Nagy et al., 2023). As such, short inductions may only be sufficient to induce a state of mindfulness for those participants who are more receptive to this practice.

1.3 | Cultivating mindfulness through digital tools

Various digital games and apps have been developed to assist people with practicing mindfulness and mindfulness-related skills. Despite the proliferation of such commercially available applications, research evidence of their effectiveness is still limited (Nunes et al., 2020; Schultchen et al., 2021). Initial evidence indicates that technology-mediated mindfulness training and practice can be beneficial both for adults and children. For example, experimental studies conducted with adults demonstrated the effectiveness of mindfulness apps in enhancing users' mindfulness levels. These studies showed improvements on facets such as observing, describing, acting with awareness, non-judging and non-reactivity (van Emmerik et al., 2018). Moreover, the use of mindfulness apps has been associated with enhanced mental well-being, reduced psychological distress (as reviewed by Mak et al., 2017), and decreased mind wandering while increasing dispositional mindfulness (Bennike et al., 2017).

Previous research has also underscored the cognitive and motivational benefits of technology-mediated mindfulness for school-aged children. A recent study, for example, explored the potential for a video game to enhance children's mindfulness and attention (Patsenko et al., 2019). Ninety-five middle school students were randomly assigned to play either Tenacity, an iPad game explicitly designed to assist children in regulating self-attention and improving mindfulness through breath monitoring (Center for Healthy Minds: University of Wisconsin-Madison, 2019), or Fruit Ninja, an attention-demanding game that does not support any aspect of mindfulness. The results indicated that, in comparison to the control game, playing the mindfulness game led to significant changes in the fronto-parietal attentional network, a brain region crucial for attention control.

Technology-mediated mindfulness may also offer more enjoyable experiences for students compared to traditional mindfulness practice. In a qualitative focus group study, Tunney et al. (2017) compared middle school students' experiences of technology-delivered versus face-to-face mindfulness training. The study revealed similarities between students' experiences of the two modes of delivery, with common themes appearing in both groups (i.e., mindfulness improving relaxation, engagement, awareness, thinking, practice and attention). However, technology-mediated mindfulness was received more positively by participants, who described the face-to-face situations as relaxing but also monotonous and exhausting, with some even finding the activities perplexing and worthless.

Given the potential benefits of digital games and apps to assist mindfulness practice, integrating playful mindfulness practice in a digital math game may increase the effectiveness of game-based learning. Yet, to our knowledge this approach has not yet been investigated.

1.4 | Digital learning game Decimal Point

The digital learning game Decimal Point (McLaren et al., 2017) was designed for late-elementary and early-middle school students learning about decimal number operations. Decimal number concepts are

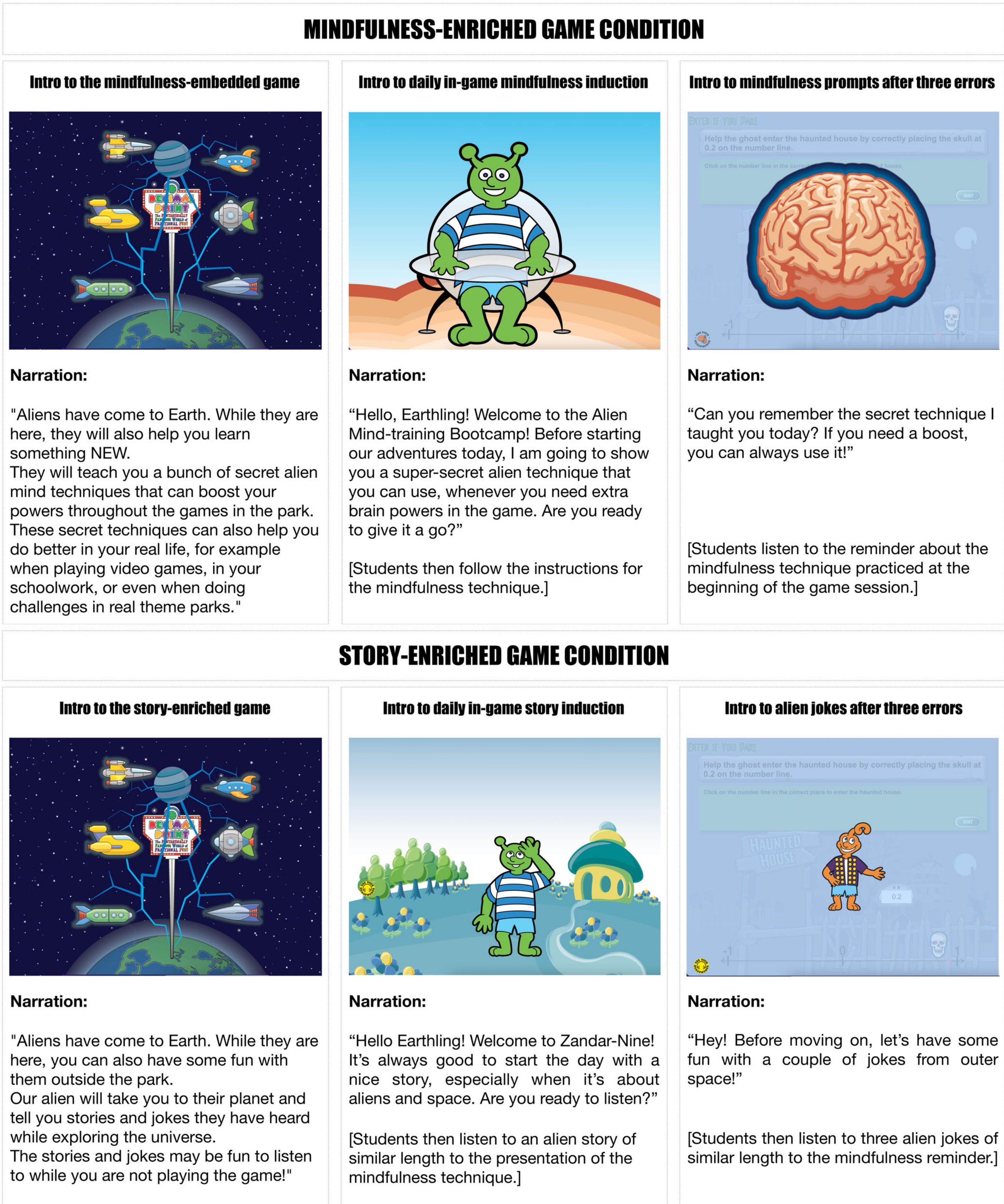

FIGURE 1 Matched daily inductions and prompts in the mindfulness and story-enriched conditions.

an important foundational topic that plays a critical role in students' learning of more advanced mathematical concepts. Students typically have a number of specific misconceptions related to decimal concepts and these misconceptions can persist through adulthood, introducing challenges in learners' later math experiences (Isotani et al., 2010). Consequently, *Decimal Point* supports students' learning of decimal concepts and addresses misconceptions when the topics are first introduced and practiced.

Students play 48 mini-game rounds designed around different rides and games in an amusement park setting (e.g., a balloon pop game, a haunted house). A group of alien characters appear at the beginning and throughout game play to encourage and provide feedback to students. Each mini-game consists of a problem-solving activity designed to address a common misconception about decimal numbers (e.g., placing a given decimal number on a number line to address the misconception that decimal numbers smaller than 1 are negative). After correctly solving the problem, students' understanding of the underlying concept is tested with a multiple-choice, self-explanation question. After each problem-solving or self-explanation attempt, students receive immediate correctness feedback. Students are not permitted to move on to another mini-game until they have correctly completed the problem-solving and self-explanation components of the current mini-game.

The initial classroom study of *Decimal Point* demonstrated that the game leads to significantly more learning and enjoyment than a conventional computer-based tutor with identical learning materials (McLaren et al., 2017). Subsequent classroom studies have also utilized *Decimal Point* to explore a variety of learning game and learning science topics, such as student agency (Harpstead et al., 2019), self-explanation formats (McLaren et al., 2022), gender effects (Nguyen et al., 2022) and the impact of hints during game play (McLaren et al., 2022).

1.5 | The present studies

In the current two studies, we extended *Decimal Point* in an attempt to temporarily enhance students' executive functioning, and thus possibly contribute to learning from the game. Based on previous evidence, we chose to induce a state of mindfulness by incorporating brief playful inductions at the start of each game session. We also included quick mindfulness reminders if students made three consecutive errors in the game. We conducted two studies (Study 1 and Study 2) comparing a version of the game *Decimal Point* with mindfulness content to a passive control condition (the original game with no enhancements) and an active control condition (the original game enhanced with stories and jokes designed as parallels to the mindfulness content). We constructed a matched, narrative-based, active comparison condition because listening to stories and jokes is an engaging activity but lacks specific mindfulness components, thus ensuring a more rigorous comparison between the two interventions (Heppner & Shirk, 2018). A brief summary of these conditions can be found in Figure 1.

An important difference from previous mindfulness studies was that students engaged in mindfulness as individuals during gameplay rather than completing the mindfulness activities in groups with an adult leading the activities, as is more typical for mindfulness-based classroom interventions. An exception is a study in which 9- and 10-year-old students practiced short breathing meditations individually with the help of an EEG device that provided feedback (Vekety et al., 2022). While this study showed that such an intervention was feasible and effective to enhance EF skills, it is an open question whether students in this age range can conduct mindfulness exercises individually, without the help of such neurofeedback. Thus, a secondary goal of the present study was to assess whether individual mindfulness practice could be supported successfully through a digital learning game for middle school students.

2 | STUDY 1

The aim of Study 1 was to investigate the effects of a mindfulness-enriched digital learning game on students' decimal achievement and in-game problem-solving behaviour, when compared to a matched story-enriched version (active control condition) and the regular version of the same decimal game (passive control condition). In addition, we were interested in possible differential effects of the mindfulness-based game on students' decimal achievement and in-game behavioural outcomes according to their levels of trait mindfulness.

Given that mindfulness-based interventions have been shown to enhance children's executive functioning (Dunning et al., 2019, 2022; Takacs & Kassai, 2019); that brief mindfulness exercises might have a similar positive effect (Bigelow et al., 2021); and that improved EF skills may contribute to increased math achievement and learning (Chi & Wylie, 2014; Zelazo & Lyons, 2012), we hypothesized the following:

> **Hypothesis 1.** (H1). Students in the mindfulness-enriched game condition will show larger learning gains than those in the story-enriched (active control) and the regular game (passive control) conditions.

Furthermore, individual differences might influence the extent of the observed learning gains in the specified conditions. Some studies have suggested that trait mindfulness in adults could moderate the efficacy of brief mindfulness inductions, indicating that such brief interventions might be more effective for participants with higher trait mindfulness, who are likely more receptive to the inductions (de Sousa et al., 2021; Laurent et al., 2015; Nagy et al., 2023). Therefore, we anticipated that:

> **Hypothesis 2.** (H2). Students' trait mindfulness will moderate the efficacy of the mindfulness inductions on learning. More specifically, we expected a larger effect of mindfulness for students with higher trait mindfulness in terms of learning gains than for students with lower trait mindfulness.

As a secondary outcome we investigated students' in-game problem-solving behaviours in the three conditions. Given the reasons discussed in H1, it is reasonable to suppose that elevated executive control and self-regulation, including less mind wandering due to mindfulness practice (Kaunhoven & Dorjee, 2017), might lead students assigned to the mindfulness condition to spend less time problem-solving, make fewer errors and self-correct more efficiently. Therefore, we expected that:

> **Hypothesis 3.** (H3). Students in the mindfulness-enriched game condition will exhibit more effective in-game problem-solving behaviours (H3a: shorter problem-solving duration, H3b: fewer errors, H3c: more accurate answers after mindfulness reminders) than those in the story-enriched or regular game conditions.

For similar reasons to those in Hypothesis 2, we expected individual differences in the secondary outcomes as well:

> **Hypothesis 4.** (H4). There will be a difference in in-game problem-solving behaviour among the conditions based on students' trait mindfulness. More specifically, we expected a larger effect for students with higher trait mindfulness in terms of effective in-game problem-solving behaviours (H4a: shorter problem-solving duration, H4b: fewer errors, H4c: more accurate answers after reminders) than for students with lower trait mindfulness.

2.1 | Methods

2.1.1 | Participants

The study was conducted in Fall 2021 with 243 5th and 6th grade students at three public schools in a mid-sized, northeastern US city. Students were excluded from the final analyses if they failed to complete at least 80% of the game ($n = 16$). The final sample included 227 students (117 female students, 110 male students), with 76 students randomly assigned to the passive control game, 74 to the story-enriched game and 77 to the mindfulness-enriched game. Students' ages ranged from 9 to 13 ($M = 10.87$, $SD = 0.70$).

2.1.2 | Materials

We modified the existing *Decimal Point* game described above to include brief mindfulness and story intervention content for the respective conditions. In the mindfulness condition, short mindfulness inductions were presented by one of the alien characters from the game at the beginning of each class. These audio inductions were adapted from mindfulness meditation scripts from the Calm Classroom Manual (Luster Learning Institute, 2007). Students listened to a different mindfulness induction each day focusing on their breath, the sounds and silence in the environment, their thoughts and their bodily sensations. Mindfulness inductions were recorded by a mix of male and female narrators and presented by a variety of gender-neutral aliens. Additionally, students received mindfulness reminders when they made three consecutive errors; the game stopped and the alien guides encouraged students to take a moment to close their eyes and focus on their breath. To avoid presenting too many reminders for students with high error rates, the system did not present an additional reminder for 10 min after each reminder regardless of errors.

Students in the story condition instead listened to short, alien-themed, age-appropriate stories at the beginning of the class, which were also presented by one of the alien characters of the game and read by a mix of male and female narrators. For a sample story used, see "*How to fix a spaceship*" (Melleen, n.d.). Additionally, instead of mindfulness reminders, when students made three consecutive errors, the game stopped and a series of alien-themed jokes were presented, for example, "Q: What do you call a tick on the moon? A: A luna-tick" (Mohawk Valley Library System, 2019). As in the mindfulness condition, there was a 10 min delay after each series of jokes during which students did not receive additional jokes regardless of errors. Induction/story materials from the beginning of each session and error prompt in the mindfulness- and story-enriched game conditions are illustrated in Figure 1.

2.1.3 | Procedures

Students worked individually on laptop computers to complete the game and tests as part of their regular classroom learning activities. Participants were randomly assigned within each class to either the mindfulness-enriched, story-enriched or regular game conditions, with all three of the conditions present in each classroom. All students first completed a demographic questionnaire, a trait mindfulness scale and a decimal test that assessed their prior math knowledge in the area of decimals. After completing the decimal test, they began working through the game. Students assigned to the mindfulness and story conditions completed the mindfulness induction or story reading at the start of each game session. Additional mindfulness or joke prompts would show up after a student made three consecutive errors in a mini-game. Students listened to inductions and reminders using headphones. In the passive control condition, students immediately began to play the game each day without any additional activities, and they did not receive any reminders or jokes after making consecutive errors. After finishing the game, students completed a decimal posttest and delayed posttest. Students moved through the surveys, pretest, learning materials and posttest materials at their own pace for a maximum of 5 days, followed by a single day a week later when they completed the delayed posttest (six classes in total, each 45–50 min long). There were no inductions or reminders during the pretest or posttest. Procedures are presented in Table 1.

2.1.4 | Measures

Data collection consisted of three decimal achievement tests, three measures of problem-solving behaviour, and a trait mindfulness scale.

TABLE 1 Procedures in Studies 1 and 2.

	Study 1			Study 2		
	Mindfulness-enriched game	Story-enriched game	Regular game	Mindfulness-enriched game	Story-enriched game	Regular game
Day 1						
Demographic questionnaire	✓	✓	✓	✓	✓	✓
Trait Mindfulness Scale	✓	✓	✓	✓	✓	✓
Decimal pretest	✓	✓	✓	✓	✓	✓
Day 2						
Game intro	✓	✓	✓	✓	✓	✓
Induction 1	✓	✓	–	✓	✓	–
State Mindfulness Scale 1	–	–	–	✓	✓	✓
Decimal gameplay	✓	✓	✓	✓	✓	✓
Prompts after three errors	✓	✓	–	✓	✓	–
Day 3–5						
Inductions 2–5	✓	✓	–	✓	✓	–
State Mindfulness Scale 2–5	–	–	–	✓	✓	✓
Decimal gameplay	✓	✓	✓	✓	✓	✓
Prompts after three errors	✓	✓	–	✓	✓	–
Day 4–6						
Decimal posttest	✓	✓	✓	✓	✓	✓
Day 14						
Decimal delayed posttest	✓	✓	✓	✓	✓	✓

Decimal pretest, posttest and delayed posttest

Students' knowledge of decimals was measured through three achievement tests: a pretest, a posttest and a delayed posttest. There were three isomorphic versions of the test that were counterbalanced across conditions and students. The tests consisted of 42 items worth a total of 52 points ($\alpha = 0.86$–0.90); some items were worth multiple points because they contained multiple parts or answer components. Items on the test were designed to probe the same decimal operations, concepts and misconceptions covered in the game.

In-game problem-solving behaviour measures

Three measures were used to assess students' problem-solving behaviours: problem-solving duration, errors and correctness after reminders. *Problem-solving duration* refers to the total time students spent solving problems during the game. *Errors in the game* represent the number of times that students provided erroneous answers to the problems and questions in the game. *Correctness after reminder* is the number of times that a student's first attempt after encountering the mindfulness reminder (mindfulness condition) or jokes (story condition) was correct, divided by the number of reminders or jokes they received. Correctness after reminder measures were calculated only in the mindfulness- and story-enriched conditions, as the regular game did not provide any prompts after frequent errors.

Trait mindfulness

Students' trait mindfulness was assessed with the 14-item Mindful Attention Awareness Scale-Adolescent (MAAS-A, Brown et al., 2011), which is designed for adolescent populations. Example items of the MAAS-A include, "I rush through activities without being really attentive to them." or "I tend not to notice feelings of physical tension or discomfort until they really grab my attention." Items are answered on a five-point scale (1 = Almost always; 5 = Almost never). The MAAS-A has been validated in adolescent normative populations with Cronbach's α varying from 0.82 to 0.84 (Brown et al., 2011). In this study, Cronbach's α was 0.85. Answers were scored such that higher scores indicate higher trait mindfulness.

2.1.5 | Data analysis

We analysed the data using IBM SPSS Statistics Version 21.0 for Mac and its PROCESS Macro extension Version 4.1 (Hayes, 2022). Data and syntax are openly available on OSF at https://doi.org/10.17605/OSF.IO/RZEC9. The effects of condition on achievement were tested using repeated measures Analyses of Variance (ANOVAs). For the effects of condition on problem-solving behaviours, we used univariate ANOVAs and Independent-Samples *T*-tests. Regarding math achievement, we chose to test results in two models: one examining the change between pretest and posttest and another for the change between pretest and delayed posttest. This was chosen instead of testing changes between the three time points since there were a number of participants with missing values on either the posttest or the delayed posttest. We conducted two a priori defined Helmert contrasts in the ANOVA models: first, we contrasted the passive control condition (game-only) to the two treatment conditions (story-enriched and mindfulness-enriched game conditions) and second, the latter two were contrasted. The moderating role of trait mindfulness was tested with the PROCESS Macro (Hayes, 2022).

We conducted a priori power analyses using G*Power version 3.1.9.6 (Faul et al., 2007) to determine the minimum sample size needed to test the study hypotheses. Results indicated that the required sample size to achieve 80% power for detecting a medium effect at $\alpha = 0.05$ was, (1) $n = 42$ in total (14 per group) for the repeated measures ANOVAs with two measurement points and three groups (H1); (2) $n = 154$ in total (52 per group) for the univariate ANOVAs with three groups (H3a, H3b); (3) $n = 90$ in total (45 per group) for the Independent Samples T-test (H3c); (4) $n = 68$ for the multiple linear regressions with two interactions tested and five total predictors (H2, H4a, H4b); and (5) $n = 55$ for the multiple linear regressions with one interaction tested and three total predictors (H4c). The obtained sample sizes were adequate to test the study hypotheses.

2.2 | Results

2.2.1 | Effects of condition on decimal achievement in Study 1

To examine whether students learned more from the mindfulness-enriched decimal game when compared to the story-enriched (active control) and regular game conditions (passive control) (H1), we conducted two repeated-measures ANOVAs. The two analyses tested learning condition as a between-subject factor and test time (pretest–posttest in Model 1 and then pretest–delayed posttest in Model 2) as a within-subject factor. Differences between pretest and posttest scores, and those between pretest and delayed posttest, followed a reasonably normal distribution without significant outliers in all three conditions. Assumptions of homogeneity were met. There was no statistically significant difference among students' pretest scores in the three conditions, $F(2, 220) = 0.39$, $p = 0.68$, $\eta p^2 = 0.004$, confirming that three equal groups were created by randomly assigning participants to the three conditions. Test performance by condition is presented in Table 2.

Model 1 assessing change from pretest to posttest showed that there was a significant effect of time, with students' scores improving significantly from pretest to posttest, $F(1, 186) = 51.91$, $p < 0.001$, $\eta p^2 = 0.218$. There was no main effect of condition, $F(2, 186) = 0.19$, $p = 0.82$, $\eta p^2 = 0.002$, and planned comparisons showed no differences between the passive control and the other two conditions, $p = 0.61$, or between the story and mindfulness conditions, $p = 0.71$. Most importantly, in contrast to our hypothesis, there was no interaction between time and condition, $F(2, 186) = 0.89$, $p = 0.41$, $\eta^2 = 0.009$; in other words, improvements in students' math scores from pretest to posttest did not differ by condition.

Model 2 assessing change from pretest to delayed posttest revealed a significant effect of time, with students' scores improving significantly from pretest to delayed posttest, $F(1, 193) = 56.52$, $p < 0.001$, $\eta p^2 = 0.227$. There was no main effect of learning condition, $F(2, 193) = 0.13$, $p = 0.88$, $\eta p^2 = 0.001$, and planned comparisons showed no differences between the passive control and the other two conditions ($p = 0.64$) or between the story and mindfulness conditions ($p = 0.83$). Again, in contrast to our hypothesis, there was no interaction between time and condition, $F(2, 193) = 1.58$, $p = 0.21$, $\eta p^2 = 0.016$, meaning that improvements in students' scores from pretest to delayed posttest did not differ by condition.

2.2.2 | The moderating effects of trait mindfulness on students' decimal achievement by condition in Study 1

To examine whether trait mindfulness moderated students' learning by condition (H2), we conducted two moderation analyses in the PROCESS Macro based on 5000 randomly selected sub-samples and with 95% bias-corrected confidence intervals (Hayes, 2022). Condition was a multicategorical independent variable with three levels (*X*). The dependent variable (*Y*) was first the difference between posttest and pretest (H2a, Model 3), and then the difference between delayed posttest and pretest (H2b, Model 4), whereas trait mindfulness was introduced as a moderator in the models (*Z*). There was no significant difference among students' trait mindfulness in the three conditions, $F(2,220) = 0.91$, $p = 0.41$, $\eta p^2 = 0.008$. We identified four multivariate outliers in both Models 3 and 4, with Mahalanobis values greater than the critical for this sample size ($D^2 > 20.52$, Stevens, 2002). After removing multivariate outliers, assumptions of the moderation analyses were met. Correlations between trait mindfulness and decimal achievement are presented in Appendix A. Moderation models and graphs of non-significant interactions are included in Appendices B and E.

Results of Model 3 showed that trait mindfulness, condition and the interactions between trait mindfulness and condition did not explain significant variance in students' learning gain scores from pretest to posttest, $R^2 = 0.03$, $F(5,180) = 1.17$, $p = 0.33$. In addition, the interaction effect between trait mindfulness and condition on learning gain from pretest to posttest was also non-significant, $\Delta R^2 = 0.01$, *F*

TABLE 2 Learning gains and in-game problem-solving behaviour by condition in Study 1.

	Regular game condition	Story-enriched game condition	Mindfulness- enriched game condition
Pretest > posttest	$n = 68$	$n = 62$	$n = 59$
Pretest scores	18.46 (9.19)	18.98 (8.78)	20.15 (9.87)
Posttest scores	22.10 (10.04)	22.39 (9.79)	22.46 (10.75)
Pretest > Delayed posttest	$n = 65$	$n = 62$	$n = 69$
Pretest scores	18.55 (9.30)	18.69 (8.17)	18.86 (8.96)
Delayed posttest scores	23.25 (11.08)	21.45 (12.51)	21.99 (10.39)
In-game problem-solving behaviour	$n = 73$	$n = 70$	$n = 70$
Problem-solving duration	68.32 (26.06)	64.69 (22.30)	66.46 (24.80)
Problem-solving errors	118.82 (55.15)	114.59 (65.37)	110.79 (61.83)
Correctness after reminder	-	0.28 (0.23)	0.30 (0.25)

Note: Test performance and problem-solving measures are reported by condition in *M* (SD) format. Test scores are measured on a scale of 0–52. Problem-solving duration is reported in minutes. The problem-solving errors measure is expressed in the number of errors made. The correctness after reminder measure is expressed by the percentage of correct answers given after reminders.

(2,180) = 1.27, $p = 0.28$. Finally, we found non-significant main effects of trait mindfulness ($p = 0.59$) and condition ($p = 0.28$ for control vs. rest, and $p = 0.39$ for story vs. mindfulness) on posttest–pretest learning gain.

Results of Model 4 showed that trait mindfulness, condition, and the interaction between trait mindfulness and condition did not explain significant variance in students' learning gain scores from pretest to delayed posttest, $R^2 = 0.04$, $F(5,186) = 1.48$, $p = 0.20$. Additionally, the interaction between trait mindfulness and condition was non-significant, $\Delta R^2 = 0.003$, $F(2,186) = 0.37$, $p = 0.69$. We found non-significant main effects of trait mindfulness ($p = 0.12$) and condition ($p = 0.08$ for control vs. rest, and $p = 0.92$ story vs. mindfulness).

In summary, contrary to our expectations, we did not find that the mindfulness-enriched game condition was more beneficial in terms of learning gains than the story or regular game condition for students with a high trait mindfulness profile. Although trait mindfulness was significantly, positively correlated with learning gains (see Appendix A), it exerted no main effect on them in either Model 3 or 4.

2.2.3 | Effects of condition on students' in-game problem-solving behaviour in Study 1

To test whether in-game problem-solving behaviour in the mindfulness condition was more effective than in the story or the regular game condition (H3), we conducted two univariate ANOVAs with condition as an independent variable, and problem-solving duration in Model 5 (H3a) and number of errors in Model 6 (H3b) as dependent variables. Additionally, an Independent-Samples T-test was conducted in Model 7 with condition as an independent variable and correctness after reminder as a dependent variable (H3c), since only the mindfulness- and story-enriched conditions could be included in this analysis. The analyses included data collected from students who completed all mini-games ($n = 213$). Problem-solving duration, errors and correctness after reminders in the different conditions did not follow a normal distribution; however, given the absence of outliers and the robustness of ANOVA with large sample sizes, these variables were not transformed (Field, 2017). Descriptive statistics are presented in Table 2.

There was no significant effect of condition on the amount of problem-solving time students spent in the mini-games, $F(2, 210) = 0.39$, $p = 0.68$, $\eta p^2 = 0.004$, or the number of errors students made in the game, $F(2, 210) = 0.31$, $p = 0.73$, $\eta p^2 = 0.003$. Similarly, there was no significant difference in correctness after reminders between the mindfulness and story conditions, $t(138) = -0.60$, $p = 0.55$.

Thus, our hypotheses that students assigned to the mindfulness condition would take less time to solve mini-game problems and make fewer errors than those in story-enriched or regular game conditions was not confirmed. Additionally, students in the mindfulness condition did not provide significantly more correct answers following mindfulness reminders than those in the story condition after jokes.

2.2.4 | The moderating effects of trait mindfulness on students' in-game problem-solving behaviour by condition in Study 1

To investigate whether students' trait mindfulness had an effect on students' in-game problem-solving behaviour by condition (H4), we ran a series of moderation analyses in PROCESS Macro. The analyses included data collected from students who completed the games ($n = 213$). Condition was a multicategorical independent variable with three levels (X). Dependent variables (Y) were the in-game problem-solving behaviours: problem-solving duration (H4a, Model 8), problem-solving errors (H4b, Model 9) and correctness after reminder (H4c, Model 10). Trait mindfulness was introduced as a moderator (Z) in the models. Again, there was no significant difference among students' trait mindfulness in the three conditions, $F(2,210) = 1.67$, $p = 0.27$, $\eta p^2 = 0.016$. We identified four multivariate outliers in both Models 8 and 9, with Mahalanobis values greater than the critical (D^2

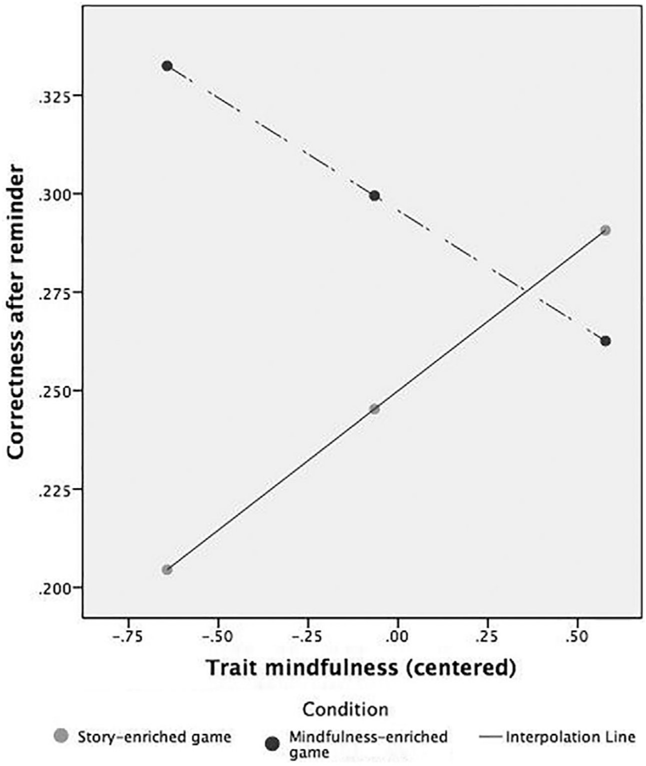

FIGURE 2 The moderating effect of trait mindfulness on correctness after reminder by condition.

>20.52, Stevens, 2002). In addition, based on the inspection of residuals we identified three additional outliers in Model 8, three in Model 9 and four in Model 10. After removing outliers, assumptions of the moderation analyses were met. Correlations between trait mindfulness and in-game problem-solving behaviour measures are presented in Appendix C. Moderation models and graphs representing non-significant interactions are included in Appendices D–E.

Results of Model 8 showed a non-significant fit, $R^2 = 0.01$, $F(5, 200) = 0.19$, $p = 0.97$. In addition, the interaction effect between trait mindfulness and condition was also non-significant, $\Delta R^2 = 0.003$, $F(2,200) = 0.30$, $p = 0.74$. Finally, we found non-significant main effects of trait mindfulness ($p = 0.91$) and condition ($p = 0.69$ for control vs. rest, and $p = 0.97$ for story vs. mindfulness).

Results of Model 9 with game errors as the dependent variable showed a non-significant fit, $R^2 = 0.02$, $F(5, 200) = 0.93$, $p = 0.46$. The interaction effect between trait mindfulness and condition was also non-significant, $\Delta R^2 = 0.01$, $F(2, 200) = 0.58$, $p = 0.56$. Finally, there was a non-significant main effect of trait mindfulness ($p = 0.18$) and condition ($p = 0.17$ for control vs. rest, and $p = 0.93$ for story vs. mindfulness).

Results of Model 10 with correctness after reminder as the dependent variable showed a non-significant model fit, $R^2 = 0.05$, $F(3, 132) = 2.16$, $p = 0.10$. We found a significant main effect of trait mindfulness ($p = 0.05$), and a non-significant effect of condition ($p = 0.20$) on correctness after reminder. However, the interaction effect between trait mindfulness and condition on correctness after reminder was significant, $\Delta R^2 = 0.03$, $F(1, 132) = 4.53$, $p = 0.04$. More specifically, simple slope analysis showed that students at one standard deviation below the mean on trait mindfulness showed a significant difference between the conditions favouring the mindfulness-enriched condition ($B = 0.13$, $SE = 0.05$, $t = 2.45$, $p = 0.015$). The same effect was not significant at the mean ($p = 0.13$) or at one standard deviation above the mean ($p = 0.58$) on trait mindfulness. Results thus indicate that students with lower trait mindfulness benefited more from the mindfulness condition and less from the story condition on correctness after reminders, as depicted by Figure 2.

In summary, contrary to our expectations (H4), we did not find that trait mindfulness moderates the effects of condition on problem-solving duration (H4a) and errors (H4b). In line with our expectations, trait mindfulness moderated correctness after reminder (H4c); however, in contrast to the direction we expected, students with lower levels of trait mindfulness made fewer in-game problem-solving errors after reminders in the mindfulness condition than in the story condition.

2.3 | Discussion of findings in Study 1

In contrast to our expectations, we found no benefits of embedding mindfulness inductions at the start of a decimal game session either on students' learning (primary outcome) or in-game behaviour (secondary outcome). Additionally, we did not find evidence that there was a difference in learning gains across the conditions based on students' trait mindfulness. Students' trait mindfulness did not moderate effects of condition on problem-solving duration or error count. However, students' trait mindfulness moderated the number of errors they made after prompts (mindfulness reminders or jokes). Students with lower trait mindfulness made fewer in-game problem-solving errors after mindfulness reminders than after jokes as reminders. This indicates that, contrary to our expectations, the mindfulness reminders were more helpful for students with lower levels of trait mindfulness, suggesting that these students may be in more need of such reminders. This partly reiterates the previous mixed results regarding the benefits of higher levels of trait mindfulness in academic settings, which depended on the specific academic outcomes measured and the characteristics of the interventions (Kuroda et al., 2022; Verhaeghen, 2023). This effect on correct responses after prompts did not; however, translate to higher math learning outcomes. Overall, our results are consistent with other studies highlighting the difficulty in producing large math learning effects through technology-enhanced mindfulness interventions (Bakosh et al., 2018).

There might be several explanations for the lack of positive effects. One explanation is that mindfulness inductions might be less beneficial in a digital learning game. Mindfulness benefits might appear stronger in learning contexts where students' are in greater need of an intervention to support attention and engagement (Richey et al., 2021). Alternatively, we may have failed to induce a state of mindfulness in the first place. Thus, before drawing any conclusions regarding the effects of mindfulness inductions on learning with digital games, we included a manipulation check in Study 2.

3 | STUDY 2

The purpose of Study 2 was to examine the evidence of success of the mindfulness manipulation in the mindfulness-enriched condition, and to determine whether we would replicate findings in Study 1 in terms of a lack of condition effects on learning gains and in-game problem-solving behaviours. In line with our aims, we proposed the following additional hypothesis:

> **Hypothesis 5.** (H5). Students in the mindfulness-enriched game condition would report higher state mindfulness after the induction than those in the story-enriched or regular game conditions.

3.1 | Methods

3.1.1 | Participants

Study 2 was conducted in Fall 2021 with 193 5th and 6th grade students in three additional public schools in the same US city. Sixteen students failed to complete at least 80% of the game and thus were excluded from analyses. The final sample included 177 students (86 females, 91 males), with 54 students randomly assigned to the passive control condition, 61 to the story-enriched condition, and 62 to the mindfulness-enriched condition. Students' ages ranged from 10 to 13 ($M = 10.99$, $SD = 0.72$), with one student failing to report their age. Based on the a priori power analyses conducted in G*Power version 3.1.9.6 (Faul et al., 2007), the obtained sample sizes were adequate to test the study hypotheses (see Section 2.1.3. Data analysis for Study 1).

3.1.2 | Procedures

Procedures were the same as in Study 1, except that at the beginning of each game session, after receiving the inductions, students in the mindfulness and story conditions completed a state mindfulness measure. Students in the regular game condition did not have any inductions, so they completed the state mindfulness measure at the beginning of each of their game sessions. The procedures in Study 2 are presented in Table 1.

3.1.3 | Measures

In addition to the same measures[1] as in Study 1, we included a state mindfulness questionnaire during each game session as a manipulation check.

State mindfulness was measured with a 5-item scale adapted from the MAAS-A (Brown et al., 2011), so that statements would reflect students' experience at the moment. Example items of the scale include “Right now I find it difficult to stay focused on what's happening.” or “Right now I'm doing things automatically, without being aware of what I'm doing.” Items were answered on a seven-point scale (1 = Not at all; 7 = Very much so). Students' answers were reversed for the analyses, so that higher scores reflect higher state mindfulness. Cronbach's α values were good-to-excellent (0.72–0.91) for each state mindfulness measurement (see Appendix F). A composite state mindfulness score was calculated for each student by averaging the means of individual state mindfulness scores.

3.2 | Results

3.2.1 | Manipulation check (state mindfulness)

First we investigated whether we managed to induce a state of mindfulness with the inductions (H5). We conducted a univariate ANOVA with condition as an independent variable, and composite state mindfulness as a dependent variable (Model 11). State mindfulness did not follow a normal distribution by condition; however, given the absence of outliers and the robustness of ANOVA with large sample sizes, we did not transform the variable (Field, 2017).

The univariate ANOVA showed no significant effect of condition on students' state mindfulness after inductions (mindfulness or story) or at the beginning of the game sessions in the case of the regular game condition, $F(2, 174) = 0.51$, $p = 0.60$, $\eta p^2 = 0.006$. Also, neither of the planned comparisons was significant: control versus rest ($p = 0.65$) and story versus mindfulness treatment ($p = 0.37$).

In summary, our results show that we did not manage to induce a higher state of mindfulness in the mindfulness condition as compared with the other two conditions. This suggests that the inductions at the beginning of the game sessions were unsuccessful, which might explain the lack of effects on learning and in-game behaviours. Accordingly, our analyses of learning outcomes and in-game behaviours are not informative regarding the effect of an enhanced state mindfulness, and thus they are only reported in Appendix G.

Given the challenges people often encounter in accurately assessing and reporting their own states of mindfulness, particularly among those with little prior experience with mindfulness (Goodman et al., 2017), it is possible that the intervention affected students' mindfulness in ways that were not detected by the self-reported questionnaire. However, given the lack of evidence that we successfully induced mindfulness, combined with the close replication of results from Study 1 (see Appendix G), it is unlikely that the mindfulness induction changed students' learning or gameplay in meaningful ways. Still, we report findings for correct responses after reminders (mindfulness or joke) considering that accuracy might be enhanced by the reminders even in the absence of a successful mindfulness induction at the beginning of the sessions (as also suggested by the results of Study 1).

[1]For the trait mindfulness scale (MAAS-A; Brown et al., 2011) Cronbach's α was 0.88 in Study 2.

3.2.2 | The effect of mindfulness prompts on correctness after reminder in Study 2

An Independent-Samples T test (Model 7) was conducted with condition as an independent variable and correctness after reminder as a dependent variable, assumptions for which were reasonably met. Analyses were based on data collected from students who completed the entire game in the story-enriched ($n = 54$) and the mindfulness-embedded ($n = 58$) conditions. Means and standard deviations were $M = 0.27$ and $SD = 0.23$ for the story-enriched condition and $M = 0.36$ and $SD = 0.30$ for the mindfulness-embedded condition.

In contrast to our results in Study 1, the Independent-Samples T-test revealed a marginally significant condition effect on correctness after reminder (H2c) between the mindfulness and story conditions, $t(107.02) = -1.82$, $p = 0.07$, as illustrated by the following Figure 3.

3.3 | Discussion of findings in Study 2

The manipulation check showed that the embedded mindfulness inductions did not induce higher state mindfulness. This is a likely explanation for the lack of beneficial effects on learning and in-game behaviour found in Study 1; consistent with this explanation, we generally saw no beneficial effects of the mindfulness condition on learning and in-game behaviour in Study 2 (see Appendix G). We still reported results regarding correct responses following prompts (mindfulness or joke) because those might be beneficial even in the absence of an induced state of mindfulness at the beginning of the sessions. Students provided marginally more correct answers following the mindfulness reminders in the mindfulness condition as compared to the jokes in the story condition. This suggests that these mindfulness reminders were somewhat more helpful than simply being stopped after three consecutive errors. This finding is partly in line with the result in Study 1 where such a difference only appeared for students with lower trait mindfulness.

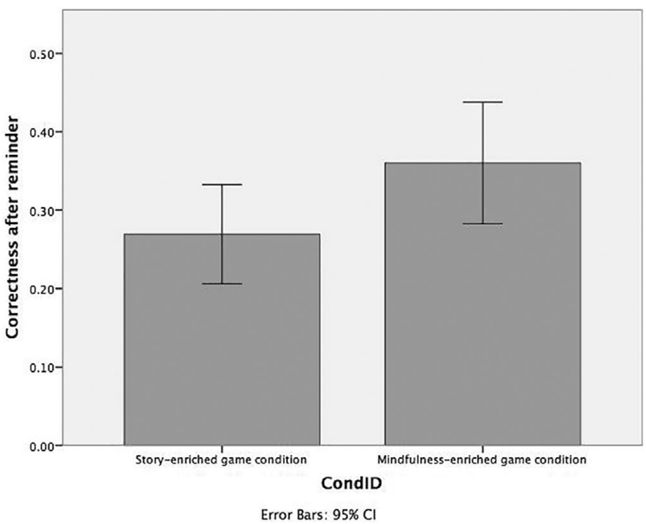

FIGURE 3 Correctness after reminder in the mindfulness and story conditions. $p = 0.07$.

4 | GENERAL DISCUSSION AND IMPLICATIONS

Our research responds to a call to further investigate the effects of mindfulness-based interventions on math learning, particularly in the space of technology-enabled mindfulness support (Bakosh et al., 2018). The goal of this research project was to explore the predicted benefits of embedding short mindfulness exercises in a digital game, *Decimal Point*, in math classrooms. We compared the mindfulness-embedded version of the game to (1) an active control condition with stories and jokes and (2) a passive control condition in which participants played the original game. Based on the effects of mindfulness inductions on EF skills and anxiety, we expected enhanced learning as the primary outcome and more efficient in-game problem-solving behaviours as the secondary outcome in the mindfulness condition. Finally, we investigated the potential moderating role of students' baseline trait mindfulness. Aside from an effect on student's correct responses following mindfulness prompts, none of our hypotheses were supported. In Study 2, we repeated the experiment and added a measure of state mindfulness after the mindfulness or story inductions at the beginning of game sessions (or at the very beginning of game sessions in the passive control condition) as a manipulation check in order to assess whether we managed to induce a state of mindfulness. We found no evidence that we induced mindfulness for students in the mindfulness condition. Thus, we cannot draw any conclusions regarding the effects of state mindfulness on math learning or in-game problem-solving behaviours. However, we can offer insights and recommendations for future work regarding how (not) to attempt to induce a state of mindfulness in the classroom.

There are several potential explanations for why the intervention failed to induce a state of mindfulness. It might be that 5-min inductions were too short, although we based the scripts on a widely used mindfulness curriculum designed for this age group, and exercises of similar lengths have been applied successfully in mindfulness-based interventions (Vekety et al., 2022). More likely, the timing and medium of the inductions contributed to the lack of an effect. A recent meta-analysis found that in-person mindfulness interventions led to significantly larger effects on academic performance than recorded interventions; in fact, pooled effects of recorded interventions were not significant (Verhaeghen, 2023). It may be that students experience less motivation or guidance when following recorded mindfulness inductions compared with live teachers. This is an important challenge to consider in efforts to embed mindfulness interventions in educational technology going forward. Additionally, Verhaeghen (2023) found that mindfulness-based interventions applied at the beginning of classes were less efficient than interventions applied in separate classes, although they still had a significant effect. Focusing on mindfulness as a distinct activity may allow students to engage more deeply and thus experience greater benefits. Although we considered it a strength to incorporate mindfulness directly in an existing educational technology, these results suggest it might be more beneficial to focus on technology-supported mindfulness interventions that are administered on their own.

A methodological decision in our experimental design may also have weakened effects. Specifically, prompting individual mindfulness exercises in a group setting might have resulted in students being self-conscious about closing their eyes and listening to a meditation script while surrounded by their peers. To achieve sufficient power we chose to randomize students to the different conditions on an individual level as opposed to a class level. Accordingly, students in the different conditions sat in the same classroom, with some being required to close their eyes (mindfulness condition) and the rest not being asked to do so (active and passive control conditions). Such differences may have made it more difficult for students in the mindfulness condition to truly engage in the meditation exercises. Yet, our informal observations in the classroom suggested that students were generally complying with the mindfulness inductions. Furthermore, Verhaeghen (2023) found that randomization of mindfulness interventions at the individual level yielded larger effects than randomization at the class level.

Finally, the failure to induce mindfulness in the digital game could also be attributed to the design of the induction itself. Following design recommendations argued to support technology-mediated mindfulness (Hu et al., 2023), we used game characters as mindfulness guides to establish an emotional connection and created a relaxing atmosphere through visual transitions from the fast-paced math world to the calmer mindfulness world (i.e., aliens in the game inviting students to join an Alien Brain Training Camp). However, the reliance on students closing their eyes and solely listening to the inductions restricted our ability to fully leverage the technological features provided by digital tools for facilitating mindfulness. For instance, previous studies have demonstrated the effectiveness of interactive breath counting programs in enhancing awareness of inner experiences and promoting mindful actions through ongoing cognitive demand and a focus on interoceptive attention (Levinson et al., 2014; Patsenko et al., 2019). Hu et al. (2023) highlighted the potential of gamifying mindfulness through progress, goals and levels. In an experimental study, Vekety et al. (2022) demonstrated the potential EF-enhancing effect of mindfulness supplemented with EEG-feedback. Additionally, the use of interactive rhythmic soundscapes modulated by participants' brainwaves has also shown promising results in supporting mindfulness practice (Cochrane et al., 2021). These examples highlight the potential benefits of incorporating multimedia elements, interactive features, feedback mechanisms and gamification principles in the design of interactive technologies to support mindfulness practices. In future studies, it is crucial to consider these design recommendations to enhance the efficacy and engagement of mindfulness practices and potentially promote better learning outcomes and student well-being in digital learning environments.

Alternatively, it is possible that the mindfulness induction altered behaviours in small ways that could not be detected by self-reports of mindfulness. Although such changes (if they occurred) did not produce significant changes in learning outcomes, it would be valuable to know if the inductions produced any behavioural changes that could be scaled up over time or through more intensive support. The fields of game-based learning and serious gaming frequently incorporate learning analytics that can detect such fine-grained patterns in behaviours (Ahmad et al., 2022). Future research could apply a learning analytics approach to assess students' behaviours throughout the game for differences associated with the mindfulness inductions (e.g., less carelessness). Researchers in the area of serious gaming have proposed and tested frameworks for incorporating learning analytics in games in ways that optimize the value of the data that are gathered and analysed (Malliarakis et al., 2016).

An interesting finding of the present project was that students who made three consecutive errors provided marginally more correct answers after listening to the mindfulness reminders as opposed to the jokes we used in the story condition. This result highlights that mindfulness prompts might be especially beneficial in moments when students are likely to experience frustration, and that prompting mindfulness might be more beneficial than simply stopping students when they are making frequent errors. Future studies could further investigate the learning effects of mindfulness prompts following errors in digital learning games.

5 | LIMITATIONS

Limitations of our study should be considered when interpreting the results. First, we did not assess students' EF skills or levels of state and trait anxiety (e.g., math anxiety). However, including such measures would have interfered with the gameplay and could have potentially acted as interventions themselves, as noted by Hauser et al. (2018). Second, our study relied on self-reported measures of trait and state mindfulness. Although these measures provide valuable insights, they are subjective and may be influenced by response biases or other individual factors. Sensing technologies, such as EEG, could provide deeper insights into students' engagement and experiences, but they also introduce additional limitations in classroom settings. Another limitation is the absence of qualitative data capturing students' experiences through observation and interviews. Collecting qualitative data could have provided insights into potential barriers or challenges faced by the students during the mindfulness inductions. Finally, the observed effects of mindfulness inductions in our study may have been small. Detecting more subtle main effects and small moderation effects would have required a larger sample size, and our limited sample size may have constrained the statistical power to identify significant differences.

6 | CONCLUSIONS

Individual short meditation scripts embedded in a digital learning game do not seem to induce mindfulness. Although it is difficult to induce mindfulness in a digital game at an individual level within a classroom setting, mindfulness prompts may be beneficial for students in moments of frustration during gameplay. Our results provide important information regarding how future research should attempt to induce mindfulness in the classroom. Specifically, we argue that future studies should continue testing design principles and boundary conditions to establish better guidance for using mindfulness meditation to support learning through educational technology and digital learning games. Understanding these factors is critical if researchers, educational technology designers and teachers wish to incorporate mindfulness interventions at a larger scale in educational contexts.

AUTHOR CONTRIBUTIONS

Enikő Orsolya Bereczki: Conceptualization; data curation; formal analysis; funding acquisition; investigation; writing – original draft; writing – review and editing; methodology. **Zsofia K. Takacs:** Conceptualization; methodology; writing – original draft; writing – review and editing; formal analysis. **J. Elizabeth Richey:** Conceptualization; methodology; writing – original draft; writing – review and editing. **Huy A. Nguyen:** Conceptualization; software; writing – review and editing. **Michael Mogessie:** Conceptualization; resources; supervision; software. **Bruce M. McLaren:** Conceptualization; funding acquisition; investigation; methodology; resources; supervision; writing – review and editing.

ACKNOWLEDGEMENTS

Thanks to Jodi Forlizzi, who contributed to the original Decimal Point design and experimentation. Thanks to Rick Henkel, who did the additional artwork required to extend Decimal Point.

FUNDING INFORMATION

This project was partially funded by the Hungarian National Research, Development and Innovation Office (grant OTKA – PD – 138723) and by the National Science Foundation Award #DRL-1661121. The opinions expressed are those of the authors and do not represent the views of the funding agencies.

CONFLICT OF INTEREST STATEMENT

All authors declare that they have no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in OSF at https://doi.org/10.17605/OSF.IO/RZEC9.

ETHICS STATEMENT

This study was approved by the Carnegie Mellon University's Institutional Review Board (IRB approval number: HS13-105).

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REFERENCES

Ahmad, A., Schneider, J., Griffiths, D., Biedermann, D., Schiffner, D., Greller, W., & Drachsler, H. (2022). Connecting the dots–A literature review on learning analytics indicators from a learning design perspective. *Journal of Computer Assisted Learning*. Advance online publication. https://doi.org/10.1111/jcal.12716

Bakosh, L. S., Tobias Mortlock, J. M., Querstret, D., & Morison, L. (2018). Audio-guided mindfulness training in schools and its effect on academic attainment: Contributing to theory and practice. *Learning and Instruction*, *58*, 34–41. 10.1016/j.learninstruc.2018.04.012.

Bellinger, D. B., DeCaro, M. S., & Ralston, P. A. S. (2015). Mindfulness, anxiety, and high-stakes mathematics performance in the laboratory and classroom. *Consciousness and Cognition*, *37*, 123–132. https://doi.org/10.1016/j.concog.2015.09.001

Bennike, I. H., Wieghorst, A., & Kirk, U. (2017). Online-based mindfulness training reduces behavioral markers of mind wandering. *Journal of Cognitive Enhancement*, *1*, 172–181. https://doi.org/10.1007/s41465-017-0020-9

Bigelow, H., Gottlieb, M. D., Ogrodnik, M., Graham, J. D., & Fenesi, B. (2021). The differential impact of acute exercise and mindfulness meditation on executive functioning and psycho-emotional well-being in children and youth with ADHD. *Frontiers in Psychology*, *12*, 1–13. https://doi.org/10.3389/fpsyg.2021.660845

Brown, K. W., West, A. M., Loverich, T. M., & Biegel, G. M. (2011). Assessing adolescent mindfulness: Validation of an adapted mindful attention awareness scale in adolescent normative and psychiatric populations. *Psychological Assessment*, *23*(4), 1023–1033. https://doi.org/10.1037/a0021338

Carsley, D., & Heath, N. L. (2019). Evaluating the effectiveness of a mindfulness coloring activity for test anxiety in children. *The Journal of Educational Research*, *112*(2), 143–151. https://doi.org/10.1080/00220671.2018.1448749

Center for Healthy Minds: University of Wisconsin-Madison. (2019). Games to teach mindfulness and compassion to adolescents. Retrieved from https://centerhealthyminds.org/science/studies/games-to-teach-mindfulness-and-compassion-to-adolescents.

Chi, M. T. H., & Wylie, R. (2014). The ICAP framework: Linking cognitive engagement to active learning outcomes. *Educational Psychologist*, *49*(4), 219–243. https://doi.org/10.1080/00461520.2014.965823

Clements, D. H., Sarama, J., & Germeroth, C. (2016). Learning executive function and early mathematics: Directions of causal relations. *Early Childhood Research Quarterly*, *36*, 79–90. https://doi.org/10.1016/j.ecresq.2015.12.009

Cochrane, K., Loke, L., Leete, M., Campbell, A., & Ahmadpour, N. (2021). Understanding the first person experience of walking mindfulness meditation facilitated by EEG modulated interactive soundscape. In *Proceedings of the fifteenth international conference on tangible, embedded, and embodied interaction* (pp. 1–17). ACM. https://doi.org/10.1145/3430524.3440637

Cragg, L., & Gilmore, C. (2014). Skills underlying mathematics: The role of executive function in the development of mathematics proficiency. *Trends in Neuroscience and Education*, *3*(2), 63–68. https://doi.org/10.1016/j.tine.2013.12.001

de Sousa, G. M., de Lima-Araújo, G. L., de Araújo, D. B., & de Sousa, M. B. C. (2021). Brief mindfulness-based training and mindfulness trait attenuate psychological stress in university students: A randomized controlled trial. *BMC Psychology*, *9*(1), 21. https://doi.org/10.1186/s40359-021-00520-x

Deng, L., Wu, S., Chen, Y., & Peng, Z. (2020). Digital game-based learning in a Shanghai primary-school mathematics class: A case study. *Journal of Computer Assisted Learning*, *36*(5), 709–717. https://doi.org/10.1111/jcal.12438

Dunning, D., Tudor, K., Radley, L., Dalrymple, N., Funk, J., Vainre, M., Ford, T., Montero-Marin, J., Kuyken, W., & Dalgleish, T. (2022). Do mindfulness-based programmes improve the cognitive skills, behaviour and mental health of children and adolescents? An updated meta-analysis of randomised controlled trials. *Evidence Based Mental Health*, *25*(3), 135–142. https://doi.org/10.1136/ebmental-2022-300464

Dunning, D. L. (2023). Mindfulness and learning. In R. J. Tierney, F. Rizvi, & K. Ercikan (Eds.), *International encyclopedia of education* (4th ed., pp. 648–657). Elsevier. https://doi.org/10.1016/B978-0-12-818630-5.14081-3

Dunning, D. L., Griffiths, K., Kuyken, W., Crane, C., Foulkes, L., Parker, J., & Dalgleish, T. (2019). Research review: The effects of mindfulness-based interventions on cognition and mental health in children and adolescents—A meta-analysis of randomized controlled trials. *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, *60*(3), 244–258. https://doi.org/10.1111/jcpp.12980

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*, 175–191. https://doi.org/10.3758/BF03193146

Field, A. (2017). *Discovering statistics using IBM SPSS statistics*. Sage.

Gee, J. P. (2008). Learning and games. In K. Salen (Ed.), *The ecology of games: Connecting youth, games, and learning, the John D. And Catherine T. MacArthur foundation series on digital media and learning (pp. 21–40)*. The MIT Press.

Geist, E. (2010). The anti-anxiety curriculum: Combating math anxiety in the classroom. *Journal of Instructional Psychology*, *37*(1), 24–29.

Gill, L.-N., Renault, R., Campbell, E., Rainville, P., & Khoury, B. (2020). Mindfulness induction and cognition: A systematic review and meta-analysis. *Consciousness and Cognition*, *84*, 102991. https://doi.org/10.1016/j.concog.2020.102991

Goodman, M. S., Madni, L. A., & Semple, R. J. (2017). Measuring mindfulness in youth: Review of current assessments, challenges, and future directions. *Mindfulness*, *8*, 1409–1420. https://doi.org/10.1007/s12671-017-0719-9

Harpstead, E., Richey, J. E., Nguyen, H., & McLaren, B. M. (2019). Exploring the subtleties of agency and indirect control in digital learning games. In *Proceedings of the 9th International Conference on Learning Analytics & Knowledge* (pp. 121–129). ACM. https://doi.org/10.1145/3303772.3303797

Hauser, D. J., Ellsworth, P. C., & Gonzalez, R. (2018). Are manipulation checks necessary? *Frontiers in Psychology*, *9*, 1–10. https://doi.org/10.3389/fpsyg.2018.00998

Hayes, A. F. (2022). *Introduction to mediation, moderation, and conditional process analysis: A regression-based approach*. Guilford Press.

Heppner, W. L., & Shirk, S. D. (2018). Mindful moments: A review of brief, low-intensity mindfulness meditation and induced mindful states. *Social and Personality Psychology Compass*, 1–14. https://doi.org/10.1111/spc3.12424

Hilt, L. M., & Pollak, S. D. (2012). Getting out of rumination: Comparison of three brief interventions in a sample of youth. *Journal of Abnormal Child Psychology*, *40*(7), 1157–1165. https://doi.org/10.1007/s10802-012-9638-3

Hu, S., Usta, A., Schmidt-Kraepelin, M., Warsinsky, S., Thiebes, S., & Sunyaev, A. (2023). Be mindful of user preferences: An explorative study on game design elements in mindfulness applications. In T. X. Bui (Ed.), *Proceedings of the 56th Hawaii International Conference on System Sciences* (pp. 1116–1125). Hawaii International Conference on System Sciences (HICSS) Retrieved from https://hdl.handle.net/10125/102767.

Hussein, M. H., Ow, S. H., Elaish, M. M., & Jensen, E. O. (2021). Digital game-based learning in K-12 mathematics education: A systematic literature review. *Education and Information Technologies*, *27*, 1–33. https://doi.org/10.1007/s10639-021-10721-x

Isotani, S., McLaren, B. M., & Altman, M. (2010). Towards intelligent tutoring with erroneous examples: A taxonomy of decimal misconceptions. In V. Aleven, J. Kay, & J. Mostow (Eds.), Intelligent Tutoring Systems. ITS 2010. *Lecture Notes in Computer Science*, vol 6095 (pp. 567–569). Springer. https://doi.org/10.1007/978-3-642-13437-1_66

Kaunhoven, R. J., & Dorjee, D. (2017). How does mindfulness modulate self-regulation in pre-adolescent children? An integrative neurocognitive review. *Neuroscience & Biobehavioral Reviews*, *74*, 163–184. https://doi.org/10.1016/j.neubiorev.2017.01.007

Kiili, K., & Ketamo, H. (2017). Evaluating cognitive and affective outcomes of a digital game-based math test. *IEEE Transactions on Learning Technologies*, *11*(2), 255–263. https://doi.org/10.1109/TLT.2017.2687458

Kim, H., Ke, F., & Paek, I. (2017). Game-based learning in an OpenSim-supported virtual environment on perceived motivational quality of learning. *Technology, Pedagogy and Education*, *26*(5), 617–631. https://doi.org/10.1080/1475939X.2017.1308267

Kuroda, Y., Yamakawa, O., & Ito, M. (2022). Benefits of mindfulness in academic settings: Trait mindfulness has incremental validity over motivational factors in predicting academic affect, cognition, and behavior. *BMC Psychology*, *10*(48), 1–14. https://doi.org/10.1186/s40359-022-00746-3

Laurent, H. K., Laurent, S. M., Nelson, B., Wright, D. B., & De Araujo Sanchez, M.-A. (2015). Dispositional mindfulness moderates the effect of a brief mindfulness induction on physiological stress responses. *Mindfulness*, *6*(5), 1192–1200. https://doi.org/10.1007/s12671-014-0377-0

Levinson, D. B., Stoll, E. L., Kindy, S. D., Merry, H. L., & Davidson, R. J. (2014). A mind you can count on: Validating breath counting as a behavioral measure of mindfulness. *Frontiers in Psychology*, *5*, 1202. https://doi.org/10.3389/fpsyg.2014.01202

Leyland, A., Emerson, L.-M., & Rowse, G. (2018). Testing for an effect of a mindfulness induction on child executive functions. *Mindfulness*, *9*(6), 1807–1815. https://doi.org/10.1007/s12671-018-0923-2

Leyland, A., Rowse, G., & Emerson, L.-M. (2019). Experimental effects of mindfulness inductions on self-regulation: Systematic review and meta-analysis. *Emotion*, *19*(1), 108–122. https://doi.org/10.1037/emo0000425

Lim, X., & Qu, L. (2017). The effect of single-session mindfulness training on preschool children's attentional control. *Mindfulness*, *8*(2), 300–310. https://doi.org/10.1007/s12671-016-0600-2

Luster Learning Institute. (2007). *Calm Classroom*. Luster Learning Institute NFP.

Mak, C., Whittingham, K., Cunnington, R., & Boyd, R. N. (2017). Efficacy of mindfulness-based interventions for attention and executive function in children and adolescents—A systematic review. *Mindfulness*, *9*(1), 59–78. https://doi.org/10.1007/s12671-017-0770-6

Malliarakis, C., Satratzemi, M., & Xinogalos, S. (2016). CMX: The effects of an educational MMORPG on learning and teaching computer programming. *IEEE Transactions on Learning Technologies*, *10*(2), 219–235.

Mayer, R. E. (2019). Computer games in education. *Annual Review of Psychology*, *70*, 531–549. https://doi.org/10.1146/annurev-psych-010418-102744

Mazzocco, M. M., & Kover, S. T. (2007). A longitudinal assessment of executive function skills and their association with math performance. *Child Neuropsychology*, *13*(1), 18–45. https://doi.org/10.1080/09297040600611346

McLaren, B. M., Adams, D. M., Mayer, R. E., & Forlizzi, J. (2017). A computer-based game that promotes mathematics learning more than a conventional approach. *International Journal of Game-Based Learning (IJGBL)*, *7*(1), 36–56. https://doi.org/10.4018/IJGBL.2017010103

McLaren, B. M., & Nguyen, H. A. (2023). *Digital learning games in artificial intelligence in education (AIED): A review* (p. 20). Handbook of Artificial Intelligence in Education.

McLaren, B. M., Nguyen, H. A., Richey, J. E., & Mogessie, M. (2022). Focused self-explanations lead to the best learning outcomes in a digital learning game. In *Proceedings of the 16th International Conference on Learning Science (ICLS 2022)* (pp. 1229–1232).

Melleen, M. (n.d.). Free Stories About Aliens for Kids. Love to Know. Retrieved June 15, 2021, from https://www.lovetoknow.com/parenting/kids/free-stories-about-aliens-kids.

Mohawk Valley Library System. (2019). Summer Reading Workshop Jokes. Retrieved June 15, 2021, from https://www.mvls.info/wp-content/uploads/2019/02/2019-Summer-Reading-Workshop-Jokes.pdf.

Nadler, R., Cordy, M., Stengel, J., Segal, Z. V., & Hayden, E. P. (2017). A brief mindfulness practice increases self-reported calmness in young children: A pilot study. *Mindfulness*, *8*(4), 1088–1095. https://doi.org/10.1007/s12671-017-0685-2

Nagy, T., Sik, K., Török, L., Bőthe, B., Takacs, Z. K., & Orosz, G. (2023). Brief growth mindset and mindfulness inductions to facilitate task persistence after negative feedback. *Collabra: Psychology*, *9*(1), 1–20. https://doi.org/10.1525/collabra.74253

Nguyen, H., Hou, X., Richey, J. E., & McLaren, B. M. (2022). The impact of gender in learning with games: A consistent effect in a math learning game. *International Journal of Game-Based Learning (IJGBL).*, *12*(1), 1–29. https://doi.org/10.4018/IJGBL.309128

Nunes, A., Castro, S. L., & Limpo, T. A. (2020). Review of mindfulness-based apps for children. *Mindfulness*, *11*, 2089–2101. https://doi.org/10.1007/s12671-020-01410-w

Patsenko, E. G., Adluru, N., Birn, R. M., Stodola, D. E., Kral, R. A. T., Farajin, R., Flook, L., Burghy, C. A., Steinkuehler, C., & Davidson, R. J. (2019). Mindfulness video game improves connectivity of the fronto-parietal attentional network in adolescents: A multi-modal imaging study. *Scientific Reports*, *9*, 18667. https://doi.org/10.1038/s41598-019-53393-x

Plass, J. L., Homer, B. D., & Kinzer, C. K. (2015). Foundations of game-based learning. *Educational Psychologist*, *50*, 258–283. https://doi.org/10.1080/00461520.2015.1122533

Ribner, A. D., Willoughby, M. T., Blair, C. B., & Family Life Project Key Investigators. (2017). Executive function buffers the association between early math and later academic skills. *Frontiers in Psychology*, *869*, 1–12. https://doi.org/10.3389/fpsyg.2017.00869

Richey, J. E., Zhang, J., Das, R., Andres-Bray, J. M., Scruggs, R., Mogessie, M., Baker, R. S., & McLaren, B. M. (2021, June). Gaming and confrustion explain learning advantages for a math digital learning game. In *Proceedings of the International Conference on Artificial Intelligence in Education* (pp. 342–355). Springer.

Samuel, T. S., & Warner, J. (2021). "I can math!": Reducing math anxiety and increasing math self-efficacy using a mindfulness and growth mindset-based intervention in first-year students. *Community College Journal of Research and Practice*, *45*(3), 205–222. https://doi.org/10.1080/10668926.2019.1666063

Schmitt, S. A., Geldhof, G. J., Purpura, D. J., Duncan, R., & McClelland, M. M. (2017). Examining the relations between executive function, math, and literacy during the transition to kindergarten: A multi-analytic approach. *Journal of Educational Psychology*, *109*(8), 1120. https://doi.org/10.1037/edu0000193

Schultchen, D., Terhorst, Y., Holderied, T., Stach, M., Messner, E. M., Baumeister, H., & Sander, L. B. (2021). Stay present with your phone: A systematic review and standardized rating of mindfulness apps in European app stores. *International Journal of Behavioral Medicine*, *28*(5), 552–560. https://doi.org/10.1007/s12529-020-09944-y

Schumer, M. C., Lindsay, E. K., & Creswell, J. D. (2018). Brief mindfulness training for negative affectivity: A systematic review and meta-analysis. *Journal of Consulting and Clinical Psychology*, *86*(7), 569–583. https://doi.org/10.1037/ccp0000324

Sharf, R. H. (2015). Is mindfulness Buddhist? (and why it matters). *Transcultural Psychiatry*, *52*(4), 470–484. https://doi.org/10.1177/1363461514557561

Sun, L., Ruokamo, H., Siklander, P., Li, B., & Devlin, K. (2021). Primary school students' perceptions of scaffolding in digital game-based learning in mathematics. *Learning, Culture and Social Interaction*, *28*, 100457. https://doi.org/10.1016/j.lcsi.2020.100457

Takacs, Z. K., & Kassai, R. (2019). The efficacy of different interventions to foster children's executive function skills: A series of meta-analyses. *Psychological Bulletin*, *145*(7), 653–697. https://doi.org/10.1037/bul0000195

Tokac, U., Novak, E., & Thompson, C. G. (2019). Effects of game-based learning on students' mathematics achievement: A meta-analysis. *Journal of Computer Assisted Learning*, *35*(3), 407–420. https://doi.org/10.1111/jcal.12347

Tunney, C., Cooney, P., Coyle, D., & O'Reilly, G. (2017). Comparing young people's experience of technology-delivered v. face-to-face mindfulness and relaxation: Two-armed qualitative focus group study. *British Journal of Psychiatry*, *210*(4), 284–289. https://doi.org/10.1192/bjp.bp.115.172783

Van Emmerik, A. A. P., Berings, F., & Lancee, J. (2018). Efficacy of a mindfulness-based mobile application: A randomized waiting-list controlled trial. *Mindfulness*, *9*, 187–198. https://doi.org/10.1007/s12671-017-0761-7

Vekety, B., Logemann, A., & Takacs, Z. K. (2021). The effect of mindfulness-based interventions on inattentive and hyperactive–impulsive behavior in childhood: A meta-analysis. *International Journal of Behavioral Development*, *45*(2), 133–145. https://doi.org/10.1177/0165025420958192

Vekety, B., Logemann, A., & Takacs, Z. K. (2022). Mindfulness practice with a brain-sensing device improved cognitive functioning of elementary school children: An exploratory pilot study. *Brain Sciences*, *12*(1), 103 https://www.mdpi.com/2076-3425/12/1/103

Verhaeghen, P. (2023). Mindfulness and academic performance meta-analyses on interventions and correlations. *Mindfulness*, *14*, 1305–1316. https://doi.org/10.1007/s12671-023-02138-z

Weger, U. W., Hooper, N., Meier, B. P., & Hopthrow, T. (2012). Mindful maths: Reducing the impact of stereotype threat through a mindfulness exercise. *Consciousness and Cognition*, *21*(1), 471–475.

Weisberg, D. S., Hirsh-Pasek, K., Golinkoff, R. M., Kittredge, A. K., & Klahr, D. (2016). Guided play: Principles and practices. *Current Directions in Psychological Science.*, *25*, 177–182. https://doi.org/10.1177/0963721416645512

Wouters, P., & Oostendorp, H. V. (2017). Overview of instructional techniques to facilitate learning and motivation of serious games. In *Instructional techniques to facilitate learning and motivation of serious games* (pp. 1–16). Springer.

Wouters, P., Van Oostendorp, H., Ter Vrugte, J., Vandercruysse, S., De Jong, T., & Elen, J. (2017). The effect of surprising events in a serious game on learning mathematics. *British Journal of Educational Technology*, *48*(3), 860–877. https://doi.org/10.1111/bjet.124

Zelazo, P. D., & Lyons, K. E. (2012). The potential benefits of mindfulness training in early childhood: A developmental social cognitive neuroscience perspective. *Child Development Perspectives*, *6*(2), 154–160. https://doi.org/10.1111/j.1750-8606.2012.00241.x

Zenner, C., Herrnleben-Kurz, S., & Walach, H. (2014). Mindfulness-based interventions in schools—A systematic review and meta-analysis. *Frontiers in Psychology*, *5*(603), 1–20. https://doi.org/10.3389/fpsyg.2014.00603

How to cite this article: Bereczki, E. O., Takacs, Z. K., Richey, J. E., Nguyen, H. A., Mogessie, M., & McLaren, B. M. (2024). Mindfulness in a digital math learning game: Insights from two randomized controlled trials. *Journal of Computer Assisted Learning*, 1–24. https://doi.org/10.1111/jcal.12971

APPENDIX A: Correlations between trait mindfulness and math achievement in Study 1

Variable	N	M (SD)	1	2	3	4	5	6
1. Trait mindfulness	223	3.23 (0.67)	-					
2. Pretest	223	18.95 (9.14)	0.16*	-				
3. Posttest	189	22.31 (10.14)	0.23**	0.82**	-			
4. Delayed posttest	196	22.23 (10.63)	0.20**	0.79**	0.91**	-		
5. Diff. posttest–pretest	189	3.15 (5.94)	0.11	−0.17*	0.44**	0.35**	-	
6. Diff. delayed posttest–pretest	196	3.53 (6.58)	0.12	−0.07	0.37**	0.57**	0.75**	-

Note: Trait mindfulness was measured on a scale of 1 to 5 with higher scores indicating higher state mindfulness. Test scores are measured on a scale of 0–52.
[a]$0.05 < p < 0.10$.
*$p < 0.05$.
**$p < 0.01$.

APPENDIX B: The moderating effects of trait mindfulness on students' math achievement by condition Study 1

Predictors	n	R^2	ΔR^2	B	SE	t	Lower 95% CI	Upper 95% CI
Model 3 (condition > difference posttest–pretest by trait mindfulness)	186	0.03						
(Constant)				3.06**	0.43	7.05	2.21	3.92
X1 (regular game vs. rest)				−0.98	0.91	−1.09	−2.77	0.80
X2 (story vs. mindfulness game)				−0.93	1.08	−0.86	−3.06	1.20
Trait mindfulness				0.41	0.77	0.54	−1.11	1.93
X1 × trait mindfulness				−1.95	1.51	−1.29	−4.94	1.03
X2 × trait mindfulness				2.55	2.02	1.26	−1.43	6.54
Conditions (X) × trait mindfulness			0.014					
Model 4 (condition > difference delayed posttest–pretest by trait mindfulness)	192	0.04						
(Constant)				3.55**	0.47	7.57	2.63	4.48
X1 (regular game vs. rest)				−1.75[a]	1.00	−1.75	−3.73	0.23
X2 (story vs. mindfulness game)				0.12	1.14	0.11	−2.13	2.37
Trait mindfulness				1.26	0.80	1.58	−0.31	2.83
X1 × trait mindfulness				0.11	1.66	0.06	−3.17	3.38
X2 × trait mindfulness				1.62	1.98	0.82	−2.30	5.53
Conditions (X) × trait mindfulness			0.004					

[a]$0.05 < p < 0.10$.
*$p < 0.05$.
**$p < 0.01$.

APPENDIX C: Correlations between trait mindfulness and in-game problem-solving behaviour in Study 1

Variable	*N*	*M* (SD)	1	2	3	4
1. Trait mindfulness	213	3.24 (0.67)	-			
2. Problem-solving duration	213	66.51 (24.39)	−0.06	-		
3. Error count	213	114.79 (60.66)	−0.14*	0.59**	-	
4. Correctness after reminder	140	0.29 (0.24)	−0.03.	−0.16*	−0.18*	-

Note: Trait mindfulness was measured on a scale of 1 to 5 with higher scores indicating higher state mindfulness. Problem-solving duration measures are in minutes. Problem-solving errors measures are expressed in the number errors made. Correctness after reminder measures are expressed by the percentage of correct answers given after reminders.

[a]0.05 < p < 0.10.

*p < 0.05.

**p < 0.01.

APPENDIX D: The moderating effects of trait mindfulness on students' in-game problem-solving behaviour by condition in Study 1

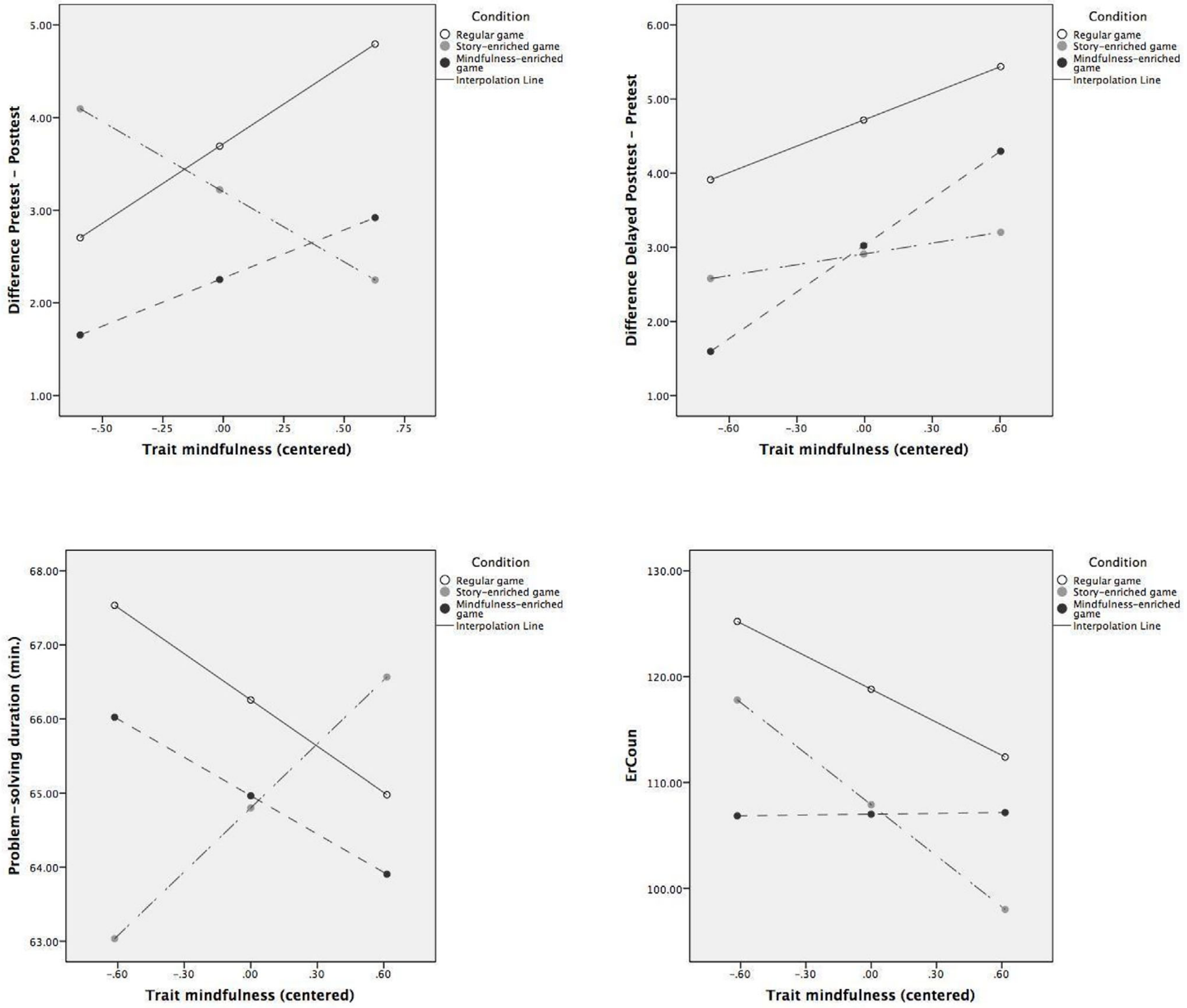
Predictors	*n*	R^2	ΔR^2	*B*	SE	*t*	Lower 95% CI	Upper 95% CI
Model 8 (condition > problem-solving duration by trait mindfulness)	206	0.005						
(Constant)				65.34**	1.61	40.51	62.16	68.52
X1 (regular game vs. rest)				−1.37	3.43	−0.40	−8.14	5.39
X2 (story vs. mindfulness game)				0.16	3.94	0.04	−7.61	7.94
Trait mindfulness				−0.31	2.71	−0.12	−5.64	5.03
X1 × trait mindfulness				2.66	5.65	0.47	−8.49	13.80
X2 × trait mindfulness				−4.60	6.73	−0.68	−17.87	8.67
Conditions (X) × trait mindfulness			0.003					
Model 9 (condition > errors by trait mindfulness)	206	0.02						
(Constant)				111.24**	3.87	28.76	103.62	118.87
X1 (regular game vs. rest)				−11.34	8.17	−1.39	−27.45	4.76
X2 (story vs. mindfulness game)				−0.89	9.52	−0.09	−19.66	17.88
Trait mindfulness				−8.75	6.49	−1.35	−21.54	4.04
X1 × trait mindfulness				2.50	13.52	0.19	−24.17	29.17
X2 × trait mindfulness				16.33	16.16	1.01	−15.52	48.19
Conditions (X) × trait mindfulness			0.006					
Model 10 (Condition > Correctness after reminder by Trait mindfulness)	136	0.05						
(Constant)				0.16[a]	0.09	1.74	−0.02	0.34
Condition (story vs. mindfulness)				0.05	0.04	1.29	−0.03	0.12
Trait mindfulness				0.33*	0.16	2.02	−0.01	0.65
Condition × trait mindfulness			0.033*	−0.13	0.06	−2.13	−0.25	−0.01

[a]0.05 < p < 0.10.

*p < 0.05.

**p < 0.01.

APPENDIX E: The effects of trait mindfulness on math achievement and in-game problem-solving behaviour by condition in Study 1 (non-significant interactions)



APPENDIX F: Reliability of the state mindfulness scale at different measurement points in Study 2

	N	Cronbach's α	*M* (*SD*)
State mindfulness 1	158	0.76	5.68 (1.25)
State mindfulness 2	159	0.85	5.72 (1.45)
State mindfulness 3	88	0.84	5.77 (1.45)
State mindfulness 4	73	0.91	5.84 (1.58)
State mindfulness 5	24	0.72	5.98 (1.26)

Note: *N* decreases with later state mindfulness measurements with the increase in the number of students who have finished the game after each session. State mindfulness was measured on a scale of 1 to 7 with higher scores indicating higher state mindfulness.

APPENDIX G: Results of Study 2

G1. Effects of condition on students' math achievement in Study 2

We conducted two repeated-measure ANOVAs to verify the learning gain (from pretest to posttest, and then from pretest to delayed posttest) results from Study 1. Differences between pretest and posttest scores, as well as those between pretest and delayed posttest, followed a reasonably normal distribution without significant outliers in all three conditions. Assumptions of homogeneity were met. There was no statistically significant difference among students' pretest scores in the three conditions, $F(2, 174) = 1.91$, $p = 0.15$, $\eta p^2 = 0.022$.

Model 1 assessing change from pretest to posttest showed that there was a significant effect of time, with students' math scores improving significantly from pretest to posttest, $F(1, 153) = 25.03$, $p < 0.001$, $\eta p^2 = 0.141$. There was no main effect of condition, $F(2, 153) = 1.67$, $p = 0.19$, $\eta p^2 = 0.021$, and planned comparisons showed no differences between the passive control and the other two conditions, $p = 0.11$, or between the story and mindfulness conditions, $p = 0.37$. No interaction between time and condition was noted, $F(2, 153) = 0.62$, $p = 0.54$, $\eta^2 = 0.008$, meaning that improvements in students' scores from pretest to posttest did not differ by condition.

Model 2 assessing change from pretest to delayed posttest revealed a significant effect of time, with students' math scores improving significantly from pretest to delayed posttest, $F(1, 155) = 40.77$, $p < 0.001$, $\eta p^2 = 0.208$. There was no main effect of learning condition, $F(2, 155) = 1.20$, $p = 0.30$, $\eta p^2 = 0.02$, and planned comparisons showed no differences between the control and the other two conditions, $p = 0.15$, or between the story and mindfulness conditions, $p = 0.59$. Again, no interaction between time and condition was detected, $F(2, 155) = 0.46$, $p = 0.64$, $\eta p^2 = 0.006$, meaning that improvements in students' scores from pretest to delayed posttest did not differ by condition.

Similarly to the results in Study 1, we found no evidence that students in the mindfulness game condition learned more (from pretest to posttest, and from pretest to delayed posttest) than those in the other two game conditions (H1). Descriptive statistics are presented in Table G1.

TABLE G1 Test performance, in-game problem-solving behaviour and state mindfulness by condition in Study 2.

	Regular game condition	Story-enriched game condition	Mindfulness-enriched game condition
Pretest > posttest	$n = 50$	$n = 51$	$n = 55$
Pretest scores	21.50 (10.99)	25.65 (11.46)	24.16 (10.31)
Posttest scores	24.70 (11.14)	28.16 (11.30)	26.00 (10.35)
Pretest > delayed posttest	$n = 46$	$n = 58$	$n = 54$
Pretest scores	21.59 (10.94)	25.28 (10.99)	24.15 (10.93)
Delayed posttest scores	25.61 (11.59)	28.16 (10.49)	27.17 (10.47)
In-game problem-solving behaviour			
Problem-solving duration	$n = 53$	$n = 57$	$n = 57$
	65.86 (26.70)	59.36 (22.01)	59.64 (21.11)
Problem-solving errors	$n = 52$	$n = 57$	$n = 59$
	113.96 (64.99)	95.72 (67.11)	99.49 (54.49)
Correctness after reminder	-	$n = 54$	$n = 58$
		0.27 (0.23)	0.36 (0.30)
State mindfulness	$n = 54$	$n = 61$	$n = 62$
	5.67 (1.30)	5.87 (1.14)	5.66 (1.39)

Note: Test performance and game play measures are reported in *M* (SD) format by condition. Test scores are measured on a scale of 0–52. Problem-solving duration is reported in minutes. Problem-solving errors measures are expressed in the number errors made. Correctness after reminder measures are expressed by the percentage of correct answers given after reminders.

G2. The moderating effects of trait mindfulness on students' math achievement by condition

To examine whether trait mindfulness moderates students' learning gains by game condition (H3), we conducted two moderation analyses in PROCESS Macro based on 5000 randomly selected sub-samples and with 95% bias-corrected confidence intervals (Hayes, 2022). Condition was a multicategorical independent variable with three levels (*X*). The dependent variable (*Y*) was, then, first, the difference between posttest and pretest (H2a, Model 3), and then the difference between delayed posttest and pretest (H2b, Model 4), whereas trait mindfulness was introduced as a moderator in the models (*Z*). There was no statistically significant difference among students' trait mindfulness in the three conditions, $F(2,174) = 0.72$, $p = 0.49$, $\eta p^2 = 0.01$. We identified one multivariate outlier in both Models 6 and 7, with Mahalanobis values greater than the critical for this sample size (D^2 >20.52, Stevens, 2002). In addition, we found one outlier in both Model 3 and 4 based on the distribution of residuals. After removing outliers, assumptions of the moderation analyses were met. Correlations between variables are presented in Table G2, whereas moderation models are presented in Table G3.

TABLE G2 Correlations between trait mindfulness, state mindfulness and math achievement in Study 2.

Variable	*N*	*M* (SD)	1	2	3	4	5	6	7
1. Trait mindfulness	177	3.28 (0.75)	-						
2. State mindfulness	177	5.74 (1.28)	0.61**	-					
3. Pretest	177	23.27 (10.67)	0.18*	0.04	-				
4. Posttest	156	26.29 (10.94)	0.25**	0.09	0.84**	-			
5. Delayed posttest	158	27.08 (10.79)	0.25**	0.05	0.82**	0.88**	-		
6. Diff. posttest–pretest	156	2.49 (6.26)	0.11	0.03	−0.29**	−0.28**	0.07	-	
7. Diff. delayed posttest–pretest	158	3.26 (6.46)	0.10	0.05	−29**	0.09	0.31**	0.65**	-

Note: Trait mindfulness was measured on a scale of 1 to 5 and state mindfulness on a scale of 1 to 7, with higher scores indicating higher state mindfulness. Test scores are measured on a scale of 0–52.
[a]0.05 < *p* < 0.10.
**p* < 0.05.
***p* < 0.01.

TABLE G3 The moderating effects of trait mindfulness on students' math achievement by condition in Study 2.

Predictors	*n*	R^2	ΔR^2	*B*	SE	*t*	Lower 95% CI	Upper 95% CI
Model 3 (condition > difference posttest–pretest by trait mindfulness)	154	0.03						
(Constant)				2.42**	0.50	4.87	1.44	3.41
X1 (regular game vs. rest)				−1.14	1.06	−1.07	−3.24	0.96
X2 (story vs. mindfulness game)				−0.96	1.21	−0.79	−3.35	1.44
Trait mindfulness				1.10	0.68	1.62	−0.25	2.45
X1 × Trait mindfulness				1.19	1.36	0.88	−1.50	3.88
X2 × Trait mindfulness				0.14	1.77	0.08	−3.53	6.63
Conditions (X) × trait mindfulness			0.005					
Model 4 (condition > difference delayed posttest–pretest by trait mindfulness)	156	0.03						
(Constant)				3.69**	0.49	6.77	2.39	4.35
X1 (regular game vs. rest)				−0.94	1.09	−0.86	−3.08	1.21
X2 (story vs. mindfulness game)				−0.39	1.18	−0.33	−2.72	1.94
Trait mindfulness				1.08	0.68	1.57	−0.27	2.42
X1 × trait mindfulness				0.67	1.38	0.49	−2.06	3.40
X2 × trait mindfulness				0.78	1.75	0.44	−2.68	4.23
Conditions (X) × trait mindfulness			0.003					

Note: Similarly to findings in Study 1, the learning benefits of the mindfulness-enriched game condition did not vary based on students' levels of trait mindfulness (H2).
[a]0.05 < *p* < 0.10.
**p* < 0.05.
***p* < 0.01.

G3. Effects of condition on students' in-game problem-solving behaviour (number of errors and duration) in Study 2

To verify results for in-game problem-solving behaviour in Study 1, we conducted two univariate ANOVAs with condition as an independent variable, and first problem-solving duration (Model 5), then number of errors (Model 6), as dependent variable. After excluding two extreme outliers in the duration (extremely long time on a problem), and one in the error distribution (extremely high number of errors indicative of a technical glitch), ANOVA assumptions were reasonably met. Analyses were based on data collected from students who have completed the entire game ($n = 169$).

Similarly to Study 1, the first two univariate ANOVAs showed no significant condition effects on the amount of time students spent completing the problem-solving portions of the mini-games (Model 3), $F(2, 164) = 1.35$, $p = 0.26$, $\eta p^2 = 0.016$, or the number of errors made in the game (Model 4), $F(2, 165) = 1.29$, $p = 0.28$, $\eta p^2 = 0.015$ among the three conditions. Descriptive statistics are presented in Table G1.

G4. The moderating effects of trait mindfulness on students' in-game problem-solving behaviour (duration and number of errors) by condition

To investigate whether students' trait mindfulness affects students' in-game problem-solving behaviour by treatment (H4), we ran a series of moderation analysis in PROCESS Macro based on 5000 randomly selected sub-samples and with 95% bias-corrected confidence intervals (Hayes, 2022). The analyses included data collected from students who completed the games ($n = 169$). Condition was a multicategorical independent variable with three levels (*X*). Dependent variables (*Y*) were, first, the problem-solving duration (H4a, Model 8), then problem-solving errors (H4b, Model 9), and correctness after reminder (H4c, Model 10). Trait mindfulness was introduced as a moderator (*Z*) in the models. The analyses included data collected from students who completed all mini-games ($n = 169$). There was no statistically significant difference among students' trait mindfulness in the three conditions, $F(2, 166) = 0.36$, $p = 0.70$, $\eta p^2 = 0.004$. We identified one multivariate outlier in both Models 8 and 9, with Mahalanobis values greater than the critical ($D^2 > 20.52$, Stevens, 2002). In addition, based on the inspection of residuals we identified four additional outliers in Model 8, one in Model 9, and two in Model 10. After removing outliers, assumptions of the moderation analyses were met. Correlations between variables are presented in Table G4, whereas moderation models are presented in Table G5 and Figure G1.

TABLE G4 Correlations between trait mindfulness, state mindfulness and in-game problem-solving behaviour in Study 2.

Variable	*N*	*M* (*SD*)	1	2	3	4	5
1. Trait mindfulness	169	3.29 (0.76)	-				
2. State mindfulness	169	5.74 (1.29)	0.63**	-			
3. Problem-solving duration	169	62.70 (25.62)	−0.13	−0.02	-		
4. Error count	169	104.85 (68.25)	−0.09	−0.03	0.67**	-	
5. Correctness after reminder	112	0.32 (0.27)	−0.07	0.04	−0.16	−0.22*	-

Note: Trait mindfulness was measured on a scale of 1 to 5 and state mindfulness on a scale of 1 to 7, with higher scores indicating higher mindfulness levels. Problem-solving duration measures are in minutes. Problem-solving error measures are expressed in the number errors made. Correctness after reminder measures are expressed by the percentage of correct answers given after reminders.

[a]$0.05 < p < 0.10$.

*$p < 0.05$.

**$p < 0.01$.

TABLE G5 The moderating effects of trait mindfulness on students' in-game problem solving behaviour by condition in Study 2.

Predictors	*n*	R^2	ΔR^2	*B*	SE	*t*	Lower 95% CI	Upper 95% CI
Model 8 (condition > problem-solving duration by trait mindfulness)	162	0.03						
(Constant)				59.76**	1.61	37.14	56.59	62.94
X1 (regular game vs. rest)				−5.28	3.46	−1.53	−12.12	1.56
X2 (story vs. mindfulness game)				−0.21	3.89	−0.05	−7.88	7.47
Trait mindfulness				−1.08	2.21	−0.49	−5.45	3.29
X1 × Trait mindfulness				6.27	4.42	1.42	−2.46	15.00
X2 × trait mindfulness				0.43	5.71	0.08	−10.84	11.70
Conditions (X) × trait mindfulness			0.013					
Model 9 (condition > errors by trait mindfulness)	166	0.05						
(Constant)				102.30**	4.69	21.81	93.03	111.56
X1 (regular game vs. rest)				−18.58[a]	10.10	−1.84	−38.53	1.37
X2 (story vs. mindfulness game)				7.87	11.31	0.70	−14.47	30.21
Trait mindfulness				−6.97	6.43	−1.08	−19.68	5.74
X1 × trait mindfulness				21.51	12.92	1.67	−4.00	47.01
X2 × trait mindfulness				1.13	16.56	0.07	−31.58	33.84
Conditions (X) × trait mindfulness			0.017					
Model 10 (condition > correctness after reminder by trait mindfulness)	110	.06[a]						
(Constant)				0.01	0.12	0.10	−0.23	0.26
Condition (story vs. mindfulness)				0.12*	0.05	2.42	−0.02	0.21
Trait mindfulness				−0.12	0.19	−0.65	−0.49	0.25
Condition × trait mindfulness			0.002	0.04	0.07	0.52	−0.10	0.17

Note: Similarly to Study 1, trait mindfulness did not moderate the effects of condition on in-game problem-solving behaviours, including problem-solving duration (H4a) and errors (H4b). Contrary to Study 1, we did not find an interaction effect of condition on correctness after reminder either (H4c). More specifically, students with low trait mindfulness in Study 2 did not have greater accuracy after reminders in the mindfulness condition than in the story condition, in contrast to results in Study 1.
[a]$0.05 < p < 0.10$.
*$p < 0.05$.
**$p < 0.01$.

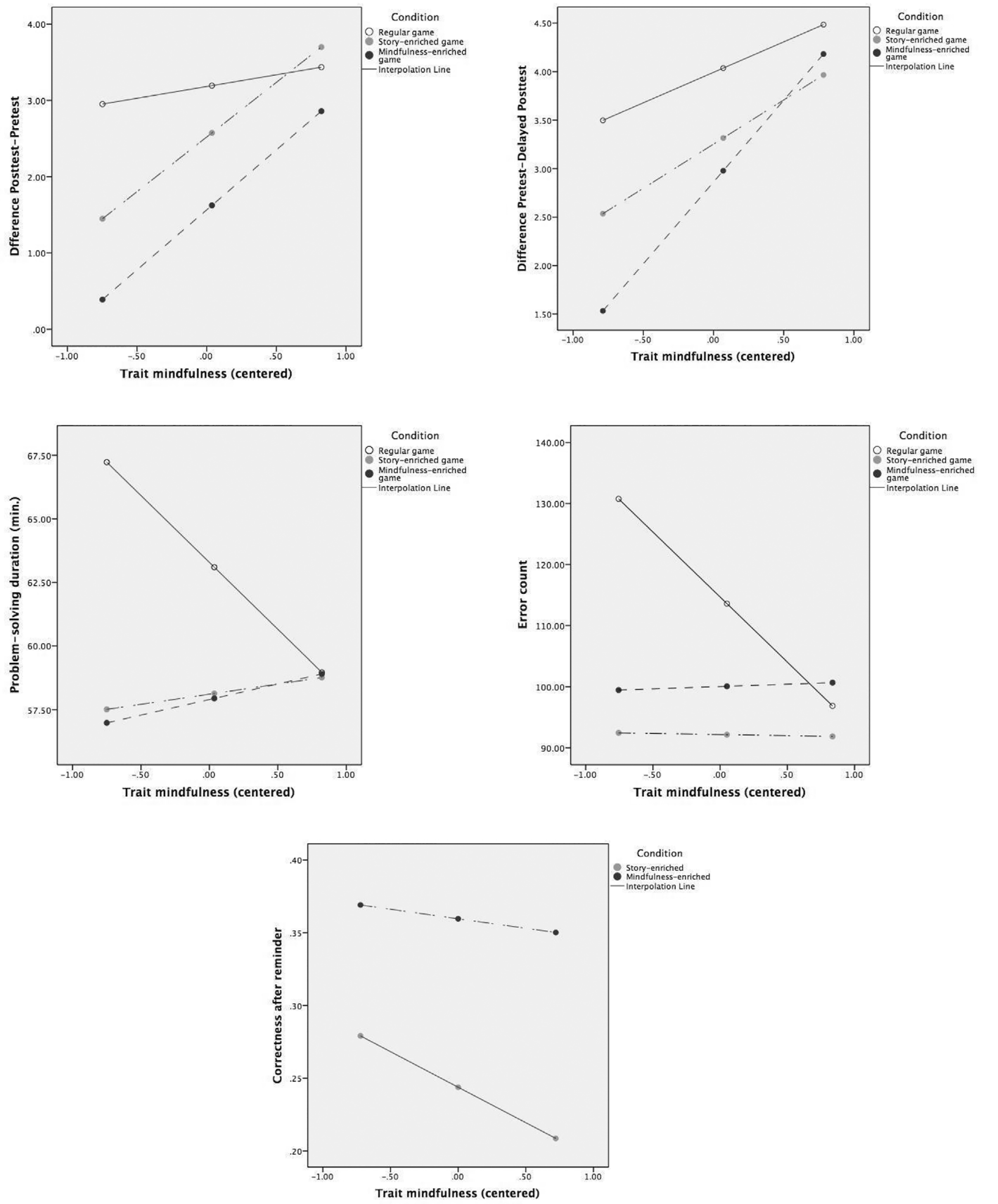


FIGURE G1 The effects of trait mindfulness on math achievement and in-game problem-solving behaviour by condition in Study 2 (non-significant interactions).