

Mathematics Learning Technologies for Students with Visual Impairments: A Literature Review



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Resume of the Presenter

- Abhishek Jariwala is a Ph.D. student under Dr. Richard Chapman and Dr. Daniela Marghitu in Computer Science and Software Engineering at Auburn University.
- Abhishek is assistive technology enthusiast and researcher with 3+ years of experience working with visually impaired students focusing on improving math education for high school students.





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Outline

- Introduction of the Literature Study
- Purpose
- Methodology
 - Search strategy
 - Inclusion/Exclusion Criteria
- Results
- Discussion



Literature Review: Introduction

- High-school mathematics acts as a baseline for students to learn and persevere in social and professional worlds.
- Students with Visual Impairment (VI) face many challenges in learning mathematics due to its visual nature.
- This disadvantage leads to a significant knowledge gap between students with visual impairment and students without disabilities.
- In this literature review, we collected, analyzed, and critiqued mathematics learning technologies for VI students developed between January 2010 and December 2020.



Literature Review: Purpose

- Investigate the use of auditory methods in digital mathematics learning.
- This literature review is based on the following research questions:
 - What are the reported accessibility approaches and outcomes in existing mathematics learning apps?
 - What are the domains, interactive mechanisms, and accessibility features of these apps?
 - What are the contextual settings in which these applications are scrutinized?



Literature Review: Methodology

A. Search Strategy:

Database and Search Engine	Link
ERIC	https://eric.ed.gov
EBSCO Information Services	https://www.ebscohost.com
ProQuest	http://www.proquest.com
Wiley Online Library	http://onlinelibrary.wiley.com
JSTOR	http://www.jstor.org
ACM Digital Library	http://dl.acm.org
Science Direct	http://www.sciencedirect.com
Google Scholar	https://scholar.google.com/

Table 1. List of databases and search engines



Literature Review: Methodology

B. Inclusion/Exclusion Criteria:

Inclusion Criteria	Exclusion Criteria
Published in English	Publication is a review/thesis/summary
Developed for VI students	For students with multiple disabilities
Published between 2010 and 2020	Research is in early stages
Investigates approaches for digital math education	

Table 2. Inclusion/Exclusion criteria



Literature Review: Methodology

Inclusion/Exclusion Criteria:

- The search operations on databases and search engines resulted in **153** publications.
- **134** papers were able to pass through all inclusion criteria.
- **126** publications after removing duplicate publications.
- **57** papers after applying inclusion criteria on methodology
- **10** publications after expert reading and only including studies for digital/math learning.

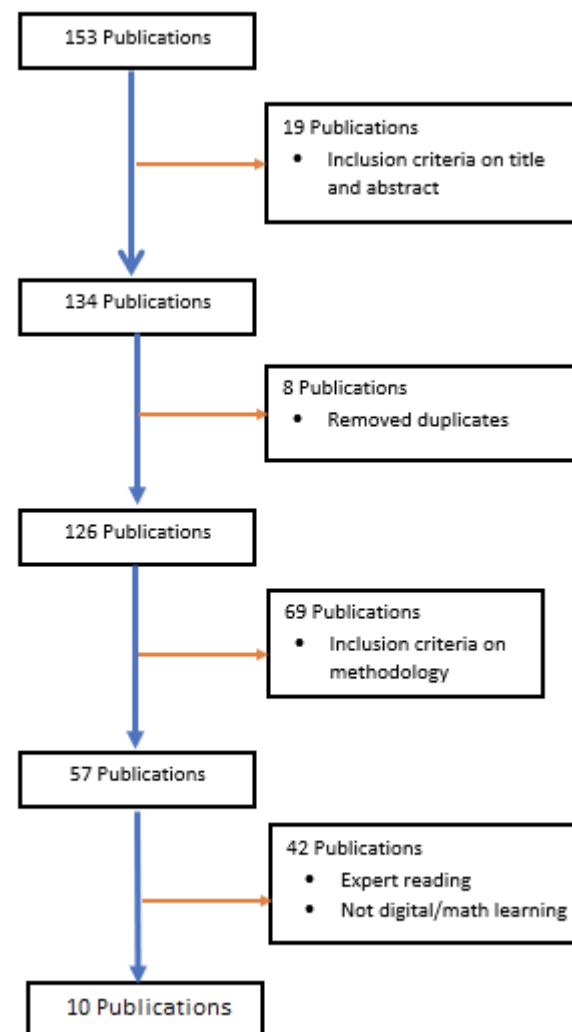


TABLE III: LIST OF APPLICATIONS IN INCLUDED STUDY

#	Title	Study Subdomain	Study Objectives	Interaction Approach	Study Results
LR1	A Pilot Study of a Self-voicing Computer Program for Prealgebra Math Problems	Prealgebra	To field-test the accessibility of a self-voicing computer program, AnimalWatch-VI-Beta, with 14 VI students working with prealgebra math problems.	<ul style="list-style-type: none"> – The program provided the participants with audio hints for word problems. – Participants interacted with the program with keyboard keys. 	<ul style="list-style-type: none"> – Although the study was not designed to evaluate the participants' algebra skills, the participants used audio hints to efficiently solve easy and medium difficulty problems. – The results showed that the audio materials could be useful resources for students with VI in learning math.
LR2	Accessing Algebra via MathSpeak: Understanding the Potential and Pitfalls for Students with Visual Impairments	Digital access to math formulae	Three VI high school students participated in this study to evaluate the impact of eText player ReadHear to access and understand algebraic expressions.	<ul style="list-style-type: none"> – The eText player provided algebraic expressions in speech format. 	<ul style="list-style-type: none"> – Finding suggests that even though the method was different from the traditional approach, students successfully used the technology to access algebraic expressions.
LR3	Math Melodies: Supporting Visually Impaired Primary School Students in Learning Math	Basic math operations	An iPad application to teach basic mathematics to primary school students. Two sighted and three blind primary school students participated in the study.	<ul style="list-style-type: none"> – The application is accessible for blind students through a screen-reader and a simplified on-screen keyboard to answer questions. 	<ul style="list-style-type: none"> – Participants were able to interact with the system and found the application accessible and entertaining. – The application enables exploring audio-visual elements on a touchscreen and provides feedback to keep VI students engaged and entertained. The iPad application has been downloaded over 14000 times.
LR4	AudioFunctions.Web: Multimodal Exploration of Mathematical Function Graphs	Exploring math functions graph	Thirteen VI participants engaged in this research study to investigate the use of sonification, earcons, and speech synthesis to explore mathematical functions graphs.	<ul style="list-style-type: none"> – AudioFunctions.web provides verbal or musical earcons on graph exploration. Additional graph information is provided through verbal messages when requested. – Users may interact with the application using a keyboard, mouse, touchscreen, or touchpad. The application is available on all browsers, mobile devices, and PCs. 	<ul style="list-style-type: none"> – The participants managed to proficiently use the system and explore the presented graphs. – Six students preferred a touchscreen and five students appreciated the touchpad/mouse and touchscreen interaction equally.
LR5	An interactive math braille learning application to assist blind students in Bangladesh	Braille	A mobile application to teach VI students math Braille and help solve mathematical calculations. 20 VI participants provided feedback in improving the functionality of the mobile application.	<ul style="list-style-type: none"> – Participants can interact with the application through a touch screen and the application provides audio and vibrational feedback to help the user make a decision. 	<ul style="list-style-type: none"> – The application evaluation by the teachers, experts, and students suggests that voice and vibrational feedback can assist students to learn Nemeth code.

TABLE III: (Cont.) LIST OF APPLICATIONS IN INCLUDED STUDY

#	Title	Study Subdomain	Study Objectives	Interaction Approach	Study Results
LR6	Adaptable Accessibility Features for Mathematics on the Web	Digital access to math formulae	This study enabled the rendering of math formulae on the web. The work is implemented in the MathJax library with new personalizing features. This package also offers accessibility features for speech and tactile outputs.	<ul style="list-style-type: none"> – MathJax accessibility features are mainly aimed at supporting users with reading disorders. MathJax provides speech and tactile output to support screen-reader users and provides visual aids to maximize accessibility on the web. 	<ul style="list-style-type: none"> – MathJax provides aural rendering for mathematical expression, which can be generated on the fly when running in the web browser or pre-computed by the author. – MathJax offers various techniques such as highlighting, contrast, formula coloring, magnification to increase the accessibility of math formulae on the web.
LR7	Axessibility: A LaTeX Package for Mathematical Formulae Accessibility in PDF Documents	Digital access to math formulae	A LaTeX package to provide math formulae accessibility in PDF documents. Four VI students participated in the evaluation of this study using Acrobat DC PDF reader.	<ul style="list-style-type: none"> – The package enables the creation of accessible PDF documents by inserting hidden replacement text for maths formulae using <i>ActualText</i> PDF attribute, making it visible to screen readers and braille bars. 	<ul style="list-style-type: none"> – The participants correctly read formulae inside PDF documents produced using Axessibility.
LR8	Web-ALAP: A Web-Based LaTeX Editor for Blind Individuals	LaTeX editor	Web-ALAP is a web-based LaTeX editor that provides speech-based prompts and automatic narration of the error messages. It also offers a "Math Mode" that offers a natural language description of the mathematical content within the document.	<ul style="list-style-type: none"> – Web-ALAP offers a comprehensive set of keyboard shortcut keys to maximize accessibility and easier navigation for math equations. – A web-based LaTeX editor is equipped with accessible debugging features for real-time auditory feedback. 	<ul style="list-style-type: none"> – The user testing with ten VI students showed that the users appreciated the Math Mode of the web application. All participants recognized the importance of being informed through audio feedback.
LR9	MathSpeak: a non-ambiguous language for audio rendering of MathML	Digital access to math formulae	To introduce a new method to provide audio-rendering of complex mathematical formulae provided in MathML.	<ul style="list-style-type: none"> – Non-ambiguous speech representation of math formulae. 	<ul style="list-style-type: none"> – While presenting mathematical terms in non-visual format, it may lead to multiple interpretations. – With MathSpeak technology, authors enabled the rapid translation of STEM material into MathML format and eventually into a non-ambiguous speech format.
LR10	Improving accessibility to mathematical formulas: the Wikipedia Math Accessor	Digital access to math formulae	To improve the accessibility of mathematical formulae by providing natural language processing descriptions of more than 420,000 formulae from Wikipedia's repository.	<ul style="list-style-type: none"> – Graphical representation of mathematical formulae. 	<ul style="list-style-type: none"> – This study introduced the MathAcc, an assistive technology designed to help VI students gain access to the graphical representations of complex mathematical formulae published on Wikipedia.



Literature Review: Discussion

1. What are the reported accessibility approaches and outcomes in existing mathematics learning apps?

- The research study mentioned in the literature review employed a variety of accessible methods.
- The main objectives of the studies include 'the alternate delivery method' and 'the effectiveness of the technology.'
- **Nine publications stated that students appreciated the audio representation of mathematical formulae.**





Literature Review: Discussion

2. What are the domains, interactive mechanisms, and accessibility features of these apps?

- Three studies investigated the effectiveness of a digital platform to teach mathematics to students with VI.
- One study introduced the use of sonification, earcons, and speech synthesis to explore mathematical function graphs.
- **Auditory methods were the most frequently applied technology in the included studies.**





Literature Review: Discussion

3. What are the contextual settings in which these applications are scrutinized?

- The VI participants evaluated most of the included studies using different interaction methods varying from the keyboard keys, mouse, trackpad, and touchpad.
- **All research studies achieved their desired results.**





Conclusion

- This paper presented 10 assistive technologies developed between 2010 and 2020 that focused on improving mathematics accessibility and offered a new way to teach mathematics to students with VI.
- After a systematic review of the focus of studies, the subdomain, and the context in which the studies took place, we can conclude that digital learning with auditory and tactile methods can improve mathematics education for VI students.

APPENDIX A. LIST OF STUDIES

Study ID	Citations
LR1	C. R. Beal, L. P. Rosenblum, and D. W. Smith, "A pilot study of a self-voicing computer program for prealgebra math problems," <i>Journal of Visual Impairment and Blindness</i> , vol. 105, no. 3, pp. 157–169, 2011.
LR2	E. C. Bouck, N. K. Meyer, G. S. Joshi, and D. Schleppenbach, "Accessing algebra via mathspeak™: Understanding the potential and pitfalls for students with visual impairments," <i>Journal of Special Education Technology</i> , vol. 28, no. 1, pp. 49–63, 2013.
LR3	D. Ahmetovic, V. Alampi, C. Bernareggi, A. Gerino, and S. Mascetti, "Math melodies: Supporting visually impaired primary school students in learning math," in <i>Proceedings of the 14th Web for All Conference on The Future of Accessible Work</i> , 2017, pp. 1–2.
LR4	D. Ahmetovic, C. Bernareggi, J. Guerreiro, S. Mascetti, and A. Capietto, "Audiofunctions.web: Multimodal exploration of mathematical function graphs," in <i>Proceedings of the 16th Web For All 2019 Personalization - Personalizing the Web</i> , 2019, pp. 1–10.
LR5	L. Nahar, R. Sulaiman, and A. Jaafar, "An interactive math braille learning application to assist blind students in Bangladesh," <i>Assistive Technology</i> , pp. 1–13, 2020.
LR6	D. Cervone and V. Sorge, "Adaptable accessibility features for mathematics on the web," in <i>Proceedings of the 16th Web For All 2019 Personalization - Personalizing the Web</i> , 2019, pp. 1–4.
LR7	D. Ahmetovic, T. Armano, C. Bernareggi, M. Berra, A. Capietto, S. Coriasco, N. Murru, A. Ruighi, and E. Taranto, "Axessibility: A latexpackage for mathematical formulae accessibility in pdf documents," in <i>Proceedings of the 20th International ACM SIGACCESS Conference on Computers and Accessibility</i> , 2018, pp. 352–354.
LR8	S. Arooj, S. Zulfiqar, M. Qasim Hunain, S. Shahid, and A. Karim, "Web-alap: A web-based latex editor for blind individuals," in <i>The 22nd International ACM SIGACCESS Conference on Computers and Accessibility</i> , 2020, pp. 1–6.
LR9	W. Sheikh, D. Schleppenbach, and D. Leas, "Mathspeak: a non-ambiguous language for audio rendering of mathml," <i>International Journal of Learning Technology</i> , vol. 13, no. 1, pp. 3–25, 2018.
LR10	J. Fuentes Sepulveda and L. Ferres, "Improving accessibility to mathematical formulas: the wikipedia math accessor," <i>New Review of Hyper-media and Multimedia</i> , vol. 18, no. 3, pp. 183–204, 2012.