Ideas for Accessible Math Education

Design Research, Generation, and Selection

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Problem and Solution Overview

Students around the world are required to learn algebra as part of their mathematics curriculums, usually diving into this topic at the beginning of high school. Online visualizers such as Desmos provide clear, free access to these graph visualizations that many students and instructors use when first learning about different functions – these are proven to be engaging, interesting, and hands-on ways for students to further their understanding of algebra (Teacher Reviews). However, there are few mainstream non-visual approaches to learning about graphing and different functions, which makes algebra education inaccessible to individuals in the blind and visually impaired community.

The proposed solution is to engage students with sonic representations of graphs, not solely visual graphs. This will ideally be done through integrating an audio graph with online graphing calculator software. By doing so, students are once again able to interact with graphs in an engaging way and this may also help them more easily identify patterns that are consistent between graphs of the same parent function. This will also make graphing more accessible to those who are blind or visually impaired, as they have multiple ways of interacting with the material. By implementing this feature directly into existing online graphing calculators, algebra education can be more accessible and intriguing to students of all abilities.

Design Research Goals, Methods, and Participants

For this project, due to unforeseen circumstances at the end of the quarter, I was unfortunately unable to connect with as many professors and experts as I had initially planned. My goal was to interview professors in various disciplines, including education, disability studies, and music to contribute to how to better develop this idea of integrating sound into math education to improve accessibility. Despite not being able to reach out to as many people as I had hoped, I did have the opportunity to conduct a semi-structured interview with Dr. Matthew Conroy, a Senior Lecturer in the Math Department at the University of Washington. He is the director of the Math Study Center on campus and has been leading the WXML (Washington Experimental Mathematics Laboratory) Number Theory and Noise project for the past four years. Dr. Conroy was also a student of a blind professor, and he was able to draw on his experiences as a student as well as an instructor during the semi-structured interview. As one of the few math professors at the University of Washington with experience and interest in the sonic representations of mathematical concepts, his insights were paramount to understanding more about how sound can fit into math education and how math instructors could implement sound into their lesson plans.

Design Research Results and Themes
During my semi-structured interview with Dr. Conroy, he brought up his initial interest in music and how making sound has followed him through many phases of life – from learning sound engineering and working as a DJ in his college's radio station, to engineering for live bands, to experimenting with creating sound on computers in the 1990s, all of his past experiences with sound have contributed to his curiosity and passion for the WXML project. While he acknowledged that sound is not currently incorporated in most math education, and it is unlikely to be used in proof-based courses, he found value in the versatility of music when used to represent mathematical ideas. Dr. Conroy also suggested for me to read Dr. Larry Baggett's autobiography, *In the Dark on the Sunny Side: A Memoir of an Out-of-Sight Mathematician*.

Dr. Larry Baggett, the first blind doctoral student in mathematics at the University of Washington and a Professor Emeritus at the University of Colorado, Boulder, detailed his life experiences in *In the Dark on the Sunny Side*. Beyond being an excellent read, this book stepped through Baggett's education, which began in the Perkins School for the Blind. Though he enjoyed his time at Perkins and the Florida School for the Deaf and Blind, Baggett credits the support and kindness of those around him with his "growth and success as a blind person in a sighted world" (Baggett 60). In junior high, Baggett noted that he primarily learned "just by listening" (Baggett 75), a skill that he had honed over the course of his life. From reading about the different methods with which Baggett studied math, to hearing about his successes with teaching college-level mathematics, I was able to better understand how sound and math education could fit together.

Common Themes
There is a significant stigma surrounding disability in the classroom. In Baggett's autobiography, he addresses how his 4th grade teacher's "willingness to accept [him] into her class was the first, and possibly the most important, milestone of [his] integration into the ordinary world of sighted people" (Baggett 61). Though he did not explicitly discuss learning math in elementary school, he did mention that the support of Mrs. Watson, his teacher, greatly aided him in ways that he can still recall today. By the time Baggett entered junior high, his teachers expressed much greater concern regarding teaching him math – "how could she teach this boy math – fractions, negative numbers, decimals – if he couldn't see the blackboard, let alone submit his written answers?" (Baggett 75). Though he achieved good grades in junior high, in high school, his algebra teacher initially had a negative attitude about teaching a blind student, and thus Baggett was unable to study nearly as well as he had before. This theme shows that overcoming the barrier of providing only visual materials and destigmatizing the idea of teaching a blind student are important to making math education much more accessible.

Many instructors have not even considered adding sound representations of their materials. When conducting the semi-structured interview with Dr. Conroy, he mentioned his passion and interest for music and music-related math research projects, but did note that he "never really saw a good way of [fitting sound into] the actual courses" that he taught. In his initial mini-brainstorm for how to incorporate sound into his instruction, he mentioned that it would be helpful to represent sinusoidal functions as they have a natural sonic representation – this concept arises in pre-calculus courses. In other courses, such as Math 309 (Linear Analysis), Dr. Conroy noted that the concept of Fourier Analysis can also be clearly represented in an audio form. When generating these sounds with electronic hardware, it is possible to approximate any periodic function as a finite sum of sine waves. Many of these ideas to integrate sound into teaching came from a rather short brainstorming session. This theme shows that it is important to introduce instructors to a variety of ideas to teach their content, from which they can develop their lessons in a multimodal and engaging way.

Math education is not always accessible to everybody, and multi-sensory representations may help more than just blind or visually impaired students. Baggett often refers to his love for music in conjunction with the development of his mathematical career, noting that music was his passion far before he became seriously interested in mathematics. When reminiscing on his courses, he remembered that "Mrs. Campbell, [his] plane geometry teacher, prepared all of the complex geometric figures for [him] using the kit… [he] still remember[s] many of the drawings used in the geometry proofs, especially the one used to prove the Pythagorean Theorem – that is, a right triangle with a square attached to each of its three sides" (Baggett 96). The kit allowed Mrs. Campbell to trace the diagrams and create raised tactile diagrams. Though this demonstrates the importance of having tactile representations, Baggett mentions later in the chapter that he still had to pay attention and listen extremely closely in class, which ended up being where he learned most of what he retained. Using audio representations to bolster his understanding of the concepts he was covering in class could have deepened the connections that he made from lectures in-class and the tactile diagrams that he had. Dr. Conroy also mentioned that learning about the mathematics behind music could have engaged students of different backgrounds and interests. This theme shows that it was necessary to develop multi-sensory representations to increase accessibility in the classroom, and that auditory learning was one of the most effective methods for learning as mathematical concepts became more advanced.

Identified Tasks

From my research, I was able to identify three primary tasks. As this is intended to be a lightweight addition to existing online graphing calculator applications, I did not want to add too many tasks for the user as they would complicate the interaction with the existing interface. These tasks, for the most part, model the existing tasks that people must complete to use the online graphing calculator but translate them into tasks used for an auditory representation.

Hear the auditory representation of a certain function and a reference tone. One concern that Dr. Conroy brought up with auditory graphs was that they might not provide enough information – the shape can be easily conveyed through the sound, but the y-intercept or other important aspects may not be as easily realized. The user can personalize their reference tone to be the y-intercept (or another significant value) and use that as a reference for where the graph falls on the coordinate plane. If there is no y-intercept, there would be no sound. A strength that Dr. Conroy mentioned with an auditory representation (referring specifically to parabolas) was that it is possible to represent the "smoothness and symmetry" of many graphs. To activate this feature, someone would just have to enter the function as they usually would, press enter, and hear their function.

Add a function to the graph and hear where two functions intersect. Oftentimes, people use online graphing calculators to identify where two functions intersect or to calculate the slope at a certain point on a function. Adding additional functions onto the graph is a task that people using online graphing calculators already complete, so it is necessary for this add-on to support this task in an auditory form as well. The two intersecting points could be indicated with an additional earcon or an overlapping sound so that it is clear that they are intersecting – the visual version of this on Desmos uses round grey dots. Dr. Conroy specifically mentioned thinking about the purpose of graphing and common existing use cases during the interview, noting that it was imperative that the graphs do not leave out any important information such as points of intersection.

Change an attribute of the sound so that each separate function is distinguishable. Another important feature that online graphing calculators have is distinguishing between different functions with different colors. With the auditory representation, changing an aspect of the sound (such as the timbre, instrument, etc.) will help distinguish separate functions so that they are all clear. This also addresses Dr. Conroy's concern about representing different lines on the graph and how to prevent excessive noise, an idea that he explores within his Number Theory and Noise project. Though adding additional instruments may make the interface a bit more complicated, it can help people clearly distinguish which functions are which, especially if they are intersecting.

Proposed Design Sketches

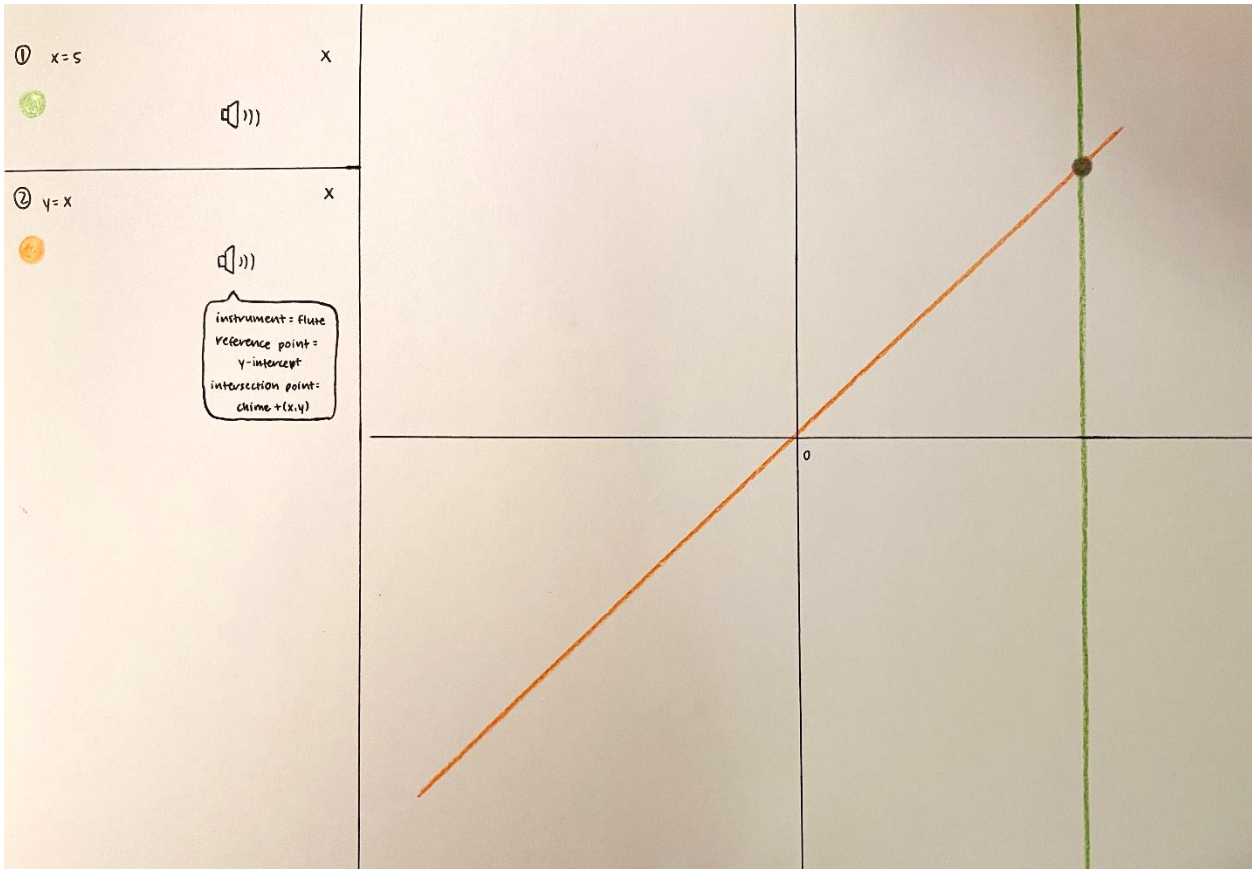

Figure 1: Online Graphing Calculator Add-On

Figure 1 shows a modified online graphing calculator interface, drawing significantly from the interface of Desmos. With this sketch, the main aspects to note are the integration of automatic audio upon entering the function and the ability to customize certain parts such as the instrument, the reference point, and the intersection point. The addition of a “play all” option also allows people to listen to the entire graph all together instead of only being able to hear separate functions. Benefits to this sketch include being able to use the same overall software as other students, in addition to requiring limited set-up. Drawbacks include adding extra buttons that will need to be navigated through with a screen reader.

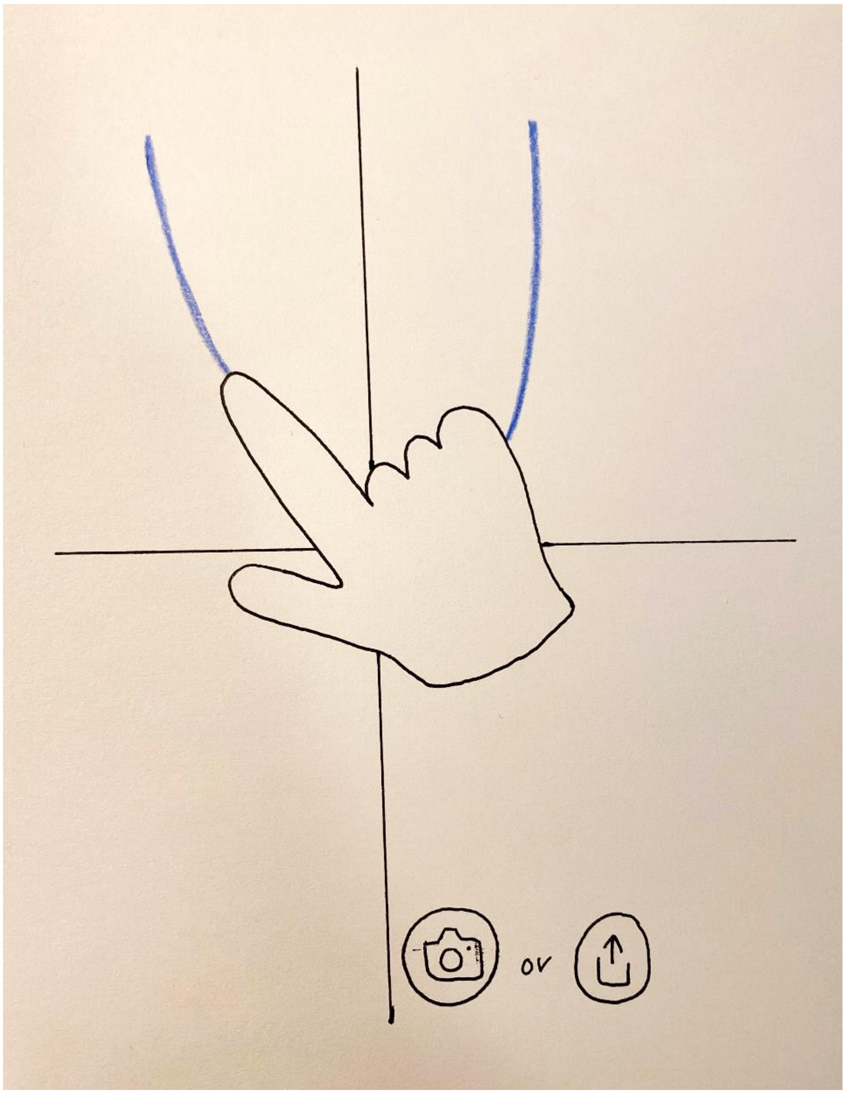

Figure 2: Tablet / Mobile App Interface

Figure 2 shows a person’s hand tracing over a graph, which will sound according to the x-position of the person’s finger. This integrates more of a tactile experience, as it is more hands-on, but does not have any discernable tactile elements because the graph representation is still on a screen. The same tasks are covered in this sketch, with the ability to customize the sounds of different graphs, reference points, and intersection points. However, since this is designed for a tablet / mobile app, there is also an opportunity to import existing graphs via an image so that people do not have to enter the functions themselves. Some benefits to this sketch include greater portability and limited set-up. Drawbacks include additional confusion from having to actively trace a function when there are no tactile references.

Selected Design and Storyboard

Ultimately, I selected the design from Figure 1 (the online graphing calculator add-on) due to its convenience, familiarity, and ease of use. This design is compatible with screen reader technology and allows people to hear all of their functions at once, which can help them contextualize how different functions sound in relation to each other. Additionally, this design addressed most of the concerns that Dr. Conroy brought up during the interview – it modeled the experience that already existed with online graphing calculators and translated it into an auditory interaction, meaning that the critical visual information about these functions and how they relate to each other is still conveyed.

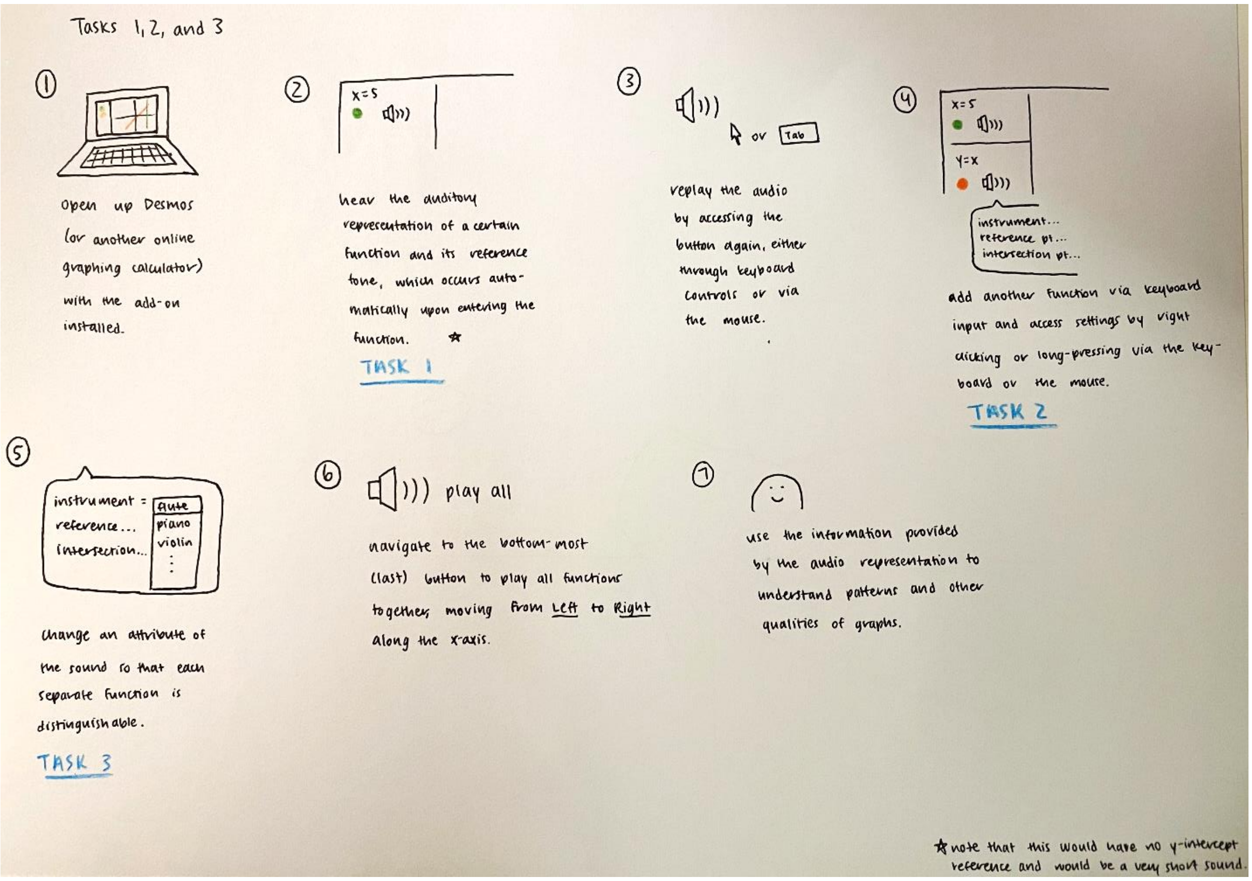

Figure 3: Storyboard of Selected Design

Reflection

As accessible technology is a subfield of HCI that I am interested in, embarking on this individual project was daunting and exciting at the same time. I was initially inspired to choose this project trajectory after attending a talk at UW by Dr. Kim Marriott, who is a professor of Inclusive Technology from Monash University. His talk, focused on his group's research in the area of accessible visualizations, covered a wide variety of options for augmented visualization solutions for those in the blind and visually impaired community. The portion discussing how STEM education materials are extremely inaccessible piqued my interest, and I became interested in thinking of a solution for visualization that did not necessarily require any additional devices or extensive physical components.

Although I was unable to contact and interview as many professors and experts as I had hoped due to COVID-19, I am incredibly thankful to Dr. Matthew Conroy for his contributions to my research and for pointing me in the direction of Dr. Larry Baggett's autobiography, as *In the Dark on the Sunny Side* was an engaging and eye-opening read. Learning about existing ways in which math and music collide was especially interesting to me. I studied piano and flute for almost 10 years throughout my elementary through high school years, yet never made the connection between music and mathematics until hearing about the different ways in with Dr. Conroy and Dr. Baggett combined their passions. This alone furthered my interest in exploring how these visual graphs could be translated into meaningful sounds and how they could adequately convey all of the same information that online visualizers could.

This ad hoc project also provided me with an opportunity to synthesize the ideas that I had learned in class into an individual project that would address much of the iterative design process. I did not quite get to testing the designs that I had created, but I found conducting research, developing tasks, and creating sketches to be incredibly valuable in fully immersing myself within this process. I would also like to thank Dr. Fogarty for his support and help with getting this project started, especially in terms of narrowing my project focus. I enjoyed delving into this field and exploring a new solution to making online interfaces more accessible and I loved learning more about how to make education more equitable as well. I hope to continue furthering my knowledge and interest in the subfield of human-computer interaction throughout the rest of my college career and beyond.

Works Cited

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