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Abstract. Mindfulness has been shown in prior studies to be an effective device to help students develop self-regulatory skills, including executive functions. However, these effects have been rarely tested at scale in technology-assisted learning systems such as digital learning games. In this work, we investigate the effects of mindfulness in the context of playing and learning with *Decimal Point*, a digital learning game for mathematics. We conducted a study with 5th and 6th grade students in which three conditions were compared - the game with short mindfulness meditations integrated, the game with similar-length, age-appropriate stories integrated, and the game in its original form. From the study results, we found no differences in time spent on the game, error rates while playing, or learning outcomes across the three conditions. Embedding mindfulness prompts within the game did not enhance learning or change students' gameplay behaviors, which suggests that we may not have successfully induced a state of mindfulness or that mindfulness is not beneficial for learning within digital learning games. We discuss the challenges of incorporating individual mindfulness meditations in elementary and middle school classrooms.

Keywords: digital learning games, mindfulness, decimal numbers, middle school math

1 Introduction

Mindfulness is the concept of attending to the present moment with focus and without judgment. Mindfulness meditation has been shown to support self-regulation, attention skills and executive function, especially working memory capacity and inhibitory control [5, 12], which could in turn contribute to math learning [4]. Additionally, mindfulness practice might reduce math anxiety, which could further enhance math performance [10].

Despite these strong theoretical reasons, the role of mindfulness for children's academic outcomes is less clear, especially due to the limited evidence so far. A meta-analysis by [7] found that five studies assessing the efficacy of mindfulness-based interventions for academic achievement showed a non-significant, small average effect. Although since then some promising preliminary results with older students [6] and

students with ADHD [11] emerged, the evidence regarding the effects of mindfulness-based interventions on academic achievement and learning is inconclusive.

In the present study we aimed to test whether the addition of mindfulness practice within a math game *Decimal Point* would contribute to students' learning. Rather than employing longer mindfulness training *interventions* on academic achievement as in prior work [7], we applied short mindfulness *inductions* at the beginning of the learning sessions to induce a state of mindfulness. Additionally, instead of applying mindfulness exercises in groups [14], our students conducted those individually as part of the math game. Given these differences, we aimed to investigate the effectiveness of state mindfulness for math learning and test the feasibility of individual mindfulness practice with middle-school-aged children, built into a digital learning game.

2 A Mindfulness Study with the *Decimal Point* Learning Game

Decimal Point [8] is a digital learning game designed to help middle schoolers learn about decimals and decimal operations. The game is based on an amusement park metaphor in which students play a series of mini-games targeted at common decimal misconceptions. Each mini-game consists of a problem-solving activity (e.g., sorting a list of decimal numbers from smallest to largest), followed by a multiple-choice self-explanation question. Students get immediate feedback after each attempt and can continue making attempts if their current answer is incorrect; they need to finish all exercises in the current mini-game to move on to the next mini-game.

Extending on the initial study of the game [8], the current study examines whether mindfulness practices may have similar impacts in a learning game, given their benefits to executive control [5]. To this end, we compare a version of *Decimal Point* with embedded mindfulness inductions against two comparison conditions: the original game version and an active comparison condition that incorporates thematically-appropriate stories and jokes instead of mindfulness. The story version was created to control for the amount of time spent on mindfulness inductions and additional material that was not designed to induce mindfulness. Across the three versions of the game, we investigate the following research questions:

RQ1: *Do students who receive short mindfulness inductions during game play of a digital learning game demonstrate different behaviors than other game playing students?* We hypothesized that mindfulness would enhance students' executive control, leading to students in the mindfulness condition spending more time and exhibiting fewer errors on the mini-game problems and self-explanation questions than in the other two conditions.

RQ2: *Do the students who receive mindfulness inductions learn more than other game playing students?* We hypothesized that students who received the mindfulness treatment would show greater learning gains than the story and control treatments, as a result of enhanced executive functioning . Additionally, mindfulness may reduce anxiety and thus free up working memory to help students to focus more on constructive learning processes that enhance learning (e.g., repairing misconceptions, connecting new information to prior knowledge [3]).

3 Method and Materials

Our study was conducted in 5th and 6th grade classrooms across three public schools in a mid-sized U.S. city during the fall of 2021. A total of 243 students participated in the study; however, 77 were excluded from our analyses because they did not complete all materials. The final sample included 166 students (76 males, 90 females), with 57 students assigned to the control treatment, 56 to the story treatment and 53 to the mindfulness treatment. Students reported an average age of 10.84 (SD = 0.65). Students participated in the study for a total of six days as part of their regular class activities. On the first day, students completed a pretest. They then progressed through the materials at their own pace for up to four additional days. In the mindfulness and story conditions, students received their respective treatments (i.e., mindfulness induction or story) at the beginning of each class. Students then completed a posttest right after finishing the game and a delayed posttest one week later. The pretest, posttest, and delayed posttest consisted of three isomorphic versions of a decimal test that were counterbalanced across students and conditions. All tests included 42 items; as some items contained multiple components, students could earn a total of 52 points on each test. Test items targeted the same decimal misconceptions addressed in the mini-games.

Across the three treatment conditions, students played the same basic version of *Decimal Point* as described above, and the order and content of the mini-games was identical. The key differences between conditions are as follows. The *Mindfulness* and *Story* conditions both incorporated a brief, five-minute audio session that students listened to at the start of each day of the study, prior to playing the game. In the *Mindfulness* condition, the audio content entailed an alien friend sharing mindfulness advice that prompted students to close their eyes, focus on their breath and sounds in the environment, and let go of passing thoughts [13]. In the *Story* condition, the audio content was related to science fiction stories selected to be age appropriate, emotionally neutral (i.e., not emotionally arousing or upsetting) and unrelated to the learning content. In addition, both conditions featured an in-game minute-long reminder that shows up when the student has made three consecutive incorrect attempts while playing. In the *Mindfulness* condition, students would be reminded about mindfulness and encouraged to slow down, close their eyes, and focus on their breath for a moment. In the Story condition, students would instead listen to a series of jokes from the aliens. Each reminder would only show up at most once every 10 minutes to avoid overwhelming the students; the reminders and stories were also omitted when students were taking the tests. Finally, students in the *Control* condition did not receive any activity with aliens before beginning to play the game each day, nor did they receive any reminders based on errors. The content and structure of the game they completed was identical to the game in the other conditions, but without the story or mindfulness components.

4 Results

For RQ1, descriptive statistics of students' game play behaviors are included in Table 1. A series of one-way ANOVAs showed no significant condition effects on the number of errors made on problem-solving in the game, $F(2, 163) = 0.08$, $p = .93$, $\eta_p^2 = .001$,

or the amount of time students spent completing the problem-solving portion of the mini-games, $F(2, 163) = 0.047$, $p = .95$, $\eta_p^2 = .001$. Similarly, there was no significant condition effect on the number of self-explanation errors made, $F(2, 163) = 0.23$, $p = .79$, $\eta_p^2 = .003$, or the amount of time students spent on the self-explanation questions, $F(2, 163) = 0.31$, $p = .74$, $\eta_p^2 = .004$. Thus, our hypothesis that students in the mindfulness condition would take more time and make fewer errors was not confirmed.

For RQ2, descriptive statistics of students' test scores by condition are reported in Table 1. A repeated-measures ANOVA tested learning condition as a between-subjects factor and test time (pretest, posttest, and delayed posttest) as a within-subjects factor. Results indicated a significant effect of test time, with students' test scores improving significantly across tests, $F(2, 162) = 27.39$, $p < .001$, $\eta_p^2 = .253$. There was no main effect of learning condition, $F(2, 163) = 0.009$, $p = .99$, $\eta_p^2 < .001$, and planned comparisons revealed no differences between the control and the other two conditions, $p = .93$, or between the mindfulness and story conditions, $p = .93$. There was also no interaction between test time and learning condition, $F(4, 324) = 1.52$, $p = .20$, $\eta_p^2 = .018$, indicating that students' test score improvements did not differ by condition. Follow-up repeated measures analyses indicated that students' test scores increased significantly from pretest to posttest, $F(1, 163) = 50.75$, $p < .001$, $\eta_p^2 = .24$, and from pretest to delayed posttest, $F(1, 163) = 45.39$, $p < .001$, $\eta_p^2 = .22$, but not from posttest to delayed posttest, $F(1, 163) = 0.44$, $p = .51$, $\eta_p^2 = .003$. In summary, our prediction that students in the mindfulness condition would learn more than the other conditions was not confirmed.

Table 1. Test performance, game play measures, and enjoyment ratings by condition, reported in *M* (*SD*) format. The test scores are on a scale from 0-52 and the duration measures are in minutes.

Category \ Condition	Control ($n = 57$)	Mindfulness ($n = 53$)	Story ($n = 56$)
Pretest scores	18.40 (9.40)	19.74 (9.33)	18.80 (8.08)
Posttest scores	22.51 (10.29)	21.68 (10.33)	22.48 (9.42)
Delayed posttest scores	23.02 (11.12)	22.36 (10.49)	21.98 (10.37)
Problem-solving duration	63.88 (21.39)	63.78 (26.05)	62.69 (22.58)
Problem-solving errors	113.32 (51.25)	115.83 (68.18)	117.91 (69.16)
Self-explanation duration	11.73 (3.45)	12.10 (3.29)	11.61 (3.46)
Self-explanation errors	16.40 (7.21)	15.81 (7.90)	15.45 (7.19)

5 Discussion

In contrast to prior work demonstrating the effectiveness of mindfulness inductions on middle schoolers [5], our study results show no evidence that the mindfulness or story treatments had an effect on students' game behaviors or on learning outcomes. A key element that could explain this difference is the study context. In previous studies, mindfulness inductions were conducted as a teacher-led synchronous group activity or when the student was alone. Our study instead examined mindfulness inductions as a self-guided and self-paced activity in a classroom context, where the lack of

mindfulness feedback from teachers may undermine their effect. In addition, the presence of other classmates who may be engaging in different game activities likely introduced more distractions and may have made students more self-conscious about closing their eyes and following along with the mindfulness induction. While randomization of student learning conditions within each classroom provides greater statistical power by minimizing class-level effects, future research could test the same mindfulness intervention administered at a classroom level so that all students would begin each day completing the same intervention with their peers.

A different explanation is that the effect of mindfulness, if present, was only in the short term and therefore not reflected in aggregate game play measures or post-intervention assessments. Future work could validate this conjecture by administering a short survey which probes students to reflect on their current mindfulness state right after the daily induction [2]. Alternatively, it might be possible that mindfulness inductions are less powerful in digital learning games, because the mechanisms through which they enhance learning – i.e., improving executive functions, reducing students' rush and carelessness – are similar to those of learning games [1]. *Decimal Point*, in particular, was shown to improve learning via reducing students' cognitive disengagement [9]. In other words, mindfulness interventions might not be as useful in a digital learning game, where attention is already enhanced, compared to other learning contexts where student attention and engagement are lower. Future research could compare the same mindfulness induction within *Decimal Point* and a non-game digital control that covers the same content [8], to see whether mindfulness has a more pronounced effect in a non-game context.

At the same time, there are a number of limitations that may influence our interpretations of the results. First, due to COVID restrictions we could not be present in the classroom to ensure that students were following the meditation guidelines, rather than being idle. Likewise, we were not able to deploy sensing technologies (e.g., eye tracking) to capture more nuanced data about students' mindfulness practice. Finally, the effect of mindfulness inductions may require a larger sample size to detect.

In conclusion, the findings from our study provide an important first step toward identifying boundary conditions for when and how mindfulness meditation can be used to support learning in classroom contexts and in conjunction with digital learning games. As described above, future research on the classroom factors and types of digital learning environments that are best suited to mindfulness inductions will contribute important additional evidence for researchers and teachers seeking to understand the conditions under which mindfulness inductions can be a useful learning tool.

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