Designing an AI Math Tutor for Children with Dyslexia, Dysgraphia, and Dyscalculia

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Abstract

Students who have conditions such as dyslexia, dyscalculia and dysgraphia tend to struggle with math significantly more than their peers. This study investigated how effective an AI-based math tutor, which has been shown to work well with students who do not have these conditions, is at teaching students who did. A website was designed which allows students to chat with the AI, which was named Mathias and uses GPT from OpenAI, as well as to move through pre-set topics to learn specific skills. This website was specifically targeted towards students who have dyslexia, dysgraphia, and dyscalculia, including features such as audio and images, both of which are generated using AI, as well as stylistic features geared towards students with dyslexia. The presentation and content of the responses are also geared towards students who have these conditions. To evaluate how effective Mathias is at what it is intended for, several students took part in an experiment to evaluate their improvement after using the website and after more traditional teaching. During this experiment, students improved more on average after using the website. This was especially true for the students with dyslexia, who saw higher increases after using the website than the students without dyslexia. This indicates that AI-based tutors can be very effective for these students, and more development of these programs could be very beneficial. However, further experimentation is needed to determine how accurate the results of this experiment were, as well as how to improve the AI to make it more effective.

Introduction

Dyslexia is a neurobiological specific learning disability that causes people to struggle with word recognition, as well as spelling and decoding of words.[1] Dyscalculia is also a specific learning disability and leads to extreme difficulties with arithmetic, including in people who have ordinary working memory and intelligence.[2] Dysgraphia is a difficulty in gaining skills involving writing, which could include spelling or producing readable handwriting.[3]

People who have dyscalculia can struggle significantly with a variety of mathematical topics, ranging from counting to telling time, which negatively affects both performance in school and daily life.[4] There are also significantly higher rates of dyscalculia among people with reading disorders such as dyslexia, and students with dyslexia generally perform worse than others on math work.[5] Students who have dysgraphia or other writing disabilities may also struggle with math work because of the writing involved in solving math problems.[6]

Besides poor math performance, there has been shown to be a higher rate of math anxiety in students with dyscalculia[7] and in students from certain grade levels with dyslexia.[8] This can lead to students avoiding math and can further harm performance in the subject.[9]

While determining how common dyslexia is can be difficult, estimates tend to land anywhere between under 5% and 20%.[1] Between 5 and 7 percent of students have been estimated to have dyscalculia,[2] while 7 to 15 percent of students are estimated to have dysgraphia.[3]

Using AI to provide math tutoring has been researched before, with one study in Ghana finding that students who used an AI math tutor had significant increases in their scores when compared to students who did not use one.[10] In order to investigate the effects of an AI math tutor on students with dyslexia, dysgraphia and dyscalculia, a website was designed that allowed students to chat with an AI, which was named Mathias. On the website students can either work through preset topics and prompts or give Mathias their own questions.

The AI model used to create Mathias is the GPT-4o model from OpenAI, with the final prompts that the AI receives edited so that the response is geared towards students who have dyslexia, dyscalculia, or dysgraphia. This includes instructing the model to split every topic into a series of small steps and to interact with the user at each step, asking them questions to evaluate their understanding and not moving on until the user understands the current step. The design of the website is also intended to make reading and understanding the text easier for dyslexic students, and other features such as images and text to speech were included as well.

In order to evaluate the effectiveness of Mathias compared to typical teaching methods, a group of students were given a paper containing twelve questions focusing on the topic of fractions, mixed numbers and decimals, a topic that students with math disorders tend to struggle with.[11]

Their performance on this paper established a baseline for the students in the topic, and they then went through either the AI instruction on the topic or were taught in a classroom style. They were then re-evaluated to determine improvement with a paper in which half of the questions were the same as the first and the other half were changed. Finally, students went through the type of instruction they had not had before and were evaluated for the final time. In the end, the results showed promising signs of improvement, particularly among the students with dyslexia. However, due to a limited sample size and other factors, the accuracy of these results is questionable.

Methods

In this section, the design and features of the website will be covered in more detail, including the programming and algorithms behind it. The method for the experiment will also be expanded upon and information about the participants in the experiment will be presented.

Website

The frontend of the website was built with HTML, CSS and JavaScript while the backend was built with Python using Flask. There are two main parts, with the first being a topics page which contains a variety of mathematical topics intended for elementary and middle school aged children. The exact list is:

- Fractions, Mixed Numbers, and Decimals
- Times Tables
- Long Multiplication and Division
- Money
- Time
- Counting
- Simple Equations

The other main part is a chat feature which allows students to submit their own questions to Mathias. This provides students with a text box to type in their question, as well as a submit button. When clicked, this button will send a POST request, sending the results of the text box to the server. It will then reload the page, but beforehand Python code will run which generates a response from the AI using the initial prompt of the conversation, the most recent prompt, and the previous response from the AI. The initial prompt and previous response are given to the AI to ensure the answer carries on from what it is already discussing, improving the flow of the conversation. All AI features used in the website are generated using the OpenAI Python API.

Once the response is generated, the prompt and response are added to a list which contains a transcript of the conversation to that point. This list is then given to the HTML when the template is rendered, and the HTML displays it so that the user can see the new response and the rest of the conversation. Because the AI needs time to generate a response, the site can take a while to reload the page after a form is submitted.

All text from Mathias is presented in size 14 Arial font with dark grey instead of black for the text and light gray instead of white for the background. There is extra spacing between letters and lines. These styles were chosen based on recommendations by the British Dyslexia Association.[12]

Because students with dyslexia and dyscalculia tend to do well when being taught using multiple senses[13], both audio and images are generated to go along with the text. The goal of including images was so that students could better visualize concepts or examples, especially as one of the instructions to the AI was to include real-world examples. However, because AI-generated images tend to struggle with text or numbers, the image generator was instructed not to add these to the pictures. Despite this, it still did so very often, and when it did the text or math equations tended to be nonsensical. Because of this, participants were told before they started not to pay close attention to any text or numbers in the images.

While images are generated with the text, the audio is generated after the audio button is clicked. It does this by running a JavaScript function every time the button is clicked which takes in the text it needs to generate audio for. It then uses a link to a Python function which generates and stores the audio. When this is done, the JavaScript plays the saved audio. Because the audio takes time to generate, this can also be a bit slow and for long texts such as AI responses it may take a minute before playing.

When users select a topic from the topics page, the communication with Mathias works the same as in the chat except the initial prompt is given to the AI prior to the start of the session and is not displayed. Each prompt in the topic represents a specific subtopic, and to move on to the next subtopic there is an additional ‘Next’ button which brings the user to the next page or, if the topic is over, back to the topics page. In both the chat and specific topics there is also a ‘Reset’ button which allows the user to restart the conversation. This is useful if Mathias is moving too quickly, or the user does not understand what is being taught and would like to be given it again.

Experiment

In order to evaluate where participants were at before any instruction, a paper containing twelve questions each corresponding to one of the twelve subtopics of the ‘Fractions, Mixed Numbers and Decimals’ topic was created. Two more papers were then created which each had 6 questions changed from the previous papers and 6 the same. This was done because if all the questions were changed, it is possible that any changes in performance were due to easier or harder questions rather than increased understanding by the student. On the other hand, keeping all the questions the same could lead to better performance simply because the student gains experience with the question and is given multiple attempts. By changing some and keeping others the same, these two circumstances can be evaluated separately to better determine whether any increases or decreases in score are legitimate.

Due to difficulties in finding students to take part in the experiment, only four students were found: two who had dyslexia, and two who did not have any of the conditions (these

students allowed a comparison of whether the students who had dyslexia improved more or less than the students who did not). Unfortunately, no students with dyscalculia or dysgraphia were found for the experiment, and further experimentation is necessary to determine the effect of the website on people who have those two conditions.

After taking the first paper, two of the students were given the website and worked their way through the topic. The other two were taught in a classroom style, which involved them sitting down and being taught about the various subjects by a human instructor using an electronic whiteboard. They were all then retested with the second paper, before undergoing the other type of teaching. Finally, they were tested a third time.

Results

Because there were only four students, the results of each individual student will be given, as well as an average. The students will be referred to as S1, S2, S3 and S4. S1 does not have dyslexia and used the website the first time, S2 does not have dyslexia and was taught in a classroom style the first time, S3 has dyslexia and used the website the first time, and S4 has dyslexia and was taught in a classroom style the first time. The table below shows how much they improved for constant questions, varied questions and overall, as well as averages for after they used the website and after they were taught in a classroom style:

Table 1. *Difference in student assessment scores before and after learning via AI instruction versus classroom-style teaching*

Students	After Website			After Classroom		
	Constant	Varied	Total	Constant	Varied	Total
S1	+ 1	0	+ 1	0	0	0
S2	0	- 1	- 1	+ 1	0	+ 1
S3	+ 1	+ 2	+ 3	- 1	- 2	- 3
S4	0	+ 1	+ 1	0	- 1	- 1

Average (Mean)	+ 0.5	+ 0.5	+ 1	0	- 0.75	- 0.75

For the two students with dyslexia, the average improvement after working on the website was +2 with +0.5 for the constant questions and +1.5 for the varied questions. After the classroom-style teaching, the students with dyslexia had an average change of -0.5 on the constant questions, -1.5 on the varied questions, and -2 overall. On the other hand, the two students without dyslexia had a net improvement of 0 after working on the website with +0.5 for the constant questions and -0.5 for the varied questions. After the classroom-style teaching, the students without dyslexia had an average change of +0.5 on the constant questions, 0 on the varied questions, and +0.5 overall.

Discussion

The study shows a slight overall improvement of +1 after the students use the website. This is evenly split into +0.5 between the varied questions and constant questions, indicating that the increase was due to more than just repetition or questions they found more easily. On the other hand, students faced an average drop of 0.75 points after classroom-style teaching, but because all of the drop was in the varied questions it is possible students simply struggled more with the new questions and numbers. However, for both results, the change is very small, and it is difficult to conclusively say whether or not students improved.

One interesting result is that students with dyslexia who used the website had an average gain of +2 as opposed to 0 for students without dyslexia. This could indicate that the website, which was designed specifically for students with conditions like dyslexia, is more effective at teaching them than at teaching students without any conditions. However, the sample size is small and there is wide variance between students in each subgroup: while S3 has by far the highest improvement after the website with +3, S4 (the other student with dyslexia) only increased +1, the same as S1 (who did not have dyslexia). In order to determine the difference between the groups more accurately, further testing involving a greater sample of students is necessary.

Although some conclusions can be drawn from this study, these results may be inaccurate due to the limitations of the study. The primary issue is that only four participants were found, and only two with dyslexia, not nearly enough to provide a picture of the entire population. There were also no participants with dyscalculia or dysgraphia, a key part of the target audience for the website which has remained untested. Both of these problems could be solved in future experiments which involve more subjects and a wider range of conditions. The

website was also only tested using the fractions, mixed numbers, and decimals topic, and other topics may be more or less effective. This is an issue which can be solved in future experiments

Another problem with the experiment is that the ages of the students are not consistent, with S3 being several years younger than the others. This led to rapidly different baselines, which can then affect how much students improve. The method of evaluating the students, with a twelve-question paper, may also be insufficient in testing the students' abilities in the subject. Different methods of evaluation should be considered in any future experimentation. The final issue with the experiment is that the attention and effort levels of the participants, particularly towards the end of the hours-long experiment, is unknown. This can affect the final results, especially in such a small sample size.

Conclusion

In conclusion, conditions like dyslexia, dyscalculia and dysgraphia can harm the maths skills of students and impact their long-term prospects. Because of this, it is important to find innovative ways to aid the learning of people with these conditions. AI tutors have been shown to be effective in the past, and finding ways to adapt these tutors to the needs of these students has potential to significantly improve their performance. In this experiment, promising results were seen with improvement by students, and particularly by students with dyslexia, after use of the tutor. However, due to the extremely small sample size and other issues with the experiment, it is impossible to draw definite conclusions about the AI's effectiveness. There is also no data on how students with dyscalculia or dysgraphia respond to the AI.

In the future, experimentation involving students from all three target groups is necessary, and this should be done with a large number of participants. New ways to evaluate student performance should also be considered in order to ensure an accurate record of improvement. Other AI models should be created to evaluate whether they are more effective than the one created in this study, and research should be done into how to increase the effectiveness of the AI and how best to supplement student learning using AI. Other topics besides the one used in this study should also be evaluated to see which subjects the AI can be most useful for.

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