Teacher Views of Math E-learning Tools for Students with Specific Learning Disabilities

Zikai Alex Wen
Computer Science, Cornell Tech, New York, New York, United States
zw385@cornell.edu

Erica O Silverstein
Information Science, Cornell Tech, New York, New York, United States
es2223@cornell.edu

Yuhang Zhao
Information Science, Cornell Tech, New York, New York, United States
yz769@cornell.edu

Anjelika Lynne S Amog
Cornell University, Ithaca, New York, United States
asa242@cornell.edu

Katherine Garnett
Hunter College, CUNY, New York, New York, United States
kgarnett@hunter.cuny.edu

Shiri Azenkot
Jacobs Technion-Cornell Institute and Information Science, Cornell Tech, New York, New York, United States
shiri.azenkot@cornell.edu

ABSTRACT

Many students with specific learning disabilities (SLDs) have difficulty learning math. To succeed in math, they need to receive personalized support from teachers. Recently, math e-learning tools that provide personalized math skills training have gained popularity. However, we know little about how well these tools help teachers personalize instruction for students with SLDs. To answer this question, we conducted semi-structured interviews with 12 teachers who taught students with SLDs in grades five to eight. We found that participants used math e-learning tools that were not designed specifically for students with SLDs. Participants had difficulty using these tools because of text-intensive user interfaces, insufficient feedback about student performance, inability to adjust difficulty levels, and problems with setup and maintenance. Participants also needed assistive technology for their students, but they had challenges in getting and using it. From our findings, we distilled design implications to help shape the design of more inclusive and effective e-learning tools.

CCS CONCEPTS

• **Applied computing** → Education; E-learning; Computers in other domains; Personal computers and PC applications; Computer games; • **Human-centered computing** → Accessibility; Accessibility technologies.

KEYWORDS

K-12 Education, Special Education, Educational Technology, Assistive Technology

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1 INTRODUCTION

According to the National Center for Education Statistics [41], five percent of public school students in the US were identified as having a specific learning disability (SLD) in 2019, although the National Center for Learning Disabilities believes the real figure is even higher [10]. SLDs predominantly affect students' abilities to understand or use language, especially in reading (dyslexia), math (dyscalculia), and writing (dysgraphia). While students with dyscalculia have difficulty with math by definition, students with other SLDs also tend to struggle with math problems that involve reading and writing [10].

Nevertheless, research shows that many students with SLDs can develop proficiency in math skills when teachers provide one-on-one support and personalized instruction that adapts to students' learning styles, abilities, and interests [17, 47]. For example, teachers can present content using various sensory modalities and adjust the difficulty or length of assignments, according to the needs and preferences of each student. However, employing these strategies is time- and resource-intensive [7, 13], making it challenging for teachers to support a large group of students with diverse learning needs.

Recently, new math e-learning tools have gained popularity across the US [44], many of which support personalized math practice. For instance, drill-and-practice websites (e.g., *Khan Academy* [32]) and educational digital games (e.g., *Prodigy* [53]) allow students to practice math exercises independently and receive immediate feedback on their performance. These tools have the potential to provide personalized support to some students while teachers are helping others, or otherwise not available.

A few math e-learning tools (e.g., *The Number Race* [65] and *Calcularis* [14]) were designed specifically for students with SLDs. These tools use interactive visual media and symbols to present problems to students who struggle with processing text-based math problems. For example, *The Number Race* [65] is a game that challenges students with SLDs to read digital symbols that are represented by a car's speedometer in simulated car racing games. A lab study conducted by Wilson et al. [64] showed that students with SLDs made fewer mistakes in whole number calculations after playing *The Number Race*. While these results were promising, they are limited because they were conducted in the lab, removed from the complexities of a classroom setting. In fact, to the best of our knowledge, all prior research evaluating math e-learning tools for students with SLDs has involved only lab studies where students completed tasks using the tools in isolated sessions [29, 64].

While lab studies can tell us whether a tool can help a student learn a particular concept over a short period of time, they cannot tell us about the use patterns, challenges, and effectiveness of these tools in real life. In the context of real life, e-learning tools must be integrated into the student's curriculum as homework or classwork. Teachers must select and assign tasks on these tools as part of their teaching. So, while prior research has shown the potential of e-learning tools for helping students with SLDs learn certain math concepts, we do not know whether they support students' needs in the math classroom. To address this gap, we first turned to the student's teachers. Specifically, we asked the following research questions:

- Which math e-learning tools are teachers using?
- Why and how do teachers use these tools?
- How do teachers perceive the effectiveness of these tools for students with SLDs?

To answer these questions, we conducted semi-structured interviews with 12 US-based teachers who have experience teaching math to students with SLDs in grades five to eight. We focused on this grade range because little attention had been paid to it by prior research [43]. In terms of e-learning tools, we mostly focused on recent websites and applications that could provide personalized exercises, such as drill-and-practice websites and educational digital games, rather than calculators or interactive whiteboards. We asked our participants about their use of math e-learning tools in teaching students with SLDs, their challenges in adopting the math e-learning tools, the accessibility issues that their students faced in using the math e-learning tools, and their teaching strategies for students with SLDs.

We found that our participants used five drill-and-practice websites and six educational digital games for math skills training, none of which were specifically designed for students with SLDs. Overall, participants used these tools for four main purposes: (1) independent practice in the classroom, (2) motivation and engagement, (3) assessment, and (4) tracking student performance. Participants found four critical challenges that made it difficult for them and their students to use these tools for the aforementioned purposes: (1) drill-and-practice websites were text-intensive; (2) e-learning tools provided insufficient feedback to teachers about their students' performance; (3) e-learning tools did not allow teachers to adjust difficulty levels; and (4) e-learning tools were difficult for teachers to setup and maintain. Participants also mentioned that they wanted their students to use assistive technologies (e.g., text-to-speech, closed captioning) within the e-learning tools but they had difficulty acquiring and using them. Based on these findings, we propose design implications for math e-learning tools that address gaps noted by our participants. For example, math e-learning tools should not depend on typing or multiple-choice answers for input but instead allow students to communicate math content using additional modalities, such as using voice-to-text and moving math manipulatives.

In summary, we contribute a study that sheds light on real-life patterns and challenges of using e-learning tools for students with SLDs from their teachers' perspectives. Since teachers are the ones who incorporate e-learning tools into the curriculum, our study represents an important first step into understanding how e-learning tools can support students with SLDs. We further contribute design implications which can help shape the design and creation of more inclusive and effective e-learning tools.

2 RELATED WORK

In this section, we present related work on helping students with SLDs succeed in learning math. First, we present research on the learning difficulties that students with SLDs experience and identify pedagogical strategies that support these students. Second, we present research on recent math e-learning tools and their use by students with SLDs. Finally, we present research on the challenges that teachers face when adopting e-learning tools in their teaching.

2.1 Math Education for Students with SLDs

Students with SLDs have neurological differences that affect their abilities to understand or use language, especially in reading (dyslexia), math (dyscalculia), and writing (dysgraphia) [57]. Dyslexia is characterized by labored, inaccurate, and slow reading, along with spelling difficulties; dyscalculia causes difficulty with math concepts, calculating, number sense, number language, and problem-solving; and dysgraphia affects writing, including handwriting, spelling, and organizing written language.

Karagiannakis et al. [28] categorized the math learning difficulties of students with dyscalculia into four categories: (1) number sense, (2) working memory, (3) visuospatial skills, and (4) reasoning. Number sense refers to the ability to recognize number symbols, to compare quantities, and to perform calculations; working memory lets people hold on to information temporarily for processing, like a mental sticky note; visuospatial skills involve the ability to mentally process and manipulate visual objects in more than one dimension; and reasoning is the ability to make structured and logical inferences from supporting arguments and evidence. Furthermore, Neelkamal et al. [54] added that students with dyscalculia might have an additional SLD in reading (dyslexia) or writing (dysgraphia) that further affects their ability to solve math problems.

Nevertheless, studies [58, 62] have shown that specific instructional interventions can help students with SLDs achieve math proficiency. One such strategy is multimodal instruction, in which teachers both present contents using multiple sensory modalities (e.g., sight, sound, touch, and movement) and also offer students opportunities to express their understanding through multiple modes [62]. For example, a teacher might use math manipulatives, such as base 10 blocks, to engage tactile learners in a lesson on whole number calculations. Another effective strategy for teaching students with SLDs is differentiation [58], in which teachers adjust aspects of their lessons (e.g., difficulty level and length), based on each student's needs. A third strategy is thinking aloud, in which teachers model their thought process while solving problems and prompt students to share their thought processes. All of these approaches require one-on-one attention from teachers, making them both time- and resource-intensive [7, 13].

Although prior work has investigated the difficulties that teachers encounter in employing certain pedagogical strategies, it has not investigated whether and how math e-learning tools can support or detract from use of these strategies. Our study is the first to investigate whether and how teachers are integrating math e-learning tools as they adjust their teaching to their students with SLDs.

2.2 Math E-Learning Tools for Students with SLDs

Math e-learning tools serve a wide range of roles in math education, from providing a simple function like calculation to teaching math. A decade ago, researchers found that students with SLDs benefited from light-tech tools such as calculators and interactive white boards [5]. Recently, new math e-learning tools that provide richer features have emerged, such as video lessons [33], math exercises [26], and virtual manipulative objects [6]. Research on recent math e-learning tools for students with SLDs has mainly focused on: (1) personalizing math skills training and (2) making digital math content accessible.

2.2.1 Math Skills Training Personalization. Recent research on math e-learning tools for students with SLDs [3, 34, 43, 45, 46] has primarily aimed to increase students' academic scores by providing supplemental math skills training without teachers' direct support. Recent math e-learning tools can be divided into two categories: drill-and-practice training and game-based training [36]. We summarize prior work in these two categories respectively.

Drill-and-practice training presents math practice in the form of standardized tests and provides immediate feedback on whether the student's answer is correct or not. Many websites (e.g., *Khan Academy* [33], *IXL Learning* [26], *CMP 3* [37], *BrainPOP* [27], and *Flocabulary* [15]) provide K-12 math drill-and-practice training. Some of the drill-and-practice websites also provide free video lessons for students to learn corresponding math concepts independently. However, these websites were not designed specifically for students with SLDs. One of the goals of our study is to discover whether and how well teachers and their students with SLDs use these websites in math education.

To our knowledge, *Calcularis* [14] is the only curriculum-based math e-learning tool designed specifically for students with SLDs. This tool visually represents elementary school math problems. For example, it teaches the concepts of whole numbers, quantity, and distance by placing whole numbers on a number line from 0 to 100. It also automatically selects an appropriate practice problem based on the student's correctness rate. Research showed that, after using *Calcularis,* students with SLDs attained higher scores on grade-level math tests [29, 35]. While *Calcularis* shows promise, it is still unknown whether and how teachers are integrating this and similar tools into their classes.

Game-based training aims to transform math practice into fun games with visual representations of math concepts and concrete examples to contextualize math skills. These games do not provide explicit feedback on incorrect answers, but let the player keep trying until they find the correct answer [12]. Some educational digital games, such as *ST Math* [38] and *Prodigy* [53], cover a wide array of math topics, spanning from whole-number calculations to two-dimensional geometry. Other games target a specific math skill. For example, *Slice Fractions* [59] and *Refraction* [9] assist in practicing arithmetic operations with fractions. None of these games, however, were designed specifically for students with SLDs.

Ke et al. [31] studied how three games designed for general education students could improve students with SLDs' performance in math. For example, one of the games, *Ker-Splash,* presented players with a mathematical expression and asked them to create one with a greater numerical value. Ke et al. observed nine students with SLDs playing this game. They found that the game fostered positive attitudes towards math practice, but only four students (44%) received higher scores on a post-test after playing *Ker-Splash.* In addition, when asked what they learned from the game, none of the students mentioned any math concepts or problem-solving procedures. The study was limited by its small sample size, and it did not compare the effects of different game features (e.g., timed task, visualizing math symbols) on engagement and learning , so it is difficult to draw conclusions.

The Number Race [65] and *Number Catcher* [67], two games designed by the French National Institute of Health and Medical Research, specifically target students with SLDs. Both games cover the recognition of whole numbers. These games present Arabic, verbal, and visual representations of numbers together for the player to decide which whole number is larger and which is smaller in a timed game. Wilson et al. [65] conducted a user study with nine participants with math difficulties, aged seven to nine years old, to find out whether these children could gain numerical proficiency after playing *The Number Race* independently for half an hour a day, four days a week, over a period of five-weeks. Their results suggested that *The Number Race* could potentially help children with math difficulties increase number sense over short periods of lab study, but, as with other research in this area, more work is needed to test its use in a real-life context.

2.2.2 Accessible Digital Math Content. Another research direction related to math e-learning tools for students with SLDs has focused on making digital math content accessible to students who struggle with reading and writing. To achieve this, researchers have followed two main approaches: leveraging speech technologies [4, 16, 56] and providing virtual math manipulatives [1, 11, 51, 60].

Several tools [4, 16, 56] enable students to verbally communicate math content. *Mathtalk* [56] reads algebra through text-to-speech. *MathShare* [4] is a specialized text editor to help students keep math work aligned, type math symbols using shortcuts, and think out loud using speech-to-text. *ViewPlus* [16] is an audio graphing calculator that allows students to plot y-versus-x graphs using speech. To our knowledge, however, no prior work has studied whether and how teachers would use these tools to personalize the math education of students with SLDs.

Research has shown that using math manipulatives allows students with SLDs to communicate math content more easily than using written or verbal formats [2, 40]. Currently, several applications using virtual math manipulatives [1, 11, 51, 60] are available on the market. For example, *The Base Ten Blocks* mobile application [11] presents whole numbers with virtual blocks. *NLVM (National Library of Virtual Manipulatives)* software [60] is a digital library containing manipulatives for numbers, operations, and geometry. *NLVM* provides virtual manipulatives in the toolbar, such as a single block representing 1 and a 10-based block representing 10. If the user generated three single blocks and five 10-based blocks in the central panel, then *NLVM* displayed the number 53.

Nevertheless, virtual manipulatives applications without math exercises might not be effective for students in improving their math skills. Research [39, 63] found that the effectiveness of math manipulatives depended on whether students understood the mathematical meaning of each action they performed. Without the direct support of teachers, however, those virtual manipulatives applications could neither teach students how to use the manipulatives to solve math problems nor ensure students understand what they were doing with the manipulatives.

2.3 Adoption of E-Learning Tools by Teachers

Standalone e-learning tools are not effective unless teachers adopt the tools in their teaching [21, 42]. Therefore, some recent research focused on addressing teachers' needs and challenges in adapting e-learning tools into their math instruction. For example, interview studies [8, 23] reported that teachers needed to customize e-learning tools for individual students because teachers wanted to manage different students' learning progress, but could not do so. Vermette et al. [61] identified the challenges that teachers faced in customizing e-learning tools for varying student needs, including setting different difficulty levels of learning content and customizing UI preferences. To enable teachers to quickly identify individual students' performance on drill-and-practice websites during the class, Holstein et al. designed dashboards on computers [25] or on wearable smart glasses [24] that visualized students' statistical data to the teacher in real-time. Prior work has investigated how to help teachers adopt e-learning tools for general education students [24, 25], but comparatively little work considers teachers for special education students, especially students with SLDs.

3 METHODS

We conducted a semi-structured interview study to investigate which math e-learning tools teachers were using when teaching students with SLDs, why and how teachers used these tools, and how effective teachers felt the tools were for their students with SLDs.

3.1 Participants

We recruited via email and social media 12 US-based participants (eight females, four males) who had been teaching math to students with SLDs in public schools. Participants had to be either (1) state-certified in special education and have experience teaching math in grades five through eight, or (2) state-certified in general education and have experience teaching math in grades five through eight alongside a special educator in an integrated co-teaching (ICT) classroom.

Two out of the 12 participants were only teaching students with disabilities in self-contained classrooms that contained one special-education teacher; nine participants were teaching students with and without disabilities in integrated co-teaching (ICT) classrooms that contained two co-teachers; and one participant had taught in both types of classrooms by the time of our interview. Their ages ranged from 25 to 62 (mean=42). They had between 1.5 and 35 years of experience in teaching (mean=11.7). In terms of location, participants were living in three states at the time of the interview: One in Georgia, two in Washington, and nine in New York. Table 1 shows participant pseudonyms and their demographic information.

3.2 Procedure

The study included a semi-structured interview that lasted 40 to 60 minutes. Interviews were conducted face-to-face, over the phone, or via video conference software (Google Hangouts). Participants received a $20 Amazon gift card upon completing the interview. We began by asking participants about demographic information and their job duties. Then, we asked questions about participants' use of different e-learning tools, their experiences and challenges with these tools, and their special teaching strategies for students with SLDs. Our questions were grouped in the following categories:

1. Pedagogical strategies for students with SLDs: e.g., Could you give me an example of using a special pedagogical strategy for students with SLDs and tell me why you use it?
2. Challenges of teaching students with SLDs: e.g., Have you encountered any difficulties when tailoring math exercises for students with SLDs?
3. Use of math e-learning tools: e.g., Which e-learning tools have you used to help students with SLDs learn math and how have you used the tools? What is your purpose for using this e-learning tool?
4. Effectiveness of math e-learning tools: e.g., Do you think the e-learning tool you used is effective for students with SLDs? If so, why?
5. Accessibility of math e-learning tools: e.g., Have your students encounter any accessibility challenges when using the e-learning tool?

3.3 Analysis

We audio recorded then transcribed all interviews. The researchers coded the transcriptions using qualitative coding based on constant comparative methods to find common themes across interviews, following the methods outlined by Saldana [48]. The coding process was iterative. Initially, two researchers coded three sample transcripts independently, then discussed the themes and categories together. Then one researcher coded the rest of the transcripts based on the agreed categories. After writing our initial draft and reflecting upon our findings, we repeated the coding process. In the second iteration, two researchers coded three sample transcripts independently, then discussed the themes and categories. In the rare cases when coders disagreed, they discussed the issue until they reached agreement. After that, they coded all transcripts together based on the agreed categories.

Table 1: Participant pseudonyms and demographic information.

Pseudonym	Age/ Gender	State	Teaching Certification	Teaching Grade(s)	Teaching Environment(s)	Years of Teaching
Carol	55/F	WA	Special Ed.	Grade 3-6	Self-Contained	8
Marcus	32/M	WA	Special Ed.	Grade K-5	Self-Contained	5
Savannah	25/F	NY	Special Ed.	Grade 5	Self-Contained & Integrated Co-Teaching	1.5
Helen	55/F	NY	Special Ed.	Grade K-5	Integrated Co-Teaching[1]	35
James	48/M	NY	Special Ed.	Grade 7	Integrated Co-Teaching	5
Victor	27/M	NY	Special Ed.	Grade 8	Integrated Co-Teaching	6
Lisa	27/F	NY	Special Ed.	Grade 6	Integrated Co-Teaching	5
Amy	45/F	GA	Special Ed.	Grade 6	Integrated Co-Teaching	7
Selena	41/F	NY	General Ed.	Grade 6	Integrated Co-Teaching	16
Darcy	62/F	NY	General Ed.	Grade 8	Integrated Co-Teaching	27
Ian	34/M	NY	General Ed.	Grade 8	Integrated Co-Teaching[2]	10
Jennifer	53/F	NY	General Ed.	Grade 8	Integrated Co-Teaching	15

[1] Helen was working as a math coach together with teachers in the classroom to help students with SLDs learn math. [2] Ian was teaching students with SLDs together with special education SETSS providers.

Table 2: Information for the drill-and-practice websites used by participants including the math topics covered, pseudonyms of participants who used these tools, key features, and methods for student input.

Website	Topics	Used by	Description
IXL Learning	Grades K-12	James, Darcy, Victor, and Ian (4 people)	**Features:** practice problems with text-based hints; **Input:** choosing the correct answer or typing the final answer.
Khan Academy	Grades K-12	Selena, Amy, Darcy, and Ian (4 people)	**Features:** practice problems with text-based hints, video lessons with a teacher giving a lecture and writing on a blackboard, and an annotation tool; **Input:** choosing the correct answer or typing the final answer.
CMP 3	Grades 3-6	James, Darcy, and Selena (3 people)	**Features:** practice problems without hints, short animations that explain and visualize math concepts, and an optional annotation tool; **Input:** typing the final answer.
Flocabulary	Math Vocabulary	Amy and Lisa (2 people)	**Features:** practice problems without hints and rap music videos that explain the meaning of math vocabulary; **Input:** choosing the correct answer.
BrainPOP	Calculations, Computations	Lisa (1 person)	**Features:** practice problems without hints and video lessons that explain math concepts using real-world examples; **Input:** choosing the correct answer.

4 FINDINGS

4.1 Use of E-Learning Tools for Math Education

Participants used a total of 11 math e-learning tools, which included five drill-and-practice websites and six educational digital games. Interestingly, we found that our participants were not using any math e-learning tools that were specifically designed for students with SLDs (e.g., *Calcularis* [14]). Instead, participants used tools designed for general education to teach students with SLDs. We report our findings on participants' use of the different e-learning tools below.

Drill-and-Practice Websites. Table 2 shows key information for the five drill-and-practice websites used by our participants. These websites incorporated two categories of math content: (1) complete curricula (*IXL Learning, Khan Academy, ST Math, and CMP 3*) and (2) specific topics (*Flocabulary and BrainPOP*). Additionally, four of these websites provided math lessons in the form of videos (*Khan Academy, CMP 3, and BrainPOP*) or music videos (*Flocabulary*). Two websites also provided students with text-based hints (*IXL Learning and Khan Academy*), and two websites allowed students to write, draw, and annotate word problems (*Khan Academy and CMP 3*). Finally, the five websites used two modes of inputting answers: (1) selecting multiple-choice answers (*IXL Learning, Khan Academy, Flocabulary, and BrainPOP*) and (2) typing short answers (*IXL Learning, Khan Academy, and CMP 3*).

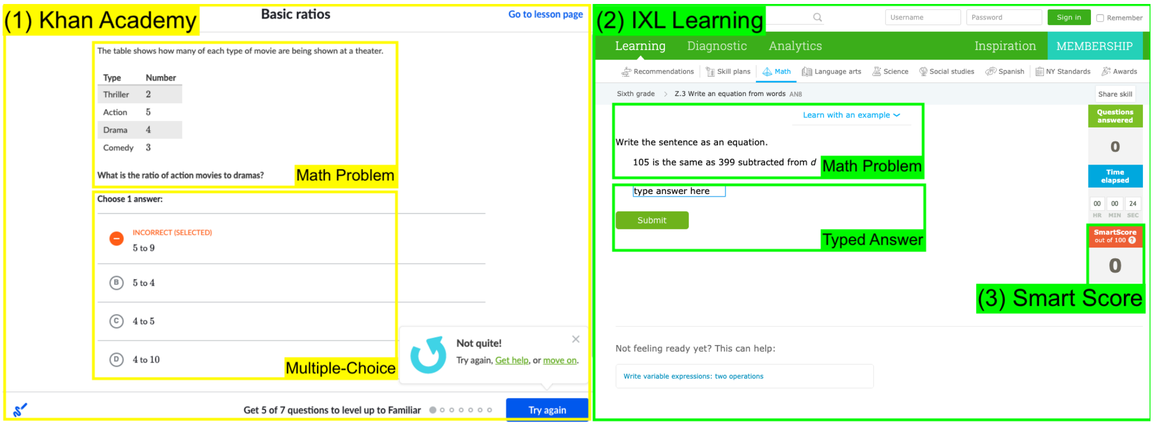

Figure 1: These are screenshots of two drill-and-practice websites: Khan Academy and IXL Learning. In Khan Academy (Highlight 1), the student needs to choose an answer to the math problem; In IXL Learning (Highlight 2), the student needs to type the answer. IXL Learning displays the student performance score in a Smart Score panel (Highlight 3).

Table 3: Information for the educational digital games used by participants including the math topics covered, pseudonyms of participants who used these games, gameplay designs, and methods for student input.

Game	Topics	Used by	Description
Kahoot!	Designed by Users	Jennifer and Victor (2 people)	**Gameplay:** a text-based trivia game with single- and multi-player modes; in the multi-player version, separate groups of players compete against each other; **Input:** choosing the correct answer.
ST Math	Grades K-6	Amy and Marcus (2 people)	**Gameplay:** a single-player puzzle game that uses visual elements to present math problems and requires players to use virtual manipulatives to solve the puzzles; **Input:** dragging-and-dropping virtual manipulatives.
Prodigy	Grades 1-8	Lisa (1 person)	**Gameplay:** a single-player role-playing game that presents text-based math problems that players must answer correctly to defeat enemies; **Input:** choosing the correct answer or typing the final answer.
DareDash	Arithmetic, Money	Darcy (1 person)	**Gameplay:** a single-player role-playing game that requires players to "drive" a vehicle and calculate the cost of driving from one place to another; **Input:** choosing the correct number of coins (manipulatives).
Jungle Math	Counting, Whole Numbers	Carol (1 person)	**Gameplay:** a single-player puzzle game that requires players to help a monkey collect the correct number of bananas that represents a given whole number; **Input:** choosing virtual bananas (manipulatives).
Slice Fractions	Fractions	Helen (1 person)	**Gameplay:** a single-player puzzle game that requires players to clear a path for a woolly mammoth by slicing up the objects in its way to form visual representations of fractions; **Input:** slicing a virtual manipulative into small pieces.

Figure 1 shows two screenshots of *Khan Academy* and *IXL Learning*, which showcases that the drill-and-practice websites presented and received most math content in text form.

Educational Digital Games. Table 3 shows key information about the six digital games used by our participants. Overall, these games incorporated three categories of math content: (1) user-designed content (*Kahoot!*), (2) complete curricula (*ST Math and Prodigy*), and (3) specific topics (*DareDash, Jungle Math, Slice Fractions*).

Additionally, these games supported three different gameplay styles: (1) trivia competition (*Kahoot!*), in which competitors are asked questions (2) role-playing game (*Prodigy and DareDash*), in which players assume the roles of characters in a fictional setting and (3) puzzle game (*ST Math, Jungle Math, and Slice Fractions*), in which players solve a math puzzle in each task.

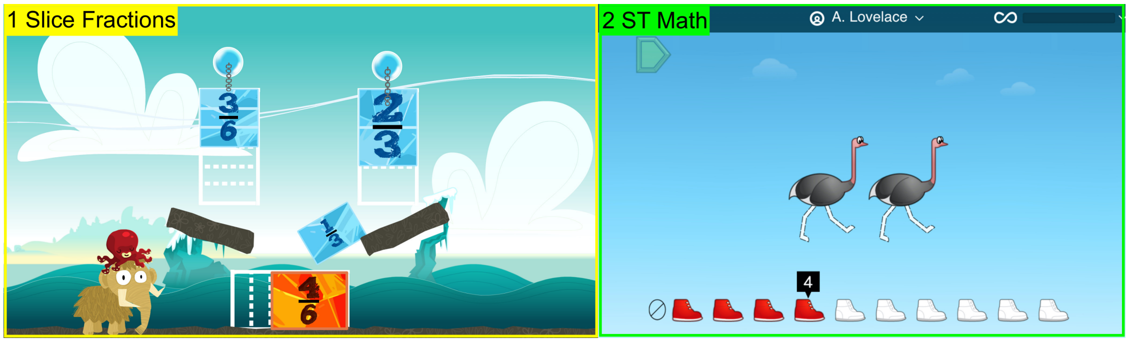

Figure 2: These are screenshots of two digital math games: Slice Fractions and ST Math. In Slice Fractions (Game 1), players slice 1/3 of the blue ice cube down to the ground to diminish the red lava cube that is blocking the wooly mammoth's way; In ST Math (Game 2), players select four shoes for two flamingos.

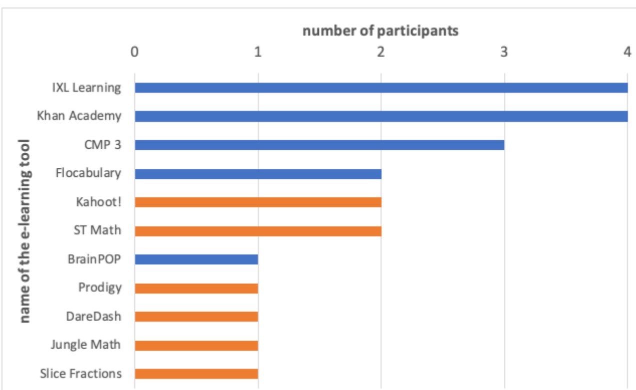

Figure 3: The number of participants who used a specific math e-learning tool. The drill-and-practice websites are in blue bars; the educational digital games are in orange bars.

These games also used three different modes of input: (1) selecting multiple-choice answers (*Kahoot! and Prodigy*), (2) typing short answers (*Prodigy*), and (3) interacting with virtual manipulatives (*ST Math, DareDash, Jungle Math, and Slice Fractions*). Figure 2 shows how players use virtual manipulatives to solve math puzzles in two games, *Slice Fractions* and *ST Math*. In *Slice Fractions*, players slice the blue ice cube in the air in order to let part of the ice cube diminish the red lava cube then clear the pathway for the wooly mammoth. In *ST Math*, players learn multiplication by selecting the number of shoes that fit the number of flamingos so that all the flamingos can run away from the scene.

Out of all the games, *Kahoot!* was the only one that supported a multiplayer mode.

In Figure 3, we show the number of participants who used each of the math e-learning tools listed in Table 2 and Table 3. More participants used drill-and-practice websites than educational games. *IXL Learning* and *Khan Academy* were the most commonly used websites while *ST Math* and *Kahoot!* were the most commonly used games. While most of the websites were used by multiple participants, the majority of the games were only used by one participant each.

Many participants used more than one math e-learning tool since they could not find one tool that fulfilled their multiple needs. For example, Victor and Amy used drill-and-practice websites to prepare students for their traditional math tests, but they needed digital games to reduce students' anxiety in practicing math exercises.

To manage and share resources from different math e-learning tools, four participants (Jennifer, Savannah, Selena, and Darcy) used learning management systems, such as Google Classroom. These systems allowed their students to follow URL links to find the resources or assignments supported by e-learning tools. However, participants did not ask their students to submit math work on learning management systems. Instead, students submitted their work directly to the e-learning tool or to the teacher in person.

4.2 Reasons for Using E-learning Tools

Participants used math e-learning tools for four reasons.

Providing Independent Practice in the Classroom. Some participants used the e-learning tools to give students independent math work, so that they could provide one-on-one instruction to other students. For example, Darcy set up *Khan Academy* accounts for every student so she could give them independent tasks to work on while she and her co-teacher provided extra support and attention to students who needed it most, including those with SLDs. As Darcy mentioned, "So we use *Khan Academy* with them. What we do is to have it set up in the class so I can give [students] assignments to work on. The special-ed teacher and I will walk around and help out. The kids with learning disabilities need a lot of support."

Motivating and Engaging Students. Participants observed that students with SLDs were more anxious and much less confident than their peers in solving math problems. As a result, these students would be reluctant to practice math exercises even if they had the ability to solve the problems. As Savannah suggested, "A lot of [students with SLDs] have this preconceived notion that they're not good at math or they don't like math." Therefore, participants used e-learning tools to make math more engaging and less intimidating.

The e-learning tool offered different sensory modalities to present content (e.g., in videos, in songs or using manipulatives).

Victor used websites that provided video solutions to problems because "[students] don't want to read [the solution] to see what they did wrong." Amy also used the video lessons on many drill-and-practice websites for her students, and she added that, "[videos] have to be short and to the point because, you know, [students with SLDs] just have trouble focusing for long periods of time." In addition to using videos, Amy engaged her students by playing the songs in *Flocabulary* that explained the meaning of math vocabulary. Participants said their students were more engaged in solving math puzzles when they could use their hands to solve puzzles or play around with the manipulatives. Their students told participants that the digital games were fun to play.

The digital game also engaged students in collaborating and competing as a group. When Jennifer used *Kahoot!* for test review, she found that, "[My students] compete against each other, and the kids love it."

Assessment. James and Savannah reported that they needed to write the Individualized Education Program (IEP) for students with SLDs. An IEP is a legal document that states important information about a student's unique strengths, needs, and current levels of performance, as well as the special education services, supports, and accommodations that the student is entitled to. Without using e-learning tools, James found it difficult to determine at which grade level his students were: "If I do a pretest with [a student] on seventh grade material, [I can determine that a student is] not doing well, but we don't really have a process to go back and say like, 'Oh, you're at a fourth grade level."' By using the *IXL Learning* diagnostic program, James was able to tell which exact level (e.g., which year and month) his students were at for specific math skills.

Tracking Student Performance. Participants reported that many students with SLDs needed more practice after class. Therefore, two participants (Savannah and Selena) would ask their students to work on math e-learning tools as homework. They chose e-learning tools over traditional homework formats so that they could more easily and efficiently track student performance. For example, Savannah sent students home with drills to do on *IXL Learning*. In this way, Savannah could keep track of "how much time they spend and what type of questions they were working on."

4.3 Challenges with Using E-Learning Tools

Participants described four critical challenges that they encountered when using math e-learning tools for students with SLDs.

Text-Intensive User Interfaces. Students with SLDs struggled with reading comprehension, which further affected their ability to solve math problems. Drill-and-practice websites required a lot of reading, with practice problems, hints, and solutions all presented in text form. This was "just like a string of steps and words" (Victor) to the students. They were intimidated and could not make sense of them. Victor found that his students randomly guessed the answers to questions because they did not want to read the words in the questions or in the hints.

To help students with difficulty decoding text, three participants (Savannah, Jennifer, and Marcus) used text-to-speech assistive technology. Although they found that students somewhat benefited from this, reading was only the first step of comprehending a problem. After decoding each word, students needed to determine which information in the problem was important and which math operations they needed to use.

When working with their students one-on-one, teachers read the problems together with their students and used annotations to help students decode the problem. For example, Lisa taught an annotation method called *CUBES* [19]. In this method, students annotated three key pieces of information: (1) **c**ircling math symbols like numbers; (2) **u**nderlining the sentence that asked the question; and (3) **b**oxing the math vocabulary that described the operations. By looking at these annotations, the student could **e**valuate what steps to take, and then **s**olve and check the answer. Using annotations was helpful for students with SLDs, because it could "slow [students] down to really know step-by-step what [the math operation] needs to be" (Carlo) and "help kids to see structural things" (Ian), which referred to the numbers needed in math operations and the math operations needed to produce the final answer. The e-learning tools provided little to no ability to annotate problems. For example, users could only highlight words in the math problem in yellow; they could not circle, underline, box, or draw arrows between the words.

Another common strategy participants employed when working with their students one-on-one was using manipulatives. Manipulatives are physical or virtual objects that students could directly interact with (in other words, manipulate) to understand and communicate math concepts. For example, Carol would translate word problems by using concrete, countable sticks to represent the numbers in the problem. Carol found that, "As [a student] was able to move [the sticks] around, he just caught [the concept]." However, only some of the games and none of the drill-and-practice website provided virtual manipulatives.

Participants also observed that students with SLDs had trouble typing their math work. Many websites required students to type their answers, which was cumbersome. Two participants (Lisa and Marcus) mentioned that many students with SLDs struggled with typing. Students also experienced challenges in figuring out how to communicate special math characters on the keyboard. As Ian said, "There are math characters like π, where's the π key?" Participants further suggested that it would be easier for these students if the e-learning tools allowed them to write or draw.

Insufficient Feedback about Student Performance. Participants reported that they kept track of students' performance and managed students' accounts through the teacher dashboards of the e-learning tools they used. These dashboards typically included summaries of students' performance on the practice problems: (1) aggregated data about the average number of questions a student solved, average time spent on practicing, etc., (2) individual students' problem solving records including their final answers, and (3) prediction of an individual student's math skills mastery level.

Although this information helped identify students who made mistakes, participants could not tell from their dashboards *why* their students made those mistakes, because there was no way for students to show their work or explain their final answers. For example, Carol wanted to know how her students annotated word problems in *Khan Academy*, but only their final answers were reported.

Additionally, dashboards provided no way for teachers to know if their students had been guessing randomly. Participants observed that repeated failure in solving math problems would frustrate students with SLDs, leading them to guess answers randomly. Many participants wished the e-learning tools would alert them when their students started to randomly guess.

Many e-learning tools, including both games and drill-and-practice websites, allowed students to repeatedly enter incorrect answers to the same question until they answered correctly. As a result, participants had to constantly monitor their students to determine whether they were actually using math reasoning and problem-solving skills, or just guessing randomly. For example, Carol had to sit with her students to make sure they were not guessing or getting frustrated from repeated mistakes. To address this problem, Lisa suggested that the e-learning tools show students messages that encourage them to ask teachers for help when they are unsure how to solve a problem or after they have repeatedly entered incorrect answers.

Inability to Adjust Difficulty Levels. Participants needed to work on more fundamental math skills with students with SLDs, reteaching many math skills that were at lower grade levels than the student's current grade. Three participants (Amy, Darcy, and Carol) emphasized the importance of adjusting difficulty levels of practice problems to adapt to the students' actual abilities.

However, participants could not lower the difficulty level of the e-learning tools, which frustrated the students. Carol remarked that "the kids throw iPads when they get frustrated or shut down." Similarly, Darcy found that when she couldn't find simpler problems on *Khan Academy* for students who needed to practice lower grade-level math, "[students] shut it down and they don't care."

Difficulties with Setup and Maintenance. Participants wanted to use e-learning tools in the classroom rather than assign their use as homework. As Selena said, "I mean homework is good because it's good practice but like is homework a lot of learning? No. I'm pushing a lot of learning in class. So, I want to know more about what kids are doing in class." However, they found it challenging to set up the tools for their students during the limited class time they had. For example, Selena mentioned that it took too long for students to log into the drill-and-practice websites because during her lessons, students only had 12 minutes or so to practice one math skill before they had to switch to another exercise. Marcus also mentioned that using computer-based tools was time consuming because of logging issues. Similarly, Savannah and Amy felt frustrated about not having enough time to set up games for their students. Amy explained: "I mean [students with SLDs] have so much skills that they need to work on, and I'm still supposed to teach the sixth-grade content with everyone else because we have to pass [the state test] at the same time." Participants were already stressed by the need to provide supplemental instruction to their students in addition to teaching the standard curriculum, and there was no time to spare for frustrating technical issues.

Other challenges participants faced included difficulties with the devices themselves. For example, Jennifer remarked, "We had tablets, but they all died. We had Kindles in our rooms [...] but they're like busted." Additionally, Selena explained that "There is a smaller set of 30 iPads, but people don't usually use it because it is hard to keep up. The apps need to be updated. And we have a tech guy, but he didn't do it." Participants did not receive support for resolving these various technical issues.

4.4 Needs and Challenges in Using Assistive Technology

As mentioned above, some participants helped their students set up and use text-to-speech to alleviate their reading challenges. Only one e-learning tool, *IXL Learning*, provided text-to-speech by default, so participants showed their students how to use built-in text-to-speech services on their devices. For example, Savannah enabled the text-to-speech accessibility feature on Google Chromebooks for her students. Similarly, Jennifer and Marcus told us that their students used the text-to-speech feature built into iOS.

In addition to text-to-speech, Darcy used closed captioning when her students watched video lessons on *Khan Academy*. She said that closed captioning was helpful because many of her students with SLDs had trouble with auditory processing. Closed captioning allowed them to use visual cues from the captions to support their understanding of the spoken content in the videos.

Participants were unaware of standalone assistive technologies in general. They were also less interested in using these technologies because they would have to add standalone assistive technology tools to a student's Individualized Education Program (IEP), a time-consuming bureaucratic hurdle. Savannah mentioned that "One student be like wanting something for [an assistive technology tool]. It took us like a whole year." Rather than having to go through the IEP process, participants preferred assistive technology that would be available by default.

Another reason to use incorporated assistive technology was to avoid stigma. Jennifer told us that, "Because it's middle school, a lot of [students] are embarrassed about [using a special tool or technology]. They don't want to be different in front of their peers." Savannah shared similar comments, "They're very conscious at this age about every little thing."

5 DISCUSSION

Our study answered our three research questions: (1) what math e-learning tools are teachers using, (2) why and how are teachers using these tools; and (3) how do teachers perceive the effectiveness of these tools for students with SLDs. To summarize, we found that each participant used at least one e-learning tool with their students, none of which were specifically designed for students with SLDs. Most participants used educational games. They primarily used these tools to let students practice math problems independently in the classroom and make the work more engaging. In other cases, three participants also used e-learning tools to assess their students' abilities and track their performance in math drill exercises after class. The effectiveness of the tools was hindered by usability problems experienced by both the teachers and the students. The text-intensive interfaces posed major barriers for the students who had difficulty processing language. Meanwhile, the teachers did not receive enough feedback about student performance to be able to adjust their teaching to the students' needs. Teachers were not able to adjust the difficulty level of math exercise on e-learning tools to accommodate students' wide range of ability-levels either. Additionally, mundane setup challenges of the hardware and software made the tools difficult to use in a classroom full of students. To alleviate some of the challenges that students faced, participants encouraged their students to use assistive technology like text-to-speech when using the math tools, but they faced challenges in getting and using the assistive technology.

As e-learning tools become widely used in classrooms, designers have an opportunity and responsibility to also make the e-learning environment more inclusive. Therefore, based on our findings, we discuss design implications for the creation of more inclusive and effective math e-learning tools.

5.1 Teacher-Oriented Design Implications

Our study suggested that teachers faced difficulties in using e-learning tools to teach. To help improve the usability of e-learning tools for teachers, we present five design implications, which range from short-term design suggestions to longer-term research directions.

Involve special education teachers in the design of e-learning tools. Existing research on math e-learning tools for students with SLDs [3, 29, 34, 43, 45, 46] rarely included teachers in the design and evaluation process. Our study revealed that teachers for students with SLDs wanted to use math e-learning tools in teaching. However, they faced critical challenges in using the e-learning tools, some of which were related to students' learning disabilities. Nor could they ascertain what confused and even frustrated their students during independent practice. Because students learned most when they studied with their teachers, if teachers could not adopt these e-learning tools in their teaching, students would be unlikely to benefit from the use of e-learning tools. Although recent work started to investigate how to help teachers adopt math e-learning tools [24, 25], it was limited to helping teachers in general education. Future work on designing e-learning tools should also involve special education teachers.

Use manipulatives to present math concepts. According to our study, teachers used manipulatives to explain complex and hard math problems (e.g., word problems) to students with SLDs. However, none of the existing software applications (e.g., web-based [1, 51, 60] and on the iOS system [11]) have combined manipulatives with math problems. The future design of e-learning tools should consider incorporating a set of commonly used manipulatives (e.g., blocks and fraction tiles) and allowing teachers to use the manipulatives to translate the math problem for their students.

Detect and report students' frustration to teachers. According to our study, teachers needed to keep students actively solving math problems on the e-learning tool. However, if the problem was too difficult, students would get frustrated and then pretend to be working on the e-learning tool. As Jennifer suggested, although her students found the games engaging, they did not ask for Jennifer's help when they got stuck on a math problem. Instead, "when students [got] frustrated, [they] started randomly clicking on [things] like 'options"' (Jennifer). One of the plausible reasons was that students might not be willing to let teachers know, possibly out of embarrassment, that they could not solve it like their classmates did. Researchers who studied people with other disabilities using digital tools also discovered this phenomenon [66]. In such situations, teachers needed to understand the root causes of students' frustration and challenges, even if the students did not verbalize them. Therefore, in the future, we should consider different ways to detect the students' frustration and report it to the teachers to help them better track the students' emotional status. One way to do that is by using AI to passively detect a student's frustration level by analyzing the pattern of students' inputs. Another way is to design friendly user-interfaces to encourage students to share their emotional status to their teachers.

Allow teachers to fine-tune difficulty levels. Based on our findings, teachers sometimes needed to teach students with SLDs math skills at lower grade levels. Prior work [20, 58] also found that differentiating math work for students with SLDs was an effective teaching strategy. However, teachers were not able to assign easier problems for their students on many math e-learning tools. Designers should give teachers the ability to adjust the difficulty levels of problems on the e-learning tool. Recently, learning analytics researchers developed AI algorithms [22, 30] to predict a suitable difficulty level for individual students. Researchers should explore using such algorithms to assist teachers in personalizing the e-learning tools.

Enable quick and easy set up for classroom use. Our study found that teachers wanted to provide independent exercises in class. However, teachers did not have enough time to set up the e-learning tools. According to our study, teachers often wasted too much time on helping students to log in. For example, they needed to help students who forgot their passwords. Our study also suggested that teachers needed to teach multiple types of math skills in one lesson. Thus, they needed to switch between the types of math skill training after every 10 minutes during the class. Based on our discussion, designers should design a classroom mode, which has a quick login process and allows teachers to pre-assign multiple 10-minute short math exercises in the students' e-learning tool account before the class begins.

5.2 Student-Oriented Design Implications

In our study, participants reported usability and emotional issues that students with SLDs experienced when using the math e-learning tools with and without assistive technology. To address these issues, we distil five design implications.

Provide a flexible annotation toolkit for word problems. According to our study, teachers taught students with SLDs to reduce mistakes in comprehending word problems by using annotation skills such as CUBES [19]. This was a very powerful skill because it allowed students to slow down in order to find all math symbols and math vocabulary and then see their relationships. While some of the e-learning tools, such as *Khan Academy*, had a simple annotation function, teachers found such features too limited. Designers should implement a flexible annotation toolkit that allows students to circle, underline, and box words, to draw arrows between words, and to highlight words in different colors.

Incorporate game design elements into drill-and-practice websites. Prior work [36] suggested that there were two distinct approaches for designing e-learning tools: drill-and-practice training and game-based training. Teachers found that these two types of tools had their own pros and cons for students with SLDs. On the one hand, game-based learning let students have fun when solving math problems by playing around with virtual manipulatives or working in groups. On the other hand, drill-and-practice websites could prepare students for their exams in solving traditional types of math problems. The current drill-and-practice websites did not incorporate any game design elements that our participants praised in the interviews. As Selena suggested, there were too many kinds of e-learning tools for her to manage. She wished she could have had one tool that helped students prepare for their traditional math tests in an enjoyable way. Therefore, future research should combine the advantages of drill-and-practice training and game-based training in one tool.

Design Augmented Reality (AR) manipulatives for math education. Our study showed that teachers used physical manipulatives frequently in teaching students with SLDs. While physical manipulatives are useful tools for students with SLDs, past research has highlighted that students depend on their teachers to learn how to use the manipulatives to solve math problems [39, 63]. Therefore, we propose using AR technology to enable students with SLDs to use physical manipulatives to solve math problems when their teachers are unavailable. Researchers have used AR technology to detect students' interactions with physical models and to teach students by combining digital information with the physical models [18, 49, 50]. For example, *Talkit* [50] enabled students with visual impairments to listen to information about components of a 3D printed model by interacting with it. Nevertheless, none of the AR-learning tools were designed for students with SLDs in math education. Future work may explore this approach to help students with SLDs use physical manipulatives to solve math problems.

Avoid using words that exacerbate students' preconceived notions of being bad at math. Our study found that students with SLDs were more anxious and much less confident than their peers in solving math problems. While we reviewed the design of websites and games, we found that some e-learning tools might deliver the unintended message to students that they are not good at math. For example, *IXL Learning* used "smart scores" (as shown in Figure 1 (Highlight 3)) to communicate the student's progress towards completion of the assignment. However, students who received low scores might internalize the message from the website that they were not smart. Therefore, we suggest that designers should carefully consider the words that are used on the dashboard and in the score-and-reward system.

Provide assistive technology in e-learning tools for general education. Shinohara et al. pointed out that social acceptability was important in designing assistive technology [52]. We learned from our study that middle school students felt embarrassed when they were using a stand-alone assistive technology tool because the tool revealed their disabilities in learning to their peers. This finding aligned with a Norwegian interview study with teenagers with visual impairments, [55]. The teenagers rejected assistive technology if the technology made them look less capable than their peers and wanted mainstream technology to include built-in accessibility. This collective evidence likely explains why stand-alone assistive technologies for digital math content [4, 16, 56] have not been broadly adopted. Therefore, we suggest that, whenever possible, assistive technology should be directly integrated into mainstream e-learning tools. For example, according to our study, students should have the option to listen to a word problem. We were glad to find that *IXL Learning* implemented a text-to-speech feature (only for K-3), but designers should follow this practice moving forward.

5.3 Limitations and Future Work

Our study was limited by our convenience sampling method and the relatively small sample size of 12 teachers. While such methods are standard in the field of human-computer interaction, we did not include perspectives from teachers in private schools and other school systems, nor did it represent teachers in most states in the US and other countries. Our study participants only came from three states in the US and taught public school students in fifth through eighth grade. That being said, we did reach saturation, finding a convergence of participants' opinions regarding use of recent math e-learning tools for students with SLDs. As with qualitative studies of this type, our findings should not be used to generalize patterns across all teachers or students, but rather to gain insight into current use patterns and shed light into future design and research directions. Researchers should interview more teachers from various locations (e.g., more US states and other countries) to provide more generalizable results.

Finally, in this study, we focused on teachers, who determine whether and how e-learning tools are used in practice. As seen from our findings, they also have keen insights into student experiences and pedagogical strategies. However, students are, of course, the primary users of e-learning tools and their first-hand experiences must be investigated. The parents of these students also observe and are often involved in after-school educational experiences and their perspectives merit consideration as well. As we move forward with our research, we plan to study the experiences of these two important stakeholder groups.

6 CONCLUSION

To understand the role of e-learning tools in supporting students with SLDs, we conducted semi-structured interviews with 12 US-based teachers who taught math to students with SLDs in grades 5-8. Our study revealed that recent math e-learning tools are not sufficiently effective or inclusive for the large number of students with SLDs. We have provided design implications and advocate future work on math e-learning tools to expand the target users from students to teachers-of-students. We hope that, by meeting both teachers' and students' needs, we can accelerate the adoption of math e-learning tools in the inclusive educational model. As a result, many more students can improve their math skills and engagement when they are using the math e-learning tools.

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