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Designing Tools for Caregiver Involvement in Intelligent Tutoring Systems for Middle School Mathematics

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Abstract: Intelligent tutoring systems (ITS) can help students learn successfully, yet little work has explored the role of caregivers in shaping that success. Past interventions to support caregivers in supporting their child's homework have been largely disjunct from educational technology. The paper presents prototyping design research with nine middle school caregivers. We ask: (1) what are caregivers' preferences for different prototypes incorporating data-driven recommendations into their math homework support? Integrating caregivers' preferences, we then ask: (2) what are caregivers' perceptions when interacting with a prototype of an intelligent chatbot tool to support students' homework? We found caregivers reported feeling comfortable integrating AI into their practices and appreciated chat-based support for understanding content and effective ITS use. Our results highlight the affordances of ITS data and AI to assist caregivers who would otherwise not be able to support their child's homework, paving the way for more effective and equitable mathematics learning.

Introduction and background

Caregivers, which include parents, guardians, and members of a child's caring community, and their involvement in children's education, especially mathematics, significantly influence academic achievement (Hill & Tyson, 2009). Caregivers engage in two levels of involvement: first, at the macro level, where they provide support for their children's motivation and performance in homework, and second, at the micro level, involving instructional activities during the homework process (Hoover-Dempsy et al., 2001). Involvement in both levels correlates positively with student outcomes such as grades, attendance, and test performance (Jeynes, 2007), while the absence of involvement negatively relates to homework effort and completion rates (Núñez, 2023), undermining learning since homework is a critical tool for reinforcing classroom learning, fostering self-regulation, and enhancing academic achievement (Bempechat, 2004). Barriers such as limited knowledge, time constraints, and insufficient resources have been associated with reduced caregiver involvement. (Pelemo, 2022). Furthermore, certain homework involvement methods can hinder academic progress, such as when caregivers undermine child autonomy, exert undue pressure, or use teaching methods that conflict with school practices (Hill & Tyson, 2009). This phenomenon of variable effectiveness becomes more pronounced when technology enters the educational landscape—a domain where rapid advancements can outpace caregiver capabilities and traditional educational support structures (Livingstone, 2007). Historically, caregiver involvement has been through non-technological means such as face-to-face meetings, parent-teacher conferences, and home-based activities (Hoover-Dempsy et al., 1992). However, technological advancements have shifted the focus toward technology-based interventions for caregiver involvement. For instance, caregiver notifications in the ASSISTments ITS for progress monitoring increased caregiver engagement (Broderick et al., 2011). In another case, text message nudges to caregivers for weekly activities improved students' GPAs (Santana, 2019). Despite these advancements, there remains a gap in providing fine-grained, personalized support that caters to individual student needs.

The present study turns to personalized, technology-based instruction that has been shown to support math homework at home and improve math achievement: intelligent tutoring systems or ITS (Kulik & Fletcher, 2016). ITS effectiveness can be even greater when they support existing instructional practices. For example, real-time analytics on student struggle and learning behaviors can inform instructors of students' needs during individualized learning (Aleven et al., 2022). However, not many works investigated how caregivers can collaborate with ITS to help children with homework. Currently, most existing caregiver support tools using ITS focus on macro-level involvement, such as progress tracking and performance alerts (Broderick et al., 2011). Fine-grained analytics, which could offer deeper insights into students' learning processes and strategies, are rarely used to their full potential in caregiver support contexts. Building on the Hoover-Dempsey framework, the present study investigates evolving caregiver involvement in the context of ITS-enhanced education, focusing on key factors, including beliefs, self-efficacy, and external cues that shape engagement (Hoover-Dempsey et al., 2001). We examine how these factors central to caregiver engagement are adapting in an era where educational practices are increasingly mediated by technology. Specifically, this research explores the design space of how caregivers could be effectively involved in homework support in the context of ITS-based learning. Our inquiry is structured into two phases, corresponding to two research questions (RQs).

Phase one investigated RQ1: *What are caregivers' preferences for different methods of incorporating personalized recommendations and support tools into their math homework support?* During the first phase, we designed low-fidelity prototype solutions for caregiver involvement during homework help and dug into caregivers' opinions of those solutions. These sessions revealed an interest in an AI-assisted caregiver-child support tool offering timely and personalized recommendations for caregiver homework support. Acting on these insights, we formulated a second research question to be investigated with a higher-fidelity prototype: Phase two investigated RQ2: *What are caregivers' perceptions when interacting with a newly developed AI-based research prototype of a chatbot tool based on caregiver needs expressed in RQ1 in supporting their child's mathematics homework?* Specifically, we implemented a caregiver support tool and evaluated the prototype in a Wizard of Oz setting.

Phase one: Initial design and exploration

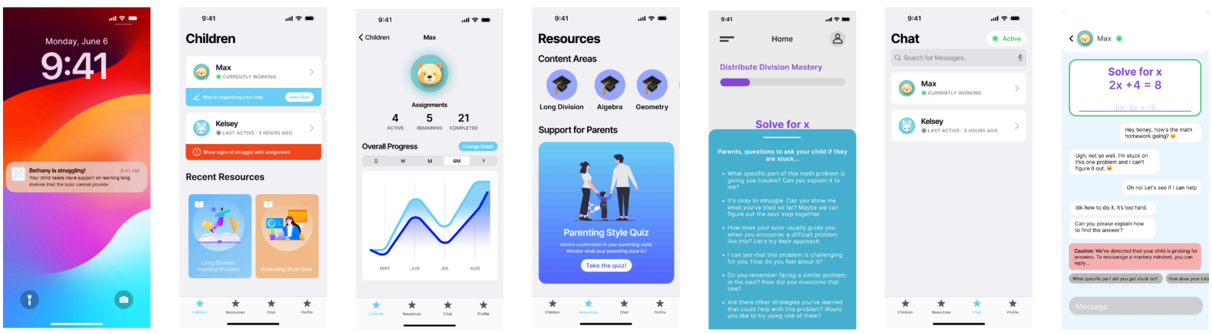
Participants

Nine caregivers, all of whom were parents, participated with compensation across two phases, with five (C1-C5) participating in Phase One. These caregivers of middle and high school students aged 10-15 were recruited via social media and email lists of caregiver associations within the Northeastern U.S. Notably, eight of these nine caregivers had also participated in a separate preliminary investigation—referred to here as Study Zero. The caregivers' demographics comprised one male and four females aged M = 42 (SD = 2.83), all white.

Materials

In Phase one, caregivers were shown five low-fidelity prototypes (Figure 1) to collect their preferences and suggestions. These prototypes were based on findings from Study Zero that utilized storyboard activities to identify caregiver preferences among seven potential ITS-based solutions. Study Zero found that the top solutions identified by caregivers included weakness reports, math content resources, notifications, and tips on motivating their children. The interactive prototypes were created via Figma for design sessions with caregivers and informed by the storyboarding activity results, log data from ITS, and prior literature on effective caregiver involvement. We describe the solutions and the rationales behind each below (in order of Figure 1's display).

Figure 1
Screenshots of our design prototypes at Phase 1, from left to right: notifications, home screen, learner progress dashboards, advising resources, modeled conversations, and two views of the caregiver-child AI chatbot tool.



(a) *(b)* *(c)* *(d)* *(e)* *(f)* *(g)*

(1) The notifications prototype (Figure 1a) informs caregivers about their child's learning progress and performance, leveraging ITS log data like completion status and struggle indicators. This design enables timely caregiver responses in offering support or encouragement, aligning with past work on positive task appraisals and responsiveness to student frustrations and struggles (Pino-Pasternak, 2014).

(2) The learner progress analytics dashboard (Figures 1b and 1c) provides a dedicated student profile that showcases interactive progress graphs of homework completion, learning rates, skill acquisition, goal completion, and engagement across multiple timeframes (i.e., days, weeks, and months). Studies have shown that similar tools, such as a parent portal, positively influence student outcomes and increase caregiver

engagement (Mac Iver et al., 2021). This design was driven by the understanding that caregivers want clear insights into their child's academic trajectory (Webber & Wilson, 2012), which may help them tailor their academic support.

(3) A set of guidelines and recommended example questions (Figure 1e) were designed for caregivers to conduct productive in-person homework support discussions, referred to as "modeled conversations." Rooted in mastery goal orientation literature, they emphasize indirect control and independent problem-solving (Pino-Pasternak, 2014). Unlike the adaptive AI chatbot, these modeled conversations offer general, context-independent prompts for enhancing interactions.

(4) A resources guide (Figure 1d) with articles about tools and resources for caregivers, encompassing subject-specific practice problems to parenting-style quizzes, was presented as another solution for caregiver involvement. Recognizing the importance of caregivers' understanding of the curriculum and effective involvement strategies, these resources aim to bridge potential knowledge gaps (Pennington, 2022).

(5) The AI-assisted caregiver-child support tool (Figures 1f and 1g) incorporates a chat feature enabling remote communication between the student and their caregiver while the caregiver observes the student's problem-solving in real-time. As this interaction unfolds, the AI serves as an on-demand support tool for the caregiver, analyzing the child's messages to pinpoint difficulties and suggest appropriate responses. These suggested responses to the child may range from explanations on tackling the problem to offering emotional support. Given the rising chatbot utilization in education, this solution addresses the need for individualized student support (Winkler & Sollner, 2018). The AI chatbot is designed to support desirable caregiver behaviors associated with self-regulated learning that encourage mastery goal orientation, such as encouraging independent problem-solving with metacognitive talk (Pino-Pasternak, 2014), and aids in addressing specific math challenges, such as explaining math vocabulary.

Procedure

Phase one began with designing solutions (Figure 1) for caregiver involvement. It was followed by semi-structured interviews with caregivers and feedback activities to understand perspectives on technologies supporting homework involvement. One session (2a and 2b, as described below) lasted 60 minutes and was online via Zoom or in person.

(1) Storyboards. Study Zero was an initial needs-finding study conducted with 11 caregivers. During these sessions, interviews were conducted, delving into homework assistance approaches, challenges, and views on homework's significance. Caregivers did a storyboard activity, which involved the use of illustrations or sequences of images to visualize and explore potential solutions or ideas, ranking seven potential caregiver involvement solutions: messages about student weaknesses, math resources, reminder notifications, motivation tips, student distractions, student progress comparison, and caregiver performance analysis.

(2a) Semi-structured Interview. Building upon the initial needs-finding interviews, our conducted sessions consolidated identified caregiver needs by revisiting key interview questions. This approach provided continuity and depth, ensuring our prototyping activity aligned with caregiver needs and preferences.

(2b) Caregiver Feedback Activity on Prototyped Solutions. After delving into caregivers' experiences and perspectives, we transitioned to presenting them with our prototyped solutions (Figure 1). The prototype feedback activity included multiple tasks, with caregivers encouraged to think aloud during interactions. Questions revolved around the perceived utility, perception, and content of the designs. These included questions such as "What is your response to this screen?", "What features or functionalities would make you more comfortable using this?" and "What is your ideal solution?" This session also asked caregivers to rank the prototypes based on their preferences and perceived effectiveness.

After data collection, we analyzed the qualitative data through an open coding scheme. A research team member manually corrected automatically generated Zoom transcripts. We then performed thematic analysis, identifying, analyzing, and reporting patterns within the data. The first stage of this analysis entailed becoming familiar with the data through repeated reading, followed by note-taking and coding, where potential themes were identified and defined. Discussions with three other research team members consolidated the themes and designs. We primarily focused on frequency in identifying which themes and comments to highlight.

Results

Caregivers' Attitudes and Motivations for Homework Involvement. Interview analysis revealed varied caregiver involvement in homework, from minimal to highly proactive. Caregiver 1 (C1) adopted a hands-off approach due to a busy schedule, relying on teachers for academic support. Caregiver 2 (C2) regularly assisted, especially in math. Caregiver 3 (C3) rarely intervened, noting the child's independent math skills. Caregiver 4 (C4) helped thrice weekly upon the child's request, while Caregiver 5 (C5) dealt with the child's resistance to caregiver assistance. Despite this variety, a common thread was the desire for children to develop independence, with caregivers often waiting for the child to initiate requests for help. Caregivers expressed a careful balance between providing support and avoiding overstepping, aiming to avoid undue stress or conflict.

Caregiver Reluctance in Providing Content Support. A notable design finding was the hesitation among caregivers to be the primary source of content support for their children. Four out of five caregivers during Phase one preferred their children not to be overly dependent on them for content-based assistance. The reasons underpinning this sentiment were multifaceted:

1. **Math Anxiety Augmented by Curriculum Shifts**: Four out of five caregivers interviewed during Phase one reported feeling ill-equipped to assist with the curriculum taught to their children. Three out of five caregivers explicitly mentioned this shift caused by Common Core when discussing their math anxiety, with C4 noting, "With like Common Core and some of the ways that they teach math. It's different from how I learned it, and so I can't, like, pretend to know the precise way they're teaching it."
2. **Occupational Constraints and Limited Attention**: A recurring theme was the challenge posed by busy work schedules and the limited resources of caregivers. Two out of five caregivers mentioned their professional commitments as barriers to consistently being available to assist their children with homework. Caregivers also described that other classroom tools already compete for their attention (e.g., Google Classroom), so they need a high relevance threshold to pay attention to the constant influx of notifications, preferring rare but essential moments of help over staying up-to-date.
3. **Perceived Division of Labor between Caregivers and Teachers**: Two out of the five participants believed that providing content-related support was primarily the teacher's domain and not the caregiver's responsibility. As C1 said, "I tell the teachers it's on them […] This is your job. My job is my job. Your job is to teach my children these concepts."

Favored Technological Solutions. A preference emerged around three caregiver support solutions based on qualitative insights and ranking activity. Out of five caregivers, three favored the AI-supported messages, three Notifications, and two Data Analytics. In comparison, caregivers did not favor offline caregiver resources (one out of five) nor modeled conversations (one out of five). The top three solutions included:

1. **AI-supported Messaging**: The AI-assisted caregiver-child support tool was favored by caregivers due to the convenience of immediate feedback on the child's needs. Caregivers appreciated that they could provide accurate, targeted support to their children with reduced need for recalling complex math concepts or extensively analyzing their child's homework challenges. C4 comments, "It's easier… There's a little less thought behind it from a parent perspective." Caregivers also highlighted that the tool could facilitate smoother, less conflict-laden interactions between them and their children, as messaging might be less tense and conflictual than in-person interactions.
2. **Notifications**: Caregivers reported finding value in being informed about their child's progress, challenges, and achievements. Specifically, caregivers valued that notifications from the ITS system allowed caregivers to quickly intervene or offer praise when necessary without constantly monitoring or inquiring about their child's progress. C1 noted, "I like the fact that it will alert you when your child completed problems [or] if they're struggling with something, [...] being able to intervene quickly"
3. **Data Analytics**: Caregivers showed a keen interest in understanding their child's performance patterns and areas of improvement through data-driven insights. Specifically, caregivers valued that the tool gave them fine-grained data to pinpoint areas of struggle. C3 noted, "I only have that one performance test [...], whereas this could be honed in on [...] I don't have to wait till the next year when I get that test, and it says, 'Oh, he's deficient in this math concept.'"

Phase two: Implementation and evaluation

Participants

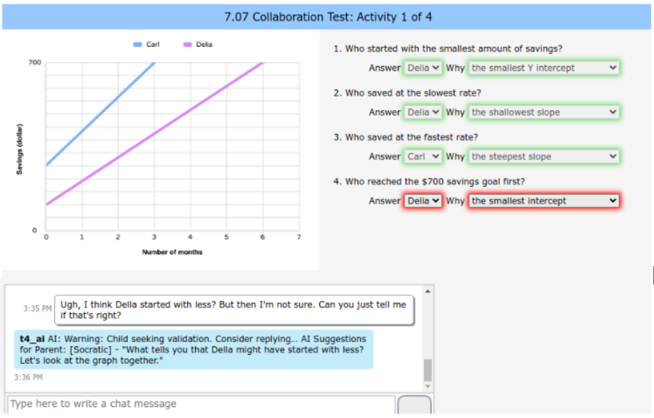
Four caregivers (C6-C9) participated in Phase two, following the same recruitment and compensation strategies as in Phase one. The participants were all white and female, aged M = 46 (SD = 7.55).

Materials

We implemented a working prototype (Figure 2) due to caregivers' preferences for the AI-chat tool and its novel approach to providing real-time, AI-assisted caregiver support. This tool permits a caregiver to remotely monitor their child's step-by-step progress through a corresponding interface and engage in real-time communication via a chat window. We based this design on adjustments to an implementation of the collaborative tutoring system APTA (Yang et al., 2023). Specifically, we repurposed the chat functionality from the collaborative tutoring system APTA, originally designed for student-to-student interaction, to facilitate a new use context—enabling caregivers to provide direct, AI-guided support to their children.

Figure 2

Screenshot of the implemented AI-caregiver support prototype used in Phase 2, including AI message example.



Procedure

During Phase two, the prototype feedback procedure was replaced by a Wizard of Oz procedure (Dahlbäck et al., 1993), where the caregiver interacted with an implemented prototype of the chat support tool. Caregivers were introduced to an ITS problem-solving environment in which they were told to imagine that their child had requested them to join for remote help. The Wizard acted as both the child and AI from a remote location. As the child, the Wizard mimicked typical student responses like seeking help or showing confusion. Concurrently, as the AI, the Wizard provided pre-generated, AI-generated advice to caregivers on handling these situations, aiming to foster productive interactions. Caregivers would see a message from "the child" followed by a recommendation from the "AI" on how to answer. The Wizard adjusted the child's and AI's messages in response to the caregiver's interventions. We are presenting three example message chains in Table 1.

Table 1

Example scenarios and message recommendations during WoZ Phase 2 sessions.

Scenario	Child's Response	AI Recommendation
(1) Child wants an explanation on a math concept	"But what about the rate? What does "rate" mean?"	Child is facing a vocabulary challenge. Consider replying… "Rate means how fast something changes as time goes on."
(2) Child makes an unsuccessful attempt at solving the problem	"Hey, Mom. I need help on this problem. I can't figure it out."	It seems the child might benefit from some additional assistance. [...] Consider replying… "Have you tried clicking on the hint button? It often provides useful clues that can help guide you through the problem."
(3) Child is experiencing frustration at not understanding the problem	"I just don't get this. I've tried multiple times in the tutor, and I keep getting it wrong! Why can't I figure this out?"	Child is frustrated with repeated mistakes and may require emotional support. Consider replying… "I understand that it can be really frustrating. Remember, mistakes are a part of the learning process. [...]Can you explain why you think it's Della?"

After the data collection, we analyzed the data by using the same coding and thematic analysis strategies and procedures as in Phase one.

Results

We summarize findings related to the AI-assisted caregiver-child support tool implementation based on relevant design insights of caregiver perceptions and preferences regarding the tool (RQ2).

Caregivers reported favoring the adaptive support messages generated by AI, helping them navigate content-level and system-level difficulties during problem-solving. When probed about the AI's message recommendations during tutoring sessions, caregivers highlighted three categories they found most helpful:

1. **Content-Level Assistance**: All participants unanimously reported seeing value in the content-related support provided by the AI, particularly appreciating its ability to offer clear explanations and definitions of math concepts and vocabulary (as shown in Table 1, Scenario 1). This feature was especially helpful for caregivers who felt less confident in their math skills or were unfamiliar with current math teaching methods. As mentioned by C9, "being able to get the definition right away as an as an immediate reply [...] takes away a step for me [...] very helpful."
2. **Recommendations about the Tutor Itself**: Three out of four caregivers reported valuing the AI's ability to analyze log data from the ITS and offer personalized recommendations (as shown in Table 1, Scenario 2). This feature helped caregivers guide their children in making the most of the ITS, ensuring efficient and productive learning sessions. C6 expressed, "It tells me that my kid has not accessed all of the support they could be using, and it gives me knowledge about how to respond appropriately."
3. **Behavioral/Emotional Support Messages**: Three out of four participants saw these recommendations as constructive reminders for patience and positivity (as shown in Table 1, Scenario 3). For example, C6 mentions, "The reminder about attending to the emotional needs was super helpful and made me change my mind about how I would respond." However, they were not unanimously appreciated. One caregiver strongly disliked this feature, perceiving it as an intrusion into their parenting style.

Caregivers would prefer interacting in person while using the tool when convenient. Although caregivers recognized the convenience of messaging, many still preferred in-person interactions. Two caregivers reported favoring face-to-face assistance due to its richer interactions, with C8 stating, "I prefer to talk to them in person because I also use their [...] facial cues and the way they're sitting and the way they're interacting with me." While half of caregivers preferred to help directly at home, the others reported being open to online interactions when in-person support was impractical. C7 even mentioned a preference for online interactions, saying, "It relieves me of the need to exit my workspace to physically go [to the child], allowing the child to maintain independence, while at the same time getting answers when they have questions or they're stuck." C9 echoed the same sentiment, saying, "communicating with them on text is better than verbally, often."

Caregivers raised concerns over the authenticity of the interaction. Caregivers raised concerns regarding the AI suggestions, fearing they might not reflect their unique tone of voice. C9 said, "I don't want him to think I'm a bot." As a result, the two caregivers who opposed the inauthenticity would edit AI recommendations to fit their style. Three out of four caregivers observed that, although AI suggestions differed from their usual responses during homework sessions, they aided in defusing tension and maintaining focus on productive behaviors. As C7 notes, "It keeps me focused on what's best for my kid in that moment. It keeps my frustration from getting ramped up because I don't like middle school math either."

Discussion and conclusion

The present study explores tools that augment caregiver support during student homework with intelligent tutoring systems. In a changing educational landscape moving toward increasing technology use, there is a lack of research investigating how caregiver support can be effectively merged with educational technology or how differences in caregiver support manifest in technology-based learning.

Phase 1 uncovered caregiver preferences for different prototypes incorporating data-driven recommendations and novel design ideas for AI-supported tools (RQ1). Caregivers highlighted challenges in providing content-level support requiring mathematics knowledge. This struggle is not a recent phenomenon; studies from as far back as the 1990s have documented similar challenges (Hornby & Lafaele, 2011). Recent curricular reforms, particularly the adoption of the Common Core State Standards (CCSS), have exacerbated these difficulties by altering the mathematics curriculum and teaching methods, contributing significantly to caregiver anxiety and perceived gaps in home-school communication (Pennington, 2022). Moreover, the interviews highlighted that caregivers are time-constrained, often balancing full-time jobs and other responsibilities. This finding aligns with past work showing that engagement in upfront training for caregiver support is often low, eventually fizzles out, or is unevenly distributed, potentially exacerbating inequities (Chacko et al., 2016). A more effective approach may be integrating content support within an AI system that provides on-demand and short bursts of content-level support to caregivers in moments when the need for support is high. Log data from educational technology can personalize support to the child's needs, allowing caregivers to learn alongside their children.

Phase two centered around the design of an AI-augmented caregiver assistance chatbot tool (RQ2), which provided real-time, adaptive support during homework assistance, offering AI-generated suggestions for effective communication and content guidance. While caregivers found the AI chatbot tool convenient, they preferred in-person interaction with their children when available. As caregivers cited the richness of in-person interactions and nonverbal cues as reasons for this preference, it remains an open question if enriching the caregiver-child interactions in our current tool, for example, through video, could improve adoption. Alternatively, a hybrid tool design that can adapt to remote and in-home scenarios could be a desirable middle ground. While the AI chatbot was favored for providing precise, context-specific guidance on content and emotional support, concerns about authenticity and personalization of interactions were raised. Allowing caregivers to personalize the tone and types of messages they receive could perhaps alleviate this issue. Future research should explore whether adaptive voices and personalities in chatbots alleviate this caregiver concern (Ruane et al., 2021).

Our findings make several theoretical contributions. Our study expands Hoover-Dempsey's (2001) framework on caregiver involvement by introducing technology's role in digital learning environments. It extends beyond traditional caregiver involvement methods (i.e., face-to-face meetings, parent-teacher conferences, and home-based activities (Hoover-Dempsy et al., 1992)) by incorporating AI-based tools embedded in ITS, highlighting the potential of technology-mediated involvement to augment caregiver homework support. We propose a novel approach that not only leverages ITS data but also equips caregivers with AI tools to enhance their ability to provide targeted support during homework sessions. This approach aims to bridge the communication and support gap between caregivers and students, thereby enriching the learning experience with more personalized, context-aware interventions that align with the caregivers' understanding and the students' academic needs. Thus, we offer a novel perspective on caregiver involvement, moving beyond traditional methods and addressing the challenges and opportunities of digital education tools. Looking ahead, enhancements to the chat-based caregiver support tool will focus on broadening its application for math homework practice in both at-home and mobile scenarios. Additionally, a key feature in the updated design will be improving the AI's ability to mimic the caregiver's vernacular and tone more precisely.

Given caregivers' positive sentiment toward AI support, the caregiver support augmentation tool might help level the playing field for households that do not naturally engage in effective homework support strategies. The caregiver support augmentation tool can potentially improve equity in educational technology use at home, as past work argued how equity gaps hinge on parental support in such contexts (Baquedano-López et al., 2013). AI-driven guidance can significantly assist caregivers struggling with current math curricula by providing essential support and adaptive feedback without requiring extensive knowledge, easing the burden for those limited by time or resources.

Our study faces three primary limitations. First, the AI functionality described in the paper has not been created or implemented, only simulated via a WOZ. Thus, our findings are based on a hypothetical model, necessitating the actual AI's future creation and validation to verify the proposed interventions' feasibility and impact. Second, the ad hoc nature of the WOZ setup occasionally resulted in misaligned AI suggestions, affecting caregiver trust. Half of the caregivers overlooked these inconsistencies and passed incorrect suggestions to students, while the other two recognized them and became skeptical of the system. This highlights the importance of future research in addressing inaccuracies in AI advice and its impact on tool adoption, particularly strategies like transparently communicating explanations for the AI's recommendations (Zerilli et al., 2022). Third, our participant group may not reflect the broader population, possibly skewing towards more engaged caregivers due to self-selection during recruitment. Future research should include a larger, more diverse sample to validate our findings and ensure the cultural responsiveness of the design, which is required for the efficacy of educational technology.

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