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

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 interactivable 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...
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 stu-
dents 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. Stu-
dents can rest their eyes or take a physical exercise during a brain
break. Therefore, we designed a kind of brain break that temporar-
ily 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 valuable 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 interven-
tion 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 inter-
vene in exercises when the student is experiencing negative emo-
tions. One teacher explained, “I know how important the emotional
status affects these students’ ability to learn. Like, if they are frus-
trated, or if they are stressed, their thinking brain is not [turned]
on.” They liked the design of our e-tutoring intervention meth-
ods, 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 emo-
tional 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 re-
sult, 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 diff-
ences of student performance (e.g., response time and body ges-
tures). 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.

ACKNOWLEDGMENTS
The authors would like to thank Bingxin Weng for designing the graphics of the virtual tutor. The authors would also like to thank all teacher participants for providing valuable comments and suggestions.

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