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StemA11y: An AI-Driven Mobile System for Non-Visual and Multisensory Access to STEM Content

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Blind and low-vision (BLV) learners encounter significant barriers in accessing STEM content, as traditional accommodations, such as braille transcription and tactile graphics, are time-consuming and labor-intensive, often resulting in delays that impede timely engagement with STEM content. Responding to this accessibility gap, we present StemA11y, an AI-powered iOS application that automatically converts STEM materials into accessible formats and delivers them via speech, audio cues, haptics, and VoiceOver support. We evaluated StemA11y with 11 BLV participants across two content types–math worksheets and adapted SAT papers. Our results revealed that System Usability Scale (SUS) scores exceeded the industry benchmark of 68 for both math worksheets (M = 75.2) and SAT papers (M = 83.2). Technology Acceptance Model (TAM) ratings indicated high perceived ease of use, ease of learning, and overall satisfaction. Further, qualitative feedback demonstrated the importance of customizable content verbosity and flexible navigation. Drawing on these insights, we reconsider STEM accessibility for BLV learners and discuss design considerations for developing multisensory AI-powered mobile systems to improve STEM accessibility, including customizable content verbosity, strategies to reduce redundant audio cues, and enhanced support for flexible navigation.

Blind and Low-Vision Learners; Inclusive STEM Education; AI for Social Good; Multisensory Interfaces; Non-Visual Interaction; Assistive Technology; Mobile HCI; Human-Centered AI; Tactile and Graphic Accessibility

1. INTRODUCTION

STEM education often relies on visual learning materials, such as mathematical equations, diagrams, and charts, to convey complex concepts and support problem-solving. Yet, despite their pedagogical value, these visual materials often remain inaccessible to blind and low-vision (BLV) students [35, 22, 11, 29]. To address this challenge, teachers of visually impaired students provide significant efforts in adapting instructional content to support their students' access needs [32, 6]. However, in addition to in-class accommodations, BLV students require accessible learning materials, such as accessible digital documents, braille, and tactile graphics, to engage effectively with instructional content [1, 4, 12]. Creating such accessible materials manually is often a labor-intensive and time-consuming process [20, 7, 19, 33]. For instance, braille textbooks are frequently delivered incrementally (e.g., one chapter at a time) as transcription work progresses throughout the semester. When classroom teachers introduce new or modified content mid-semester, it can further delay the production of accessible learning materials [19]. These delays, combined with inconsistencies in the quality of visual-to-accessible content conversion, can significantly impede the learning experiences of BLV students [41, 7, 26, 3].

To this end, there have been ongoing efforts to enhance the accessibility of STEM content for BLV learners–focusing on making various content types, such as mathematical equations [11], graphics [12, 42], and tables [23] more accessible. While these initiatives have contributed to enhancing accessibility, much of the work has centered on isolated content types or discipline-specific representations. In real-world educational settings, though, BLV learners encounter learning materials that include a variety of visual content types, such as equations, diagrams, charts, and more, often within the same document.

To address this broader challenge, we introduce StemA11y, an AI-powered iOS application that supports end-to-end generation and delivery of accessible STEM learning materials through a multisensory experience using speech, audio cues, haptic feedback, and VoiceOver support. To evaluate the usability and effectiveness of StemA11y, we conducted a user study with 11 BLV participants. In particular, our work investigates the research question: *How do BLV learners perceive an AI-powered application, StemA11y, that supports end-to-end generation and delivery of accessible STEM learning materials in real-world learning contexts?*

Drawing on participants' experiences and feedback, we reconsider the accessibility of STEM learning for BLV learners by exploring how AI tools like StemA11y can support access needs and open up new possibilities. We also present key design considerations to inform future AI systems, including supporting customizable verbosity, reducing redundant audio cues, and enhancing navigation flexibility.

2. BACKGROUND AND RELATED WORK

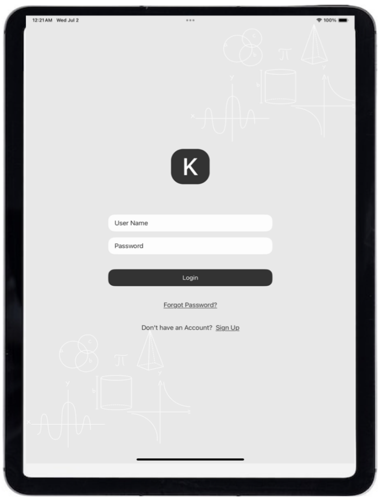
BLV learners encounter significant accessibility challenges when engaging with STEM content. Their challenges include the prevalence of heavily visual STEM materials [2, 15, 16], the exclusion of graphic-based questions from assessments [36], and the limited availability of braille-compatible exams. To address these barriers, accessibility practitioners, such as teachers of the visually impaired, often adapt academic content to meet the diverse access needs of BLV learners [32, 6]. These adaptations often involve the integration of tactile learning resources [28] and hands-on learning activities [13] that allow students to engage with educational content through non-visual modalities. Despite these efforts, the process of producing accessible STEM materials remains time-consuming and resource-intensive. The lack of standardization in tactile graphic design [41], inconsistencies in the availability and quality of accessible learning materials [7], and associated workload and financial costs involved in creating accessible resources [26] often impede the delivery of timely and accessible learning experiences to BLV learners.

In response to these challenges, researchers [12, 25, 38, 14, 4, 40, 5, 31, 23] have been developing tools to enhance the accessibility of visual STEM content through non-visual modalities. For example, [12] created a tool to explore visual graphics through auditory and haptic feedback and [25] presented Chart4Blind that converts bitmap images of charts into accessible digital formats, such as SVG. Similarly, to improve access to image-based tables, [23] introduced TableNarrator, an AI-powered system that generates alternative text specific to the preferences of BLV learners. Other researchers [24, 17, 11, 39, 30] have focused on improving accessibility for discipline-specific representations. For instance, [24] developed IncluSim to enable BLV learners to design, simulate, and debug electronic circuits with tactile and digital components. [17] presented AutoChemplete to convert chemical structural formulas into accessible formats. To support contextualization of mathematical expressions for BLV learners, [11] developed an equation editor, StereoMath, incorporating spatial audio cues and intuitive navigation support. However, these tools have focused on enhancing accessibility for specific content types, such as tables, charts, and graphics. In real-world educational contexts, BLV learners often need to access STEM learning materials that incorporate diverse visual elements, including equations, charts, and diagrams within the same learning resources. Therefore, our study introduces StemA11y, an AI-powered iOS application that supports end-to-end generation and delivery of accessible STEM materials, incorporating a variety of visual elements.

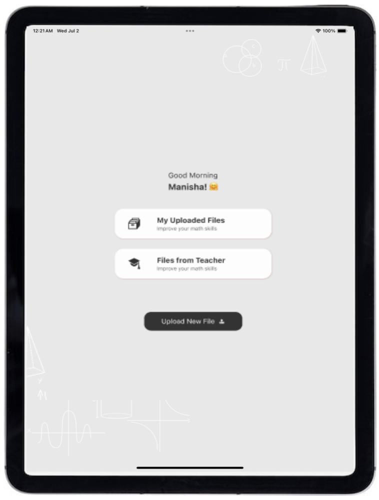
3. SYSTEM DESIGN AND IMPLEMENTATION

We implemented StemA11y, which comprises an accessible iOS application frontend built on a backend engine originally developed in our prior work on the Kanak system [27]. While Kanak focused on supporting professional transcribers in preparing accessible learning materials, StemA11y adapts and extends this backend to enable direct access to STEM content for BLV learners themselves. The system delivers content through a multisensory experience integrating speech output, audio cues, haptic feedback, and VoiceOver support. Below, we describe the main interface components, workflow, and backend architecture.

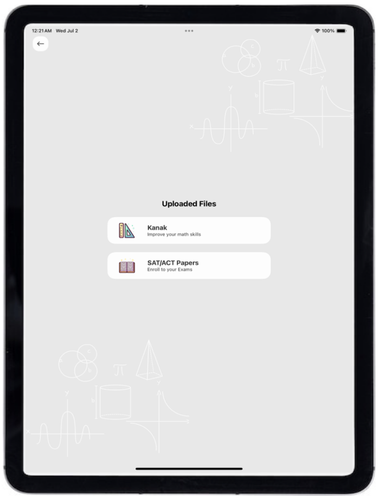
- **Login, Dashboard, and Document Upload:** Users begin by logging into the app, after which they are directed to the dashboard, where users could access their files or upload new files (Figure 1 (a), (b), (c)). The backend engine process uploaded files to automatically extract structured content blocks (text, math, tables, and graphics). Further, the dashboard displays uploaded documents to allow users to revisit materials or start new conversions. The layout is screen reader compatible and streamlined with large fonts and clearly labeled controls.
- **Interactive Math Content Support:** To support non-visual interaction with math content, the app includes dedicated interface for equations and graphics (Figure 2 (a), (b)). Users could listen to math expressions with audio cues clarifying structure (e.g., fractions, superscripts) and explore math graphics using



(a) *Login Page*



(b) *Upload Page*



(c) *Dashboard Page*

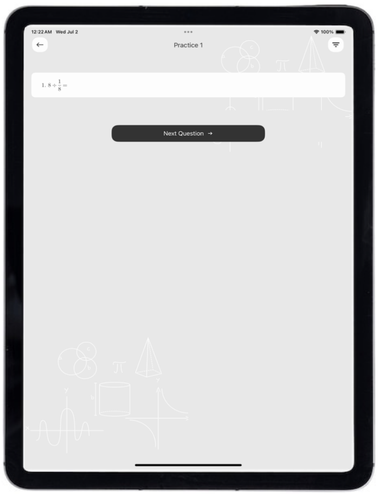
Figure 1: *Steps of StemA11y's workflow across login, document upload, and dashboard page: (a)–(c).*

spatial touch feedback (Figure 2 (c)). Selecting a graphic would launch a corresponding tactile exploration mode incorporating haptic and auditory cues to convey position and shape for non-visual interpretation of graphs and geometric diagrams.

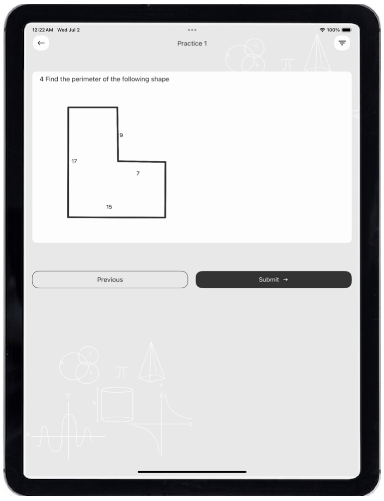
- **SAT Content Navigation Support:** StemA11y provides a structured SAT navigation dashboard to enable users to move between subject sections: reading, writing, math with calculator, and math without calculator (Figure 2 (d), (e), (f)). On the interface, each question appears on its own page in a consistent format. VoiceOver audio descriptions and simplified layouts make navigation efficient and predictable.
- **Backend Architecture:** StemA11y's backend builds on the modular pipeline established in Kanak [27], which incorporates: (1) preprocessing modules to extract text and graphical elements from uploaded PDFs, (2) semantic parsing of math content and tables, (3) graphical object reconstruction for tactile and audio rendering, and (4) cross-platform delivery modules for generating structured content in the iOS frontend. While Kanak was designed for professional transcribers to edit and finalize outputs, StemA11y adapted this pipeline to deliver ready-to-use accessible materials directly to BLV learners.

4. SYSTEM EVALUATION: METHOD

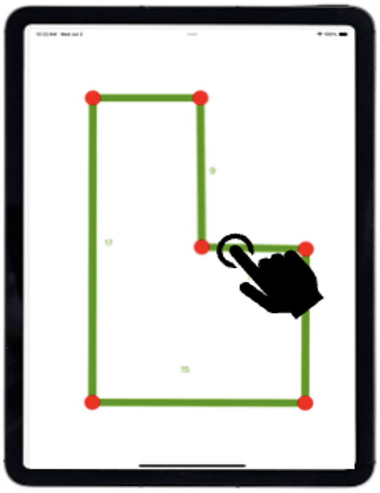
With approval from the institutional review board of our university, we conducted a two-condition,



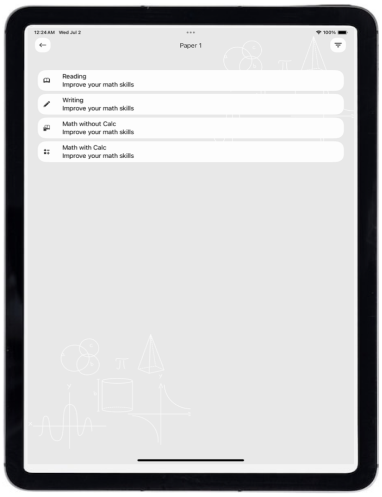
(a) *Math Equation Question Page*



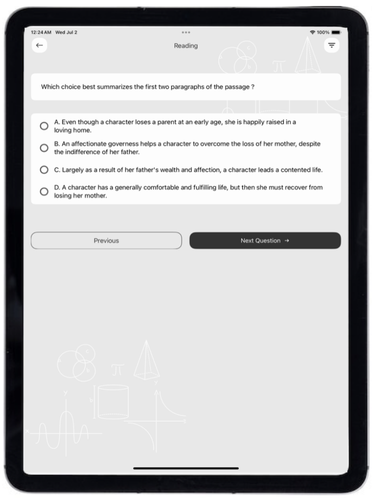
(b) *Math Graphic Question Page*



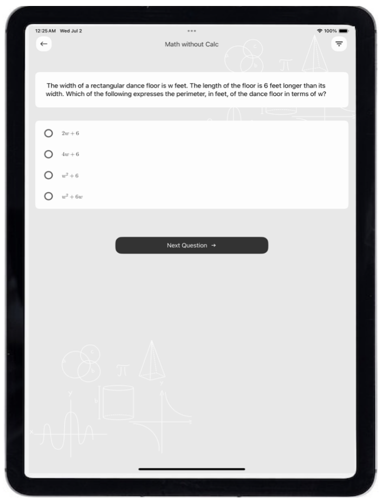
(c) *Math Spatial Touch Page*



(d) *SAT Question Dashboard*



(e) *SAT Reading Question Page*



(f) *SAT Math Question Page*

Figure 2: *Steps of StemA11y's workflow for math worksheet and SAT paper access: (a)–(f).*

within-subjects user study to evaluate the usability of StemA11y.

4.1. Participants

We recruited 11 BLV participants (7 Male; 4 Female) through a study announcement distributed via an organization that works with BLV people. Participants ranged in age from 20 to 60 years: one participants was aged 21–25, three were 26–30, one 31–35, one 36–40, four 51–55, and one 56–60. All participants were from the United States and primarily used assistive technologies, including one or more screen readers (e.g., VoiceOver, NVDA, Jaws) for digital access. Demographic data, including education, preferred learning methods, and braille/Nemeth proficiency, are reported in Table 4.

4.2. Procedure

During the evaluation session, participants completed two conditions: one involving math worksheets and another involving modified SAT test papers. For condition one, we prepared two math worksheets in PDF format, each containing four questions, including mathematical equations and diagrams. For condition two, we prepared two modified SAT test papers in PDF format, each including questions from four sections of typical SAT papers: reading, writing, math with calculator, and math without calculator. The content of the modified SAT PDF documents included text passages, multiple-choice options, tables, and diagrams. These conditions were designed to observe how participants interacted with the system while accessing a diverse range of STEM content.

Each condition included a practice trial followed by an experimental trial. In the practice trial, we guided participants as they used the system with one of the sample documents to familiarize them with the user interface, gesture commands, and available content formats (e.g., text, equations, graphics). During this phase, participants were encouraged to ask questions about the interface. In the subsequent experimental trial, participants independently navigated another comparable document similar to the practice trial. We instructed them to think-aloud while interacting with the system and to share feedback on their experience. For both conditions, we clarified to participants that it was not necessary to solve any questions and probed them to assess the accessibility and usability of the system.

At the end of the session, we requested participants to fill up three questionnaires: two System Usability Scale (SUS) questionnaires [18] for each condition and one Technology Acceptance Model (TAM) questionnaire [21] for evaluating the system overall. Each session lasted approximately 90 minutes and was video-recorded and transcribed. We compensated each participant with prorated Amazon gift cards valued at US$50 per hour.

4.3. Analysis

We performed statistical analysis of the quantitative data using the SciPy and Pandas libraries [10, 9] in Python. For both conditions, we calculated the mean System Usability Scale (SUS) scores and compared them against the industry benchmark of 68 (Table 1). To assess differences between conditions, we conducted Wilcoxon signed-rank tests, appropriate given the small sample size and non-parametric and non-normal distribution of the data. Additionally, we reported the mean and standard deviation for each item in the SUS questionnaire (Table 2). For the Technology Acceptance Model (TAM) questionnaire, we similarly reported the mean and standard deviation for each item (Table 3).

5. SYSTEM EVALUATION: FINDINGS

We found that the average SUS score was 75.23 (SD = 21.58) for the math worksheet condition and 83.18 (SD = 16.13) for the SAT condition, both exceeding the industry benchmark of 68. As such, participants indicated a higher perceived usability during the SAT condition. However, the Wilcoxon signed-rank test comparing SUS scores between the math and SAT conditions revealed that there was no statistically significant difference ($p = 0.067 > 0.05$). Item-level analysis of SUS responses aligned with these findings. Participants highly agreed with the statement “I would like to use this system frequently” in the SAT condition (M = 4.64, SD = 0.50) compared to the math condition (M = 3.64, SD = 1.29). They also rated the system less complex (M = 1.55) and easier to use (M = 4.36) in the SAT condition. Across both conditions, participants disagreed on the need for technical support to use the system (SAT M = 1.45, Math M = 1.91) and agreed that the functionalities within the system were well integrated (SAT M = 4.18, Math M = 4.27). Participants expressed confidence in navigating SAT test paper (M = 4.36) using the system compared to the math worksheet (M = 3.91). These results suggest that while participants perceived StemA11y as usable in both conditions, they had a more positive experience when navigating SAT content.

The TAM questionnaire responses indicated that participants perceived the system easy to use, easy to learn, and satisfactory. In the ease of use category, participants agreed that the system was simple to use (M = 4.64, SD = 0.67), user-friendly (M = 4.55, SD = 0.69), and could be used without written instructions (M = 4.45, SD = 0.93). They

Table 1: System Usability Scale (SUS) scores for each participant (n=11) for both conditions

ID	Condition 1 (Math)	Condition 2 (SAT)
P1	75.0	82.5
P2	82.5	95.0
P3	72.5	82.5
P4	97.5	95.0
P5	62.5	92.5
P6	55.0	67.5
P7	92.5	77.5
P8	80.0	100.0
P9	97.5	95.0
P10	37.5	42.5
P11	80.0	85.0
Mean	75.23	83.18
SD	21.58	16.13

Table 2: Ratings of participants (n=11) for math worksheet and SAT paper conditions in System Usability Scale (SUS). (Scale: 1=Strongly Disagree, 5=Strongly Agree)

Statements	Math Worksheet		SAT Paper	
	Mean	SD	Mean	SD
I think that I would like to use this system frequently.	3.64	1.29	4.64	0.5
I found this system unnecessarily complex.	2.36	1.29	1.55	0.69
I thought the system was easy to use.	4.18	0.98	4.36	0.92
I think that I would need the support of a technical person to be able to use this system.	1.91	1.22	1.45	0.93
I found the various functions in this system were well integrated.	4.27	1.01	4.18	0.87
I thought there was too much inconsistency in this system.	1.27	0.47	1.64	0.5
I would imagine that most people would learn to use this system very quickly.	3.64	0.92	4.18	0.6
I found the system very cumbersome to use.	2.0	1.41	1.91	0.83
I felt very confident using the system.	3.91	1.38	4.36	0.92
I needed to learn a lot of things before I could adapt it to my process/approach.	2.0	1.26	1.91	0.94

also reported being able to recover from mistakes within the system (M = 4.27, SD = 0.90) and could successfully use the system every time (M = 4.18, SD = 0.87). However, participants provided slightly lower ratings for effortlessness (M = 3.82, SD = 0.87) and consistency (M = 3.91, SD = 1.22) of the system. In the ease of learning category, participants agreed that they could quickly learn to use the system (M = 4.73, SD = 0.47) and found it easy to remember how to use it (M = 4.82, SD = 0.40). In the satisfaction category, participants agreed that the system was pleasant to use (M = 4.45, SD = 0.93), they would recommend it to others (M = 4.45, SD = 0.69), and worked as intended (M = 4.00, SD = 1.00). However, they showed slightly lower agreement with statements regarding their need to have it (M = 3.91, SD = 0.94). Thus, participants found the system easy to learn, usable, and satisfactory. However, they experienced challenges with math-intensive content, which indicated a need for flexible and customizable control over how math content is presented and navigated. The high usability ratings for the SAT condition further indicate that clear structure and non-cluttered navigation patterns might enhance non-visual access.

Qualitative feedback revealed both strengths and areas for improvement in StemA11y's accessibility and user experience. Several participants appreciated the system's ability to interpret mathematical content, particularly in representing fractions and geometric shapes. For example, P10 noted that structural audio cues like *"Begin numerator"* or *"End fraction"* were helpful for complex expressions. However, some participants found the default verbosity overwhelming, as P5 said, *"... way too many words on the math. I probably have to listen to it a few times to keep track of what it says."* Similarly, P1 suggested reducing redundant phrases. Thus, while participants appreciated the audio support, they expressed a desire for control over speech verbosity. P3 and P5 suggested the system *"need not say unselected"* (P5) and could *"just say 'button' for faster reading"* (P3).

Repetitive audio cues were another concern, particularly in graphical content. For instance, P4 said, *"... [it] keeps saying the intro every time on the graph."* Labeling was another area where users identified improvement opportunities. Participants recommended clearer and more specific labels for

Table 3: Ratings of participants (n=11) for StemA11y in Technology Acceptance Model (TAM) scale. (Scale: 1=Strongly Disagree, 5=Strongly Agree)

Statements	Mean	SD
A. Ease of Use		
It is easy to use.	4.45	0.69
It is simple to use.	4.64	0.67
It is user friendly.	4.55	0.69
It requires the fewest steps possible to accomplish what I want to do with it.	4.09	1.04
Using it is effortless.	3.82	0.87
I can use it without written instructions.	4.45	0.93
I don't notice any inconsistencies as I use it.	3.91	1.22
Both occasional and regular users would like it.	4.09	0.94
I can recover from mistakes quickly and easily.	4.27	0.90
I can use it successfully every time.	4.18	0.87
B. Ease of Learning		
I learned to use it quickly.	4.73	0.47
I easily remember how to use it.	4.82	0.40
It is easy to learn to use it.	4.82	0.40
I quickly became skillful with it.	4.45	0.69
C. Satisfaction		
I am satisfied with it.	4.27	0.90
I would recommend it to a friend.	4.45	0.69
It works the way I want it to work.	4.00	1.00
I feel I need to have it.	3.91	0.94
It is pleasant to use.	4.45	0.93

graphical elements, such as labeling plot lines or explicitly referencing question numbers (e.g., *"Maybe it could say question 2"* (P8)).

Participants also highlighted the benefits of the system's structured layout, especially for adapted SAT documents. They appreciated the single-question-per-page format and intuitive navigation. For instance, P8 commented that *"...the info [of the content] is clear, navigation is easy to use"* and appreciated that *"having one question per page is quite helpful."* Similarly, some participants suggested breaking down math content into smaller segments and recommended item-by-item navigation as an alternative for navigating complex mathematical expressions. Participants also suggested interaction improvements, including support for zooming in, gesture-based navigation, and figure overviews (P7, P3). Overall, participants appreciated StemA11y's multi-sensory and structured design; however, they also identified areas of improvement, particularly the need for flexibility in navigation and customizable audio verbosity.

6. DISCUSSION

Below, we analyze our findings, reconsider the accessibility of STEM learning, and provide design insights to inform future accessible STEM systems for BLV learners.

6.1. Reconsidering the Accessibility of STEM Learning

Despite efforts in classroom adaptations of accessible educational materials [32, 6, 37, 41, 13], BLV learners continue to face barriers in STEM education due to different visual content, such as equations, diagrams, and graphics. Our findings with StemA11y indicate that AI-powered accessible systems have the potential to bridge this gap by providing an end-to-end solution and delivering mixed-media contents in real-time similar to how their sighted peers encounter learning materials.

In particular, achieving inclusive STEM learning requires moving beyond isolated accessibility improvements targeting specific content types [17, 24, 11, 42] toward integrated end-to-end workflows that provide BLV learners with the same immediacy and flexibility in learning experience as their sighted peers. Further, quantitative usability scores and qualitative feedback revealed that users appreciated uncluttered and clear content structure, as in the SAT paper condition. In addition, users desired on-demand control over verbosity and segment-by-segment navigation [8, 43]. These insights highlighted the need for re-envisioning STEM accessibility as an uncluttered, dynamic, multi-sensory, and customizable ecosystem.

6.2. Design Considerations for Accessible STEM Content

Prior work [12, 25, 38, 14, 4, 40, 5, 31, 23, 34] called attention to several design interventions to improve accessibility of academic content for BLV learners. Building on this research, we discuss design insights to inform the design of accessible STEM systems.

6.2.1 Supporting Customizable Verbosity

Participants appreciated StemA11y's ability to interpret and vocalize mathematical content for complex expressions. However, many found the default level of verbosity to be overwhelming, especially when navigating simpler structures. Therefore, we propose that accessible STEM systems could provide customizable verbosity controls, such as toggling verbosity based on context or preference. Such opportunities could extend prior work [11] that focused on contextualizing mathematical expressions for BLV learners.

6.2.2 Reducing Redundant Audio Cues

While auditory feedback is essential for non-visual access [37, 12, 11], our findings revealed that irrelevant and repetitive audio cues were a common issue encountered by participants with StemA11y. This could be contributing to increased cognitive load. Participants expressed their need for streamlined audio outputs that avoid unnecessary redundancy. As such, we recommend that developers should minimize redundant audio cues while ensuring that essential contextual information is preserved to support non-visual access.

6.2.3 Enhancing Navigation Flexibility

Participants' positive feedback about StemA11y's single-question-per-page layout suggests that content segmentation into smaller parts can make it easier to follow within lengthy assessments and less overwhelming. Aligning with this, we propose that math content could also be broken down into step-by-step pieces, to allow users to move through each part one at a time or skip to the parts they need. Further, having a summary view of all graphics with the option to explore them in more detail could help users understand the overall layout before diving into each part. These recommendations extend prior work on improving the accessibility of STEM graphics for BLV learners [12, 25, 32, 38], by highlighting the importance of breaking content into smaller parts and layered exploration for accessible navigation.

6.3. Limitations and Future Work

We believe that this work lays important groundwork for designing end-to-end AI-powered solutions that convert STEM content into accessible formats for BLV learners. While StemA11y currently supports numerous STEM content types, it does not yet accommodate formats such as interactive simulations or handwritten content, which are common in both digital and classroom-based learning environments. Future research could explore expanding StemA11y's capabilities to include these complex content types, as well as investigate integrations with in-class instructional workflows.

While participants appreciated the multisensory features of StemA11y, further research is needed to develop AI-driven approaches to dynamically adjust verbosity and audio cues to further enhance the accessibility of STEM learning materials. Finally, future research could involve longitudinal studies to assess how StemA11y influences students' comprehension, retention, and academic performance over time.

7. CONCLUSION

This study contributes to the accessibility of STEM education by demonstrating the potential of StemA11y, an AI-powered application that enables end-to-end conversion and delivery of accessible learning materials to BLV learners. Our user evaluation with StemA11y also showed both the promise and the complexity of making STEM content accessible. In particular, participants expressed a desire for customizable controls and flexible navigation when engaging with diverse STEM materials. Drawing on these findings, we proposed several design insights to guide future development of accessible STEM systems, including supporting customizable verbosity, reducing redundant audio cues, and enhancing navigation flexibility.

Together, these insights highlight the need to move beyond content-specific accessible solutions toward integrated and end-to-end approaches that deliver immediacy and flexibility in learning experiences. Overall, our study calls attention to the importance of designing dynamic and multisensory systems that support BLV learners to engage with STEM content independently and equitably, moving towards more accessible learning environments.

REFERENCES

[1] American Foundation for the Blind. *Resources for Learning and Refreshing Literary Braille Skills*. Accessed: 2025-05-19. n.d. URL: `https://www.afb.org/blindness-and-low-vision/braille/resources-teachers-braille/resources-learning-and-refreshing`.

[2] Catherine M. Baker, Cynthia L. Bennett, and Richard E. Ladner. "Educational Experiences

of Blind Programmers". In: *Proceedings of the 50th ACM Technical Symposium on Computer Science Education*. SIGCSE '19. Minneapolis, MN, USA: Association for Computing Machinery, 2019, pp. 759–765. ISBN: 9781450358903. DOI: 10.1145/3287324.3287410. URL: https://doi.org/10.1145/3287324.3287410.

[3] Catherine M. Baker, Lauren R. Milne, and Richard E. Ladner. "Understanding the Impact of TVIs on Technology Use and Selection by Children with Visual Impairments". In: *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*. CHI '19. Glasgow, Scotland Uk: Association for Computing Machinery, 2019, pp. 1–13. ISBN: 9781450359702. DOI: 10.1145/3290605.3300654. URL: https://doi.org/10.1145/3290605.3300654.

[4] Catherine M. Baker et al. "Tactile Graphics with a Voice". In: *ACM Trans. Access. Comput.* 8.1 (Jan. 2016). ISSN: 1936-7228. DOI: 10.1145/2854005. URL: https://doi.org/10.1145/2854005.

[5] Tigmanshu Bhatnagar and Catherine Holloway. "PRET Printer: Development and Evaluation of a Passive Refreshable Tactile Printer". In: *Proceedings of the 7th ACM SIGCAS/SIGCHI Conference on Computing and Sustainable Societies*. COMPASS '24. New Delhi, India: Association for Computing Machinery, 2024, pp. 156–166. ISBN: 9798400710483. DOI: 10.1145/3674829.3675070. URL: https://doi.org/10.1145/3674829.3675070.

[6] Abena Boadi-Agyemang et al. "Understanding Experiences, Attitudes and Perspectives towards Designing Interactive Creative Tools for Teachers of Visually Impaired Students". In: *Proceedings of the 25th International ACM SIGACCESS Conference on Computers and Accessibility*. ASSETS '23. New York, NY, USA: Association for Computing Machinery, 2023. ISBN: 9798400702204. DOI: 10.1145/3597638.3614512. URL: https://doi.org/10.1145/3597638.3614512.

[7] Anne L Corn and Robert S Wall. "Training and Availability of Braille Transcribers in the United States". In: *Journal of Visual Impairment Blindness* 96.4 (2002), pp. 223–232. URL: https://doi.org/10.1177/0145482X0209600404.

[8] Frank Elavsky, Lucas Nadolskis, and Dominik Moritz. "Data navigator: an accessibility-centered data navigation toolkit". In: *IEEE transactions on visualization and computer graphics* 30.1 (2023), pp. 803–813. URL: https://doi.org/10.1109/TVCG.2023.3327393.

[9] Python Software Foundation. *pandas 2.2.2*. 2024. URL: https://pypi.org/project/pandas.

[10] Python Software Foundation. *scipy 1.14.0*. 2024. URL: https://pypi.org/project/scipy.

[11] Kenneth Ge and JooYoung Seo. "StereoMath: An Accessible and Musical Equation Editor". In: *Proceedings of the 26th International ACM SIGACCESS Conference on Computers and Accessibility*. ASSETS '24. St. John's, NL, Canada: Association for Computing Machinery, 2024. ISBN: 9798400706776. DOI: 10.1145/3663548.3688487. URL: https://doi.org/10.1145/3663548.3688487.

[12] Nicholas A. Giudice et al. "Learning non-visual graphical information using a touch-based vibro-audio interface". In: *Proceedings of the 14th International ACM SIGACCESS Conference on Computers and Accessibility*. ASSETS '12. Boulder, Colorado, USA: Association for Computing Machinery, 2012, pp. 103–110. ISBN: 9781450313216. DOI: 10.1145/2384916.2384935. URL: https://doi.org/10.1145/2384916.2384935.

[13] Cicely Hayes and Michael J Proulx. "Turning a blind eye? Removing barriers to science and mathematics education for students with visual impairments". In: *British Journal of Visual Impairment* 42.2 (2024), pp. 544–556. URL: https://doi.org/10.1177/02646196221149561.

[14] Md Naimul Hoque et al. "Accessible Data Representation with Natural Sound". In: *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems*. CHI '23. Hamburg, Germany: Association for Computing Machinery, 2023. ISBN: 9781450394215. DOI: 10.1145/3544548.3581087. URL: https://doi.org/10.1145/3544548.3581087.

[15] Earl W. Huff et al. "Exploring the Perspectives of Teachers of the Visually Impaired Regarding Accessible K12 Computing Education". In: *Proceedings of the 52nd ACM Technical Symposium on Computer Science Education*. SIGCSE '21. Virtual Event, USA: Association for Computing Machinery, 2021, pp. 156–162. ISBN: 9781450380621. DOI: 10.1145/3408877.3432418. URL: https://doi.org/10.1145/3408877.3432418.

[16] Fituma Yadasa Kana and Asmerom Tekle Hagos. “Factors hindering the use of Braille for instruction and assessment of students with visual impairments: A systematic review”. In: *British Journal of Visual Impairment* 43.2 (2025), pp. 396–406. DOI: 10.1177/02646196241239173. URL: https://doi.org/10.1177/02646196241239173.

[17] Merlin Knaeble et al. “AutoChemplete - Making Chemical Structural Formulas Accessible”. In: *Proceedings of the 20th International Web for All Conference*. W4A ’23. Austin, TX, USA: Association for Computing Machinery, 2023, pp. 104–115. ISBN: 9798400707483. DOI: 10.1145/3587281.3587293. URL: https://doi.org/10.1145/3587281.3587293.

[18] James R Lewis. “The System Usability Scale: Past, Present, and Future”. In: *International Journal of Human–Computer Interaction* 34.7 (2018), pp. 577–590. URL: https://doi.org/10.1080/10447318.2018.1455307.

[19] JoLynne Lyon. *USU Project Eases Braille Transcriber Shortage*. https://www.usu.edu/today/story/usu-project-eases-braille-transcriber-shortage. Accessed: 2025-05-18. Utah State University, Dec. 2023.

[20] Sheena Manuel. *Collaboration: Free and Appropriate Education for Blind Students*. https://nfb.org/images/nfb/publications/jbir/jbir20/jbir100107.html. Accessed: 2025-05-18. 2020.

[21] Nikola Marangunić and Andrina Granić. “Technology acceptance model: a literature review from 1986 to 2013”. In: *Universal access in the information society* 14 (2015), pp. 81–95. URL: https://doi.org/10.1007/s10209-014-0348-1.

[22] Michael McLinden et al. “‘Access to learning’ and ‘learning to access’: Analysing the distinctive role of specialist teachers of children and young people with vision impairments in facilitating curriculum access through an ecological systems theory”. In: *British Journal of Visual Impairment* 34.2 (2016), pp. 177–195. URL: https://doi.org/10.1177/0264619616643180.

[23] Ye Mo et al. “TableNarrator: Making Image Tables Accessible to Blind and Low Vision People”. In: *Proceedings of the 2025 CHI Conference on Human Factors in Computing Systems*. CHI ’25. Association for Computing Machinery, 2025. ISBN: 9798400713941. DOI: 10.1145/3706598.3714329. URL: https://doi.org/10.1145/3706598.3714329.

[24] Aya Mouallem et al. “IncluSim: An Accessible Educational Electronic Circuit Simulator for Blind and Low-Vision Learners”. In: *Proceedings of the 2025 CHI Conference on Human Factors in Computing Systems*. CHI ’25. Association for Computing Machinery, 2025. ISBN: 9798400713941. DOI: 10.1145/3706598.3713437. URL: https://doi.org/10.1145/3706598.3713437.

[25] Omar Moured et al. “Chart4Blind: An Intelligent Interface for Chart Accessibility Conversion”. In: *Proceedings of the 29th International Conference on Intelligent User Interfaces*. IUI ’24. Greenville, SC, USA: Association for Computing Machinery, 2024, pp. 504–514. ISBN: 9798400705083. DOI: 10.1145/3640543.3645175. URL: https://doi.org/10.1145/3640543.3645175.

[26] Agata Mrva-Montoya. “Towards “born-accessible” educational publishing”. In: *Publishing Research Quarterly* 38.4 (2022), pp. 735–748. URL: https://doi.org/10.1007/s12109-022-09922-0.

[27] Hari Prasath Palani, Rudaiba Adnin, and Shivangee Nagar. “Kanak: Automating the Generation of Accessible STEM Materials for Blind and Low-vision Students”. In: *Proceedings of the 37th Australian Computer-Human Interaction Conference*. OzCHI ’25. Sydney, Australia: Association for Computing Machinery, 2025.

[28] Mahika Phutane et al. “Tactile Materials in Practice: Understanding the Experiences of Teachers of the Visually Impaired”. In: *ACM Trans. Access. Comput.* 15.3 (July 2022). ISSN: 1936-7228. DOI: 10.1145/3508364. URL: https://doi.org/10.1145/3508364.

[29] Yash Prakash et al. “Understanding Low Vision Graphical Perception of Bar Charts”. In: *Proceedings of the 26th International ACM SIGACCESS Conference on Computers and Accessibility*. ASSETS ’24. St. John’s, NL, Canada: Association for Computing Machinery, 2024. ISBN: 9798400706776. DOI: 10.1145/3663548.3675616. URL: https://doi.org/10.1145/3663548.3675616.

[30] Emily Randall. “Making Science Simulations Accessible For Students With Vision Impairments”. In: *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*. CHI EA ’16. San Jose, California, USA: Association for Computing Machinery, 2016, pp. 122–127. ISBN: 9781450340823. DOI: 10.1145/2851581.2890385. URL: https://doi.org/10.1145/2851581.2890385.

[31] Juliette Regimbal et al. "IMAGE: An Open-Source, Extensible Framework for Deploying Accessible Audio and Haptic Renderings of Web Graphics". In: *ACM Trans. Access. Comput.* 17.2 (July 2024). ISSN: 1936-7228. DOI: 10.1145/3665223. URL: https://doi.org/10.1145/3665223.

[32] L. Penny Rosenblum, Li Cheng, and Carole R. Beal. "Teachers of Students with Visual Impairments Share Experiences and Advice for Supporting Students in Understanding Graphics". In: *Journal of Visual Impairment & Blindness* 112.5 (2018), pp. 475–487. DOI: 10.1177/0145482X1811200505. URL: https://doi.org/10.1177/0145482X1811200505.

[33] Wendy Sapp and Phil Hatlen. "The Expanded Core Curriculum: Where We Have Been, Where We are Going, and How We Can Get There". In: *Journal of Visual Impairment & Blindness* 104.6 (2010), pp. 338–348. DOI: 10.1177/0145482X1010400604. URL: https://doi.org/10.1177/0145482X1010400604.

[34] Lei Shi et al. "Designing Interactive 3D Printed Models with Teachers of the Visually Impaired". In: *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*. CHI '19. Glasgow, Scotland Uk: Association for Computing Machinery, 2019, pp. 1–14. ISBN: 9781450359702. DOI: 10.1145/3290605.3300427. URL: https://doi.org/10.1145/3290605.3300427.

[35] Yayoi Shimomura, Ebba Thora Hvannberg, and Hjalmtyr Hafsteinsson. "Accessibility of audio and tactile interfaces for young blind people performing everyday tasks". In: *Universal Access in the Information Society* 9 (2010), pp. 297–310. URL: https://doi.org/10.1007/s10209-009-0183-y.

[36] Andreas Stefik et al. "Computer Science Principles for Teachers of Blind and Visually Impaired Students". In: *Proceedings of the 50th ACM Technical Symposium on Computer Science Education*. SIGCSE '19. Minneapolis, MN, USA: Association for Computing Machinery, 2019, pp. 766–772. ISBN: 9781450358903. DOI: 10.1145/3287324.3287453. URL: https://doi.org/10.1145/3287324.3287453.

[37] Andreas M. Stefik, Christopher Hundhausen, and Derrick Smith. "On the design of an educational infrastructure for the blind and visually impaired in computer science". In: *Proceedings of the 42nd ACM Technical Symposium on Computer Science Education*. SIGCSE '11. Dallas, TX, USA: Association for Computing Machinery, 2011, pp. 571–576. ISBN: 9781450305006. DOI: 10.1145/1953163.1953323. URL: https://doi.org/10.1145/1953163.1953323.

[38] Ruoting Sun et al. "Tactile Data Comics: A Step-by-step Multimodal Presentation Method on a Refreshable Tactile Display for Blind and Visually Impaired Individuals". In: *Proceedings of the Extended Abstracts of the CHI Conference on Human Factors in Computing Systems*. CHI EA '25. Association for Computing Machinery, 2025. ISBN: 9798400713958. DOI: 10.1145/3706599.3720192. URL: https://doi.org/10.1145/3706599.3720192.

[39] R. Michael Winters, E. Lynne Harden, and Emily B. Moore. "Co-Designing Accessible Science Education Simulations with Blind and Visually-Impaired Teens". In: *Proceedings of the 22nd International ACM SIGACCESS Conference on Computers and Accessibility*. ASSETS '20. Virtual Event, Greece: Association for Computing Machinery, 2020. ISBN: 9781450371032. DOI: 10.1145/3373625.3418025. URL: https://doi.org/10.1145/3373625.3418025.

[40] Hantian Wu et al. "AI-Generated Tactile Graphics for Visually Impaired Children: A Usability Study of a Multimodal Educational Product". In: *International Journal of Human-Computer Studies* (2025), p. 103525. URL: https://doi.org/10.1016/j.ijhcs.2025.103525.

[41] Kim T Zebehazy and Adam P Wilton. "Charting Success: The Experience of Teachers of Students with Visual Impairments in Promoting Student Use of Graphics". In: *Journal of Visual Impairment & Blindness* 108.4 (2014), pp. 263–274. URL: https://doi.org/10.1177/0145482X1410800402.

[42] Zhuohao Zhang et al. "ChartA11y: Designing Accessible Touch Experiences of Visualizations with Blind Smartphone Users". In: *Proceedings of the 26th International ACM SIGACCESS Conference on Computers and Accessibility*. ASSETS '24. St. John's, NL, Canada: Association for Computing Machinery, 2024. ISBN: 9798400706776. DOI: 10.1145/3663548.3675611. URL: https://doi.org/10.1145/3663548.3675611.

[43] Jonathan Zong et al. "Rich Screen Reader Experiences for Accessible Data Visualization". In: *Computer Graphics Forum*. Vol. 41. 3. Wiley Online Library. 2022, pp. 15–27. URL: https://doi.org/10.1111/cgf.14519.

Appendix

Table 4: *Background details of participants (n=11)*

ID	Cause of vision loss	Existence of residual vision	Blindness onset age	Education	Preferred learning method	Proficiency in braille	Familiarity with Nemeth Code
P1	Crushed optic nerves	Light perception	9 years old	Masters	Audio	Grade 2	Yes
P2	Glaucoma	No	Birth	Bachelors	Braille, audio	Grade 2	Yes
P3	Born prematurely	No	Birth	Grad School	Braille, audio	Grade 2	Yes
P4	Craniopharyngioma	No	Birth	Masters	Braille	Grade 2	Yes
P5	Retinitis pigmentosa	No	15 years old	PhD	Audio	Grade 1	Yes
P6	Retinopathy of prematurity	Light perception	Birth	Bachelors	Audio	Grade 2	Yes
P7	Aniridia	Yes	Birth	Bachelors	Audio	No	No
P8	Glaucoma	Yes	Birth	Masters	Magnification, braille, audio	UEB	Yes
P9	Leber's congenital amaurosis	No	Birth	Bachelors	Braille, audio	Grade 2, UEB	Yes
P10	Genetic disorder	No	Birth	Bachelors	Audio	Grade 1	No
P11	Retinitis pigmentosa	No	Birth	Junior College	Audio	Minimal	No