

Conversational AI Meets Mindfulness: Exploring LLMs as a Socio-Emotional Layer in a Math Intelligent Tutoring System

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Abstract. Intelligent Tutoring Systems (ITSs) traditionally focus on cognitive support, often overlooking students’ emotional state. We developed an ITS that leverages Large Language Models (LLMs) to provide both cognitive and socio-emotional support in algebra through a pedagogical agent “Matt”. The system offers LLM-based mindful chats, breathing exercises, and mindful hints and feedback based on Kabat-Zinn’s seven principles of mindfulness to support students’ learning experiences and reduce math anxiety. In a classroom study with 7th graders, we compared a Mindful version against Cognitive support-only version. Although external disruptions limited the final analysis to 42 students, the results provide important exploratory insights. While no significant differences were found in math learning or state-math anxiety, the Mindful group reported significantly higher perceived socio-emotional support and warmth from the agent. Exploratory log data revealed that students in the Mindful condition completed fewer problem-solving steps with fewer hints requested. Our study demonstrates the feasibility of integrating mindfulness into ITSs through LLM-based interactions and positions LLMs as an adaptive, socio-emotional layer within cognitive math tutoring.

Keywords: Math Anxiety · Mindfulness · Large Language Models · Intelligent Tutoring Systems.

1 Introduction and Background

For many students, mathematical problems do not merely present cognitive challenges; they trigger an aversive emotional state of fear and tension known as *Math Anxiety* (MA) [14]. This phenomenon is widespread and carries severe consequences, including impaired working memory, diminished performance, lowered self-confidence, and avoidance of math learning opportunities [1].

The practice of *Mindfulness* – the continuous, non-judgmental awareness of the present moment cultivated through deliberate, non-reactive attention [7] – can reduce MA by de-automatizing maladaptive cognitive and emotional patterns and enhancing self-regulation [2]. Prior research demonstrates that short mindfulness-based practices, such as guided breathing before a task, can reduce anxiety during task execution (*state-MA*) and restore performance [5]. However, most interventions remain difficult to scale as they typically depend on trained professionals and extended multi-session formats [17]. In the context of technology-enhanced learning, Intelligent Tutoring Systems (ITSs) and pedagogical agents offer strong cognitive and motivational support, yet they rarely attend to emotional states during problem solving [8, 15]. While recent advances in Large Language Models (LLMs) enable flexible, context-sensitive conversations, their integration into ITS as an emotional layer remains limited [16].

We developed and empirically tested an ITS that leverages LLMs to provide both cognitive and mindfulness scaffolding through offering LLM-based mindful chats for socio-emotional support, guided breathing exercises, and cognitive-mindful hint and feedback messages. Our system is grounded in Kabat-Zinn’s seven principles of mindfulness (*Non-Judgment, Patience, Beginner’s Mind, Trust, Non-Striving, Acceptance, and Letting Go*) [7] to prevent MA through a non-judgmental approach to math that values process over outcome, allows an individual pace, and help trust learners’ own abilities [13].

2 Methods

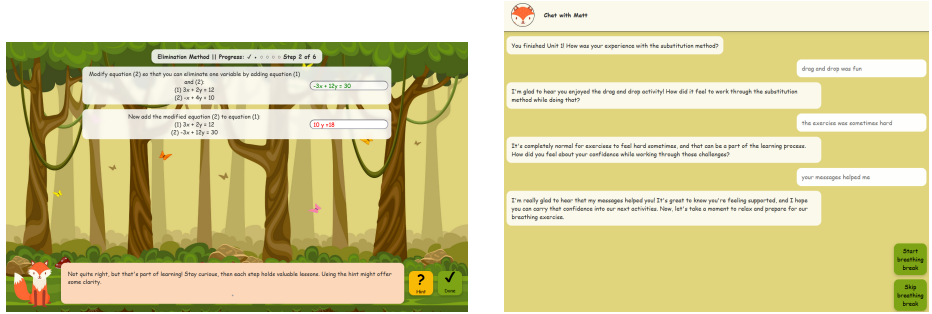
2.1 Design of the Mindful Intelligent Tutor for Algebra

The ITS was implemented using the Cognitive Tutor Authoring Tools¹. A fox-shaped pedagogical agent called “Matt” who uses human-like expressions and converses in first- and second-person language (“you”, “we”) provides cognitive and mindful support. The ITS covers three learning units (with three exercises each) on linear equation systems. Unit 1 uses drag-and-drop interactions, while in Units 2 and 3 students type in equation-solving steps (Fig. 1a). Matt offers three levels of hints for each problem-solving step and gives feedback.

Mindful chats with Matt. Students participate in chats during the introduction and after each learning unit to reflect on their learning experience and feeling with Matt (Fig. 1b). The LLM (GPT-4o-mini, temperature=0.4, max 100 tokens) was prompted to role-play as a warm, supportive tutor using mindful language. The system prompt incorporated Kabat-Zinn’s seven mindfulness principles [7], adapted for an educational context (e.g., validating learners’ pace) [5] (Listing 1).

Breathing exercises. Before each learning unit, Matt offers to engage in a 1-minute guided breathing exercise, inspired by [5, 17].

¹ <https://github.com/CMUCTAT/CTAT>



(a) Free-text input interaction where Matt gives error feedback using mindful language (b) LLM-based chat interaction with Matt, offering a breathing exercise

Fig. 1: Interface design of our tutoring system

- [Mindfulness Attitude]
 Your communication should integrate the following 7 mindfulness principles:
1. Non-judging: acknowledge all thoughts (including “I can’t do this”) without labeling them good or bad.
 2. Patience: remind learners that understanding takes time.
 3. Beginner's Mind: encourage curiosity and viewing each problem as a novel experience.
 4. Trust: reinforce self-confidence in students’ understanding and problem-solving abilities.
 5. Non-striving: focus on engagement and exploration during the process rather than perfect outcomes.
 6. Acceptance: guide students to view both mistakes and setbacks as natural opportunities for growth.
 7. Letting go: gently release self-doubt and return to the task at hand.
- These principles are interconnected. Your language and responses should reflect this philosophy without explicitly naming it.

Listing 1: Mindfulness principles in LLM prompt

Mindful hints and feedback. We avoided dynamic LLM feedback during problem solving due to hallucination risks. Instead, we prompted an LLM to convert standard ITS hints into mindful messages (Listing 1, Table 1), verified them for accuracy, and hard-coded the outputs into the CTAT architecture.

2.2 Classroom Study

We conducted a classroom experiment comparing the “Mindful” ITS against a “Cognitive” version of the same ITS without the above-described mindfulness interventions. We ask three research questions: (RQ1) How do students’ state-MA change by interacting with the Mindful ITS? (RQ2) Do students learn math

Table 1: Mindful language enhancement of cognitive hint and feedback message

	Cognitive Base	Mindful Language Enhancement
Success feedback	You've created an equation with just one variable. Let's simplify it next.	Nice work creating an equation with one variable. Let's explore simplification next.
Failure feedback	If you would like my help, click on the hint button.	Not quite there, but that's completely okay! Learning takes time and patience. The hint can help you get moving again.
Hint	Combine like terms: $2x+x=3x$.	Combining like terms could be the next step.; $2x+x$ can simplify to $3x$. This process shows how we can make equations easier to work with.

skills using the Mindful ITS? (**RQ3**) How do students perceive the usability of the Mindful ITS, and the effectiveness of the pedagogical agent in providing support, building confidence, and regulating emotions?

Participants included 252 7th-graders from seven classes at an international school in Japan. Due to illness and a subway incident, the final sample comprised 42 students (18 Mindful, 24 Cognitive), randomly assigned within class.

The study consisted of two weekly 50-minute sessions involving a pre/posttest and ITS use. We measured math learning outcome, trait-MA (Abbreviated Math Anxiety Scale (AMAS) [6]), state-MA (State-Trait Anxiety Inventory (STAI) [11]), system usability (System Usability Scale (SUS) [3]), and agent effectiveness on socio-emotional support, warmth, and competence [4, 5, 9, 10, 12]). We also gathered ITS log data to gain further insights.

3 Results

Math Anxiety. For trait-MA (AMAS), no significant group difference was found ($W=224$, $p=.849$). Regarding state-MA (STAI-6), we measured both anticipatory (before math test) and executive (during math test) anxiety. While both groups showed a significant decline in executive state-MA over time ($F(1, 15)=5.422$, $p=.034$, partial $\eta^2=0.27$), no significant group or time*group interaction effects were found for anticipatory or overall state-MA (Table 2).

Table 2: State-MA mean scores (range: 20 to 80)

Group	State-MA Type	Pretest ($M(SD)$)	Posttest ($M(SD)$)
Cognitive	Anticipatory	41.67 (13.48)	37.64 (13.78)
	Executive	43.64 (14.79)	33.64 (9.48)
Mindful	Anticipatory	40.37 (13.57)	44.63 (16.61)
	Executive	38.89 (13.93)	33.89 (14.82)

Math Learning. The pre/posttest each consisted of six questions (maximum score=9). Both groups showed pre-posttest learning gains: the Cognitive group

increased from $M=4.38$ ($SD=2.06$) to $M=5.33$ ($SD=2.08$) and the Mindful group from $M=4.39$ ($SD=1.72$) to $M=4.72$ ($SD=1.93$). A linear mixed-effect model confirmed a significant main effect of time ($F(1, 40)=6.418$, $p=.015$, partial $\eta^2=.14$), but no significant group effect or time*group interaction.

System Usability. System usability was rated relatively low in both groups (range: 0 to 100). The Mindful version received higher SUS ratings $M=55.56$ ($SD=21.05$) than the Cognitive version $M=43.96$ ($SD=26.06$), though this difference was not statistically significant ($t(39.74)=-1.594$, $p=.119$, $d=-0.48$).

Characteristics of the Pedagogical Agent. We evaluated the agent across three dimensions: socio-emotional support, warmth, and competence. While overall group differences were not significant, single-item analysis revealed that Mindful group rated the items “*I feel supported by Matt*” ($W=167.0$, $p=.028$, socio-emotional support) and “*I believe that Matt is very concerned about my well-being*” ($W=139.5$, $p=.046$, warmth) significantly higher.

Log Data Analysis. As the final sample who completed all study activities was small ($N=42$), we complement it with additional insights from the log data, which were collected from all 252 participating students. The Mindful group completed significant fewer problem-solving steps than the Cognitive group ($M=12.43$, $SD=8.88$ vs. $M=21.28$, $SD=11.61$; $W=11930$, $p<.001$), corresponding to the middle of the third problem in Unit 1 vs. start of the second problem in Unit 2. They also used significant fewer hints per step ($M=0.61$, $SD=0.76$ vs. $M=1.06$, $SD=1.17$; $W=8645$, $p=.002$). Error rates did not differ ($W=7257$, $p=.606$).

4 Discussion and Conclusion

This study explored integrating LLM-based mindfulness interventions into a math ITS through a pedagogical agent. Although mindfulness did not improve math anxiety or learning outcomes compared to cognitive support only, it fostered a stronger socio-emotional connection with learners. Log data further showed that the Mindful group completed significantly fewer problem-solving steps while achieving comparable learning gains, suggesting that time spent on breathing exercises and conversation did not hinder learning.

The lack of a significant group difference in anxiety (RQ1) may reflect the classroom environment, where peer presence and social dynamics can undermine engagement with breathing exercises. Regarding learning outcomes (RQ2), both groups showed significant posttest improvements, confirming that the shared ITS elements, such as instructions, hints, and feedback are effective (consistent with prior work on ITSs, e.g., [8]). While the evidence is limited, the agent “Matt” was also well-received (RQ3). Students in the Mindful group specifically perceived him as more supportive and caring, demonstrating the potential for LLM-supported interactions to provide effective socio-emotional scaffolding.

We acknowledge several limitations. First, the small sample size due to external constraints limits generalizability. Language barriers led to translator use,

which likely decreased usability and masked intervention effects. Also, the classroom setting appeared to limit breathing exercise engagement. Future studies could integrate the study into homework to mitigate environmental interference.

In conclusion, this work demonstrates the feasibility of integrating LLM-driven mindfulness into structured ITS, offering a scalable approach to socio-emotional support that does not require specialized instructors.

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