# An Intelligent Math E-Tutoring System for Students with Specific Learning Disabilities

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## ABSTRACT

Students with specific learning disabilities (SLDs) often experience negative emotions when solving math problems, which they have difficulty managing. This is one reason that current math e-learning tools, which elicit these negative emotions, are not effective for these students. We designed an intelligent math e-tutoring system that aims to reduce students' negative emotional behaviors. The system automatically detects possible negative emotional behaviors by analyzing gaze, inputs on the touchscreen, and response time. It then uses one of four intervention methods (e.g., hints or brain breaks) to prevent students from being upset. To form this design, we conducted a formative study with five teachers for students with SLDs. The teachers thought that the design of four intervention methods would help students with SLDs. Among the four intervention methods, providing brain breaks is new and particularly useful for the students. The teachers also suggested that the system should personalize the detection of negative emotional behaviors to help students who have more severe learning disabilities.

## 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, Intelligent Tutoring System

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## 1 INTRODUCTION AND BACKGROUND

Many math e-learning tools (e.g., Khan Academy [6], ST Math [8]) have been developed to provide independent math practice exercises. However, the commonly used math e-learning tools were not designed for students with specific learning disabilities (SLDs). As a result, our prior research study [15] showed that these students had difficulties in using math e-learning tools. For example, the students struggle with reading problems, hints, and solutions that are presented in text form. The students may also struggle when they have to solve a problem that is beyond their math abilities. As the students struggle in practicing math exercises, they build up feelings of frustration and irritation, which leads up to exhibiting negative emotional behaviors (e.g., randomly guessing answers or even damaging the e-learning device).

Recent research on math e-learning tools for students with SLDs [1, 5, 12] has mainly focused on helping students overcome text processing difficulty by designing interactable manipulatives that can represent text-based math problems. For example, Calcularis [5] challenges students to compare the size of two quantities by positioning two numbers on a number line from 0 to 100. French National Institute of Health and Medical Research designed two games, The Number Race [16] and Number Catcher [17], for the students. These games present Arabic, verbal, and visual representations of numbers together to help students compare which whole number is larger and which is smaller. However, if students struggle in using these e-learning tools, they can only receive two types of help: feedback for wrong answers or step-by-step hints, which were ineffective in preventing students from exhibiting negative emotional behaviors [15].

Therefore, we worked together with a teacher for students with SLDs to design an intelligent e-tutoring system (as shown in Figure 1) that reduces students' negative emotional behaviors. First, the teacher summarized her students' negative emotional behaviors: (1) staring at the problem without trying, (2) being distracted away from the screen, (3) tapping the screen agitatedly, and (4) showing negative facial expressions. Then, we studied previous work that had tried to automatically detect these behaviors, but we did not find a solution that we can use. Prior work [3, 9] has focused on using machine learning to detect negative facial expressions for students with special needs. Although these systems can detect obvious facial expressions (e.g., crying), they did poorly in distinguishing subtle facial expressions (e.g., mind-wandering compared

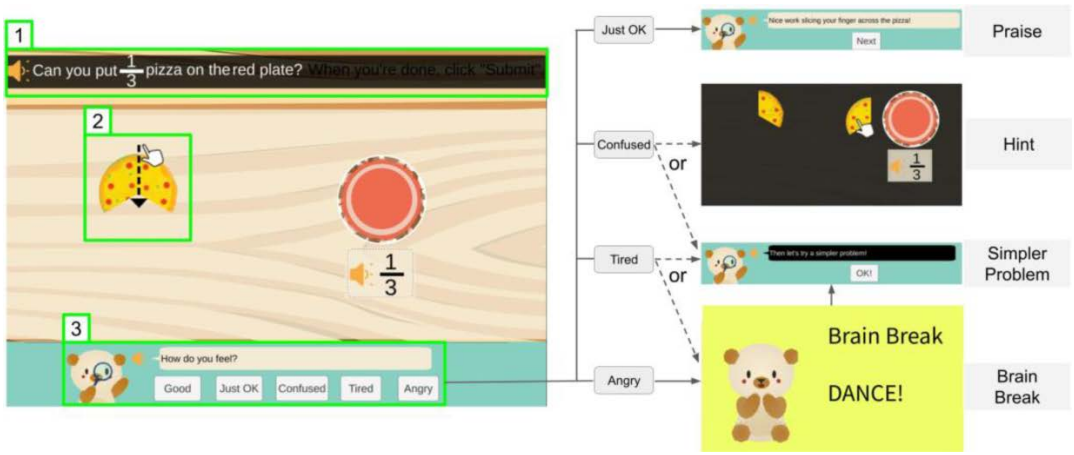


**Figure 1: An overview of the intelligent math e-tutoring system for students with SLDs. Zone 1 presents the problem in text form (and highlights the sentence that the system is reading). Zone 2 illustrates how students slice their finger across the pizza to make half pizza slices. Zone 3 presents the dialogue system that asks the students about their emotional state.**

with active thinking). So, these systems do not work for students with SLDs because the students already need help before they start crying [10].

Instead of using facial expression detection technology, analyzing gaze was found to be effective in detecting students who do not know how to solve a math problem [7]. Nonetheless, the existing studies of gaze analysis for learning [4, 7] did not consider students with SLDs. The teacher on our team suggested that analyzing gaze may also be useful for students with SLDs because it is possible for teachers to speculate whether the student is focusing on solving a problem. She also suggested that the system should combine gaze with other student behaviors to predict negative emotions, especially the behaviors that teachers have been observing. For example, teachers pay attention to students who do not attempt a problem for a long time or students who keep tapping the screen. The teachers in our prior research study [15] also mentioned these student behaviors when they talked about observing negative emotional behaviors. Therefore, our system combines eye-tracking data, inputs on the touchscreen, and response time to model the student behaviors.

After detecting a negative emotional behavior, our system confirms the student's emotional state through dialogue. Our system, like what teachers do, is speculating about the negative feelings of the students, so it is necessary to confirm with the students before deciding how to intervene.

The existing math e-learning tools for SLDs [1, 5, 12] only provide two intervention methods (i.e., hints or feedback for wrong answers), which is not effective in lightening a student's mood. So, we designed four intervention methods based on the teacher's tutoring experience. To prevent students from getting upset when they don't have the ability to solve the problem, our system provides hints or to switch to a simpler problem. To calm students who have been experiencing negative emotions (i.e., just ok, tired, or angry), our system sends personalized encouraging messages or provides brain breaks.

To form our design, we conducted a formative study with five special education teachers. The study was conducted virtually through video conferencing. During the study, we demonstrated our design prototype to the participants. We then asked teachers to provide feedback about the system design based on their teaching experience. The teachers thought it was necessary for e-learning tools to check in with students' emotional status. They reported that our design of e-tutoring intervention methods would effectively reduce the students' negative emotions. Teachers also suggested that we should personalize the detection of negative emotional behaviors for students who have more severe learning disabilities.

We present an intelligent e-tutoring system for students with SLDs that can reduce the students' negative emotional behaviors. We designed this system together with teachers for SLDs and conducted a formative study with teachers. In the future, we will conduct studies with students to get feedback from them. Our work will inspire e-learning tool designers and developers to design inclusive e-learning tools for students with SLDs.

## 2 SYSTEM DESIGN

### 2.1 System Prototype

We developed a math game prototype that uses the intelligent e-tutoring system to manage students' negative emotional behaviors. This prototype helps students practice fraction problems. Students practice fraction skills by manipulating pizza in two ways: cutting a pizza into different slices and moving the correct amount of pizza slices onto different plates (as shown in Figure 1, Highlight Zone 2).

The prototype runs in Windows 10 operating system on a Windows Surface Pro 7 tablet. Students use the touchscreen to play the game. A Tobii Eye Tracker 5 is stuck to the bottom of the tablet to detect where the student gazes at the screen. The game prototype processes the eye-gazing data stream to identify the in-game elements that the student gazes at, including texts, fraction numbers,

pizza slices, plates, and UI buttons. The game prototype also logs the running time and touchscreen inputs.

### 2.2 Triggering Intervention in Outstanding Behaviors

Many students with SLDs are reluctant to seek help when they were exhausted or agitated, but they show specific negative emotional behaviors [15]. Therefore, our system actively detects three types of negative emotional behaviors. First, students are distracted away from the screen if their eyes have not gazed on the screen for more than one minute. Second, students are touching the screen agitatedly if they repeatedly pressed the screen more than three times within 0.1 seconds. Third, students are hesitating to solve the puzzle if they have not touched the screen for more than two minutes and they have spent more than 70% of the time gazing at UI buttons and interactable but useless manipulatives. After detecting that a student is exhibiting one of the three behaviors, the system will confirm the student's emotional state through dialogue.

### 2.3 Interventions for Learning Difficulties

Students with SLDs build up frustration and irritation in using math e-learning tools for two main reasons [15]. One main reason is that students have to solve a math problem that is too difficult to solve. The other reason is that students cannot manage their negative emotions when they feel exhausted or angry.

To help students who do not know how to solve a problem, we designed two methods: providing hints or switching to a simpler problem. Providing hints is a traditional method to point the students in the direction of the correct answer. Nevertheless, if the students cannot comprehend the hint due to weak math abilities, switching to a simpler problem that matches their math ability is more useful than providing new hints.

Reducing the difficulty level of exercises, however, may not help students recover from exhaustion or anger. Many students with SLDs, due to cognitive differences, feel exhausted or angry quicker than general education students [2]. Inspired by the guidelines for tutoring students with SLDs [11, 13, 14], we designed two methods to help the students maintain or restore a good emotion: praising for a correct problem-solving behavior or providing brain breaks. The behavior-specific praise describes the approval of correct student inputs (e.g., "Nice work slicing your finger across the whole pizza! You made half pizza slices!"). The genuine approval is more effective in encouraging students with SLDs than generic encouragement (e.g., "you are doing awesome!") [14]. Nevertheless, students would need brain breaks instead of encouragement when they reach the tipping point of negative emotions [13]. A brain break is a break from the current learning task that students are working on. Students can rest their eyes or take a physical exercise during a brain break. Therefore, we designed a kind of brain break that temporarily hides all e-learning interfaces and guides students to play a kinesthetic game (i.e., a body dancing game that gets the student moving and grooving).

We mapped the e-tutoring interventions in exercises to three negative emotional states (just OK, tired, and angry). If the students feel just ok, they will receive behavior-specific praise. If the students feel confused, they may choose to get a hint or to try a simpler problem. If the students feel tired, they can try a simpler problem or take a brain break. If the students feel angry, they will take a brain break then continue to a simpler problem.

## 3 FORMATIVE STUDY: TEACHER FEEDBACK

To form our design, we conducted a formative study with teachers for students with SLDs (3 females, 2 males, between 0.5 and 7 years of experience in teaching students with SLDs in grades 3-6). We started from interviewing teachers because they have been designing and practicing interventions in tutoring the students. We anticipated that teachers would be able to use their teaching experience to offer valuate insights in our current design. During the study, we demonstrated our prototype to the participants. We asked them to give feedback on the design of e-tutoring intervention methods and the specifications to detect negative emotional behaviors. We screen recorded then transcribed all interviews. We coded the transcriptions and found two main themes that were summarized from the teacher feedback.

All five teachers mentioned that e-learning tools should intervene in exercises when the student is experiencing negative emotions. One teacher explained, "I know how important the emotional status affects these students' ability to learn. Like, if they are frustrated, or if they are stressed, their thinking brain is not [turned] on." They liked the design of our e-tutoring intervention methods, especially providing brain breaks for students with SLDs. One teacher said, "there are kids who might be on a computer for a little while and they might get, you know, overwhelmed or zoned-out [. . .] For example, I have a kid who works for like 10 or 15 minutes and then gets to break. That's part of their IEP [Individualized Education Program]." Therefore, our design provides an important accommodation for the students as they practice math exercises independently.

Three teachers commented that the detection of negative emotional behaviors may not work for students who have more severe learning disabilities. These students may take significantly longer time to decode information and comprehend the problem. As a result, the current system may initiate chats with these students too early, and thus interrupt the students' thinking. To detect whether students are struggling, teachers had been providing the students both non-math exercises and math exercises to compare the differences of student performance (e.g., response time and body gestures). Teachers will intervene when the students behave much slower or agitatedly in math exercises. However, there is no known way to automate this detection approach.

## 4 CONCLUSION AND FUTURE WORK

We presented the design of an intelligent math e-tutoring system for students with SLDs. The system provides four types of intervention methods to reduce negative emotional behaviors. It automatically intervenes in exercises by detecting students' negative emotional behaviors then asking the students about their emotional state to eventually determine which intervention method to use. Teachers in the formative study mentioned that the system meets the needs of students with SLDs. They also suggested that the detection of negative emotional behaviors can be personalized to help students with more severe learning disabilities. In the future, we will explore

the personalization of negative emotional behaviors detection. We will also recruit students with SLDs to try our prototype and to provide feedback. Our work provides a starting point for e-learning tool designers and developers to leverage our design to develop e-tutoring systems for students with SLDs.

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