ASSESSING THE USE OF AUDITORY GRAPHS FOR MIDDLE SCHOOL MATHEMATICS

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ASSESSING THE USE OF AUDITORY GRAPHS FOR MIDDLE SCHOOL MATHEMATICS

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SUMMARY

Graph literacy is an important skill to master for a variety of reasons, for instance in order to pursue a career in science, technology, engineering, or mathematics (STEM), but the problem with graphs is that they are visual in nature. This puts people who have vision impairment at a disadvantage because they have difficulty accessing that information. Auditory graphing systems that use sound to convey information are a strategy for addressing this issue. Auditory graphs are capable of delivering graphing information in real-time, are easy to customize, more portable, and, as a teaching medium, can be accessed by low-vision, blind, or sighted users. However, they have largely not been evaluated in real-world classrooms despite their potential benefits in this context. Consequently, not much is known about the circumstances which allow for classroom adoption or the costs/benefits and impact of introducing this technology.

This dissertation addresses those issues and provides an in-depth analysis on the impact of introducing a new assistive technology in a visually impaired classroom. I discuss the motivation, design, implementation, and deployment of the Graph and Number line Input and Exploration (GNIE) software, an auditory graphing tool that enables students with visual impairment to navigate and interact with a coordinate plane or number line graph.

First, I discuss how a computer-based auditory graphing software can be a beneficial supplement to aiding teachers and students with vision impairment with middle-school based graphing principles. I also demonstrate that auditory graphing software supports collaboration between students of different levels of vision loss and that bone-conduction headphones can be used with software to perform concurrent think aloud protocols without degradation of qualitative data. Finally, I examine the challenges of introducing GNIE into a classroom with students who have vision impairment.

CHAPTER 1

INTRODUCTION

Coordinate graphs and number lines are an essential part of mathematics education in the United States. In Georgia, graphs and number lines are part of the Common Core standard from kindergarten through high school [1] . Graph literacy is an important skill to master for a variety of reasons, for instance in order to pursue a career in science, technology, engineering, or mathematics (STEM), but the problem with graphs is that they are visual in nature. This puts people who have vision impairment at a disadvantage because they have difficulty accessing that information.

Tactile graphics are the traditional medium for learning graphs for students who are visually impaired. While graphing principles can be represented using this medium, producing tactile graphs requires specialized equipment and knowledge about how to effectively convey graph components through tactile means. Examples of tactile graphics include push-pins and rubber bands on foam boards, specialized building blocks imprinted with Braille, and embossed paper graphs (Figure 1). These tools, with the exception of the embossed paper, tend to be bulky and hard to carry around, and once created, are difficult to change, making them not as flexible as digital representations of the same graphs. Additionally, using bulky materials makes it difficult for students to save their work for future review or transport boards between school and home. Teachers who prepare lessons using paper graphs must also do so using Nemeth Code – a special system of Braille used exclusively for math and science notations – and will often use additional specialized software to translate from text to Nemeth Code. Thus, the unique factors required for using tactile graphs make it necessary for teachers to take more time to prepare and give lessons and also make it harder for students to do work independently and at home. More details about this system are discussed in the next chapter.

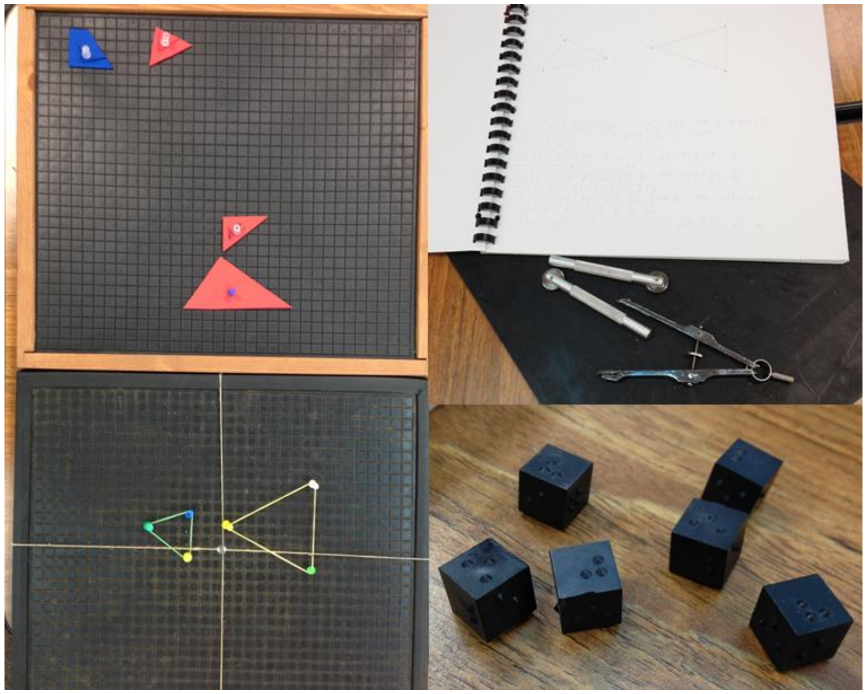

Figure 1: Traditional tactile graphics shown. Clockwise from top right: embossed paper, Braille cubes, boards with pushpins and rubber bands

Auditory graphing systems that use sound to convey information are one strategy for addressing graph literacy in individuals with vision impairment. Auditory graphs are capable of delivering graphing information in real-time, are easy to customize, more portable, and, as a teaching medium, can be accessed by low-vision, blind, or sighted users. One such tool, the Graph and Number line Input and Exploration software (GNIE), is being developed by the Georgia Institute of Technology Sonification Lab.

1.1 Research and Thesis

In this dissertation, I support the thesis that a computer-based auditory graphing software can be a beneficial supplement to aiding teachers and students with vision impairment with middle-school based graphing principles. I also demonstrate that auditory graphing software supports collaboration between students of different levels of vision loss and that bone-conduction headphones can be used with software to perform concurrent think aloud protocols without degradation of qualitative data. I examine the challenges of introducing GNIE into a classroom with students who have vision impairment. These claims are aimed to address the research questions that are listed in Table 1 and are explored in the rest of this document. Research questions R1 – R3 investigate the impact of introducing GNIE into the classroom as an effect of time and collaboration. Research questions R4 – R6 investigate the differences between auditory graphing tools and tactile graphing tools.

Table 1 Research Questions

R1	How does introducing auditory graphing tools to the classroom affect classroom dynamics?
R2	How will the use of GNIE affect time spent one-on-one per student?
R3	How will the use of GNIE affect student collaboration among themselves?
R4	How do auditory graphing tools differ from traditional tactile graphing tools?
R5	How do auditory and tactile tools impact the lesson planning process?
R6	What mental procedures do students employ to interact with GNIE and does this differ from what they use for tactile graphics?

1.2 Dissertation Overview

The remainder of this dissertation is as follows. In Chapter 2, I begin by briefly discussing related literature on accessible auditory graphs research. I then outline the overall goal of the study and methodologies employed during the two-year deployment of GNIE as well as provide an overview of our system.

In Chapter 3, I discuss data collected from the teacher and analyzed according to the teacher’s perspective and feedback of the system.

Chapter 4 discusses the collaboration within the classroom. This is collaboration between the teacher and student as well as students with each other. I go over how technology can help support this type of interaction.

Chapter 5 goes over briefly the features that were implemented in GNIE when I took it back to the lab over the summer between the two school year deployments.

Chapter 6 and 7 discuss how introducing GNIE into the classroom impacts students. Here, I examine the students' perspective on the deployment, beginning with data collected through focus groups and surveys and ending with a think aloud protocol that was conducted during the second year of deployment.

Finally, in the conclusion of this dissertation, I revisit my research questions and assess how I was able to answer them. I discuss contributions of this research and potential future work of this project.

CHAPTER 2

BACKGROUND

The National Federation of the Blind estimates that there are 93,600 school aged children in the United States who have vision impairment [2]. Depending on the level of vision loss, typically these students can use some type of assistive technology (AT) such as a screen reader to aide in their daily activities. AT can help students gain greater independence and increase engagement. With the many benefits that assistive technology for students with vision impairment can provide, it is unfortunate that studies report less than half the students who could benefit from AT use, actually use it during school [3]. Nevertheless, it is still important to study ways in which AT can be implemented to help with teaching and learning. For this dissertation, I examine ways AT can be used in a classroom for mathematical graphing concepts at the middle-school level. The particular type of AT investigated is an auditory graphing system.

Auditory graphing systems use sonification (nonspeech audio) to convey information about data [4]. They can provide an alternative medium for data analysis of both simple and multidimensional data, and have utility for any user regardless of ability to see visual plots and graphs [5][6]. There have been many studies that demonstrate that auditory graphs can present data in a meaningful way such that a user can perform various mathematical functions. For instance, research has shown that auditory graphing systems can be used to find patterns, conduct point estimation, provide context, and show error and uncertainty [7][8][9][10]. Using sound and sonification can be a very effective way to explore and interact with data, and are often used as a category of AT for users with vision impairment.

Auditory graphing systems are not a new concept. One of the earliest uses of an auditory system for exploring graphs was the prototype “sound graph” developed by Mansur et al [7]. This system used pitch to map two-dimensional line graphs. Subjects were tested on their ability to determine mathematical concepts such as the slope of a line, symmetry, and identification of straight lines versus exponentials. These results were compared to results from completing similar problems using tactile graphics. Sound graph compared favorably to tactile graphs in terms of accuracy, but performed better in terms of speed. Authors also argue that it is more cost-effective to produce and provides more flexibility and greater independence for persons with vision impairment.

Other early systems have demonstrated that people with vision impairment can access information from sonified line graphs with different types of data series [11] [12]. The success and potential of using sound-mappings to display data has led to the creation of some software packages built with auditory graphing in mind [13] [14]. These applications, while a good first step toward accessible graphing systems, have not been studied in a learning environment and are typically only used after graphing concepts are already learned rather than as a tool to teach graph principles.

Employing auditory graphs in classrooms is a promising solution to aiding students with vision impairment learn graphing principles not only because of the reasons listed above, but also because they require no additional specialized equipment or assistive technology to use. Additionally, there is some evidence that presenting information using multiple representatives can enable students to customize their learning experience and improve understanding and transfer [15][16]. However, they have only been tested or evaluated to a limited extent in real-world classrooms [17][18] despite their potential benefits in this context. Consequently, not much is known about the circumstances which allow auditory graphing software to be adopted in a classroom, the costs/benefits of using this technology, and what the impact of introducing this technology encompasses.

Our system, the Graph and Number line Input and Exploration software (GNIE), was originally created to align with the 6^{th} grade Common Core [1] graphing standards to ensure that it was practical and useful for teachers and students. Curriculum standards are used in order to ensure that students are equipped with sufficient foundational knowledge in core subject areas such as English and Math. While these standards may have varied state-by-state in the past, more states and territories are moving toward a uniform curriculum, called the "Common Core" [19]. The state of Georgia is among the states that have adopted this measure, and the standards are known as the Common Core Georgia Performance Standards (CCGPS). The statewide Georgia Performance Standards (GPS) are still in place for certain subjects, while the CCGPS is being used for English language arts, mathematics, science, history/social studies, and technical subjects. The CCGPS for mathematics was formally adopted in 2010, with implementation to begin in school year 2012-2013 for kindergarten through ninth grade. The introduction of the Common Core standards and changing expectations may leave students with vision impairment behind. We cannot expect students to keep up while using antiquated equipment when more is expected from them without the scaffolding and support that's provided to their sighted peers.

2.1 Understanding tactile graphics

Before going into detail about our system, it is important to understand the features of traditional tactile graphics that are employed by students and teachers today. Graphics are extensively prevalent as part of a learning curriculum in all school subjects, not only in mathematics. The consideration when using graphics with students with vision impairment is ensuring that the information is presented in a comprehensible way, especially since many graphics have multiple parts and labels. This means that care must be taken when producing these graphs.

Tactile graphics are the typical method of representing graphical information, and have been around for over 200 years [20]. There are many different ways to produce tactile graphics [21]. Choosing the right method involves a combination of assessing the material to be produced, the intended audience, the materials and resources at hand, and the expertise of the producer.

Many graphs also have accompanying text and notations that must be made accessible. There are many advantages to having a standard notation that is consistent and can be translated easily between written texts. There are three common approaches to accomplishing this: 1) by using Braille; 2) by using Nemeth code; or 3) by using synthesized speech. Braille is the most straightforward approach to presenting mathematical problems and notation. However, there is no universally accepted standard for Braille and countries can differ in the system that is taught and used for math. For instance, the UK uses UK Mathematics Braille, Germany uses Marburg code, and here in the US Nemeth code is used. Aside from the inconsistent standards for Braille, another concern is that many students are not using Braille. According to the American Printing House for the Blind's annual report, only 8.5% of students report using Braille as their primary reading medium [22]. Using an entirely Braille system for math would first require more support and outreach to increase the literacy rate.

There are a few systems available for translating visual mathematics equations and formulae into Braille. Systems such as LAMBDA [23] and the universal maths conversion library [24] each attempt to facilitate the translation between visual and tactile. For this study, the teacher-participant uses the Duxbury Braille Translator [25] for converting written text to Braille. These graphics and their accompanying text are then often printed on paper using an embosser. While the translation and production costs using these methods are lower than sending them to a specialized company to print (for instance using thermal paper expansion), they still run into the problem of having poorer discrimination between elements due to lack of height variability; further, graphs take up more space than a regular-print version.

Synthesized speech can also be used to convey information for math problems. Some work has been done to study methods for describing data graphs [26]. GNIE uses synthesized speech to read out text that is inputted by the teacher and the students. There are issues with this approach, however, including how to best group expressions for increased understanding and how to incorporate punctuation and phrasing [27]. All of these factors taken together make producing appropriate and accessible graphics for students with vision impairment a challenging project.

2.2 Understanding the Common Core

To begin with, the CCGPS is not a lesson plan issued to teachers that they must follow. Rather, it is a set of standards that highlight what concepts students should know at each grade level. Each standard is comprised of three parts: the standard, the domain it falls under, and the cluster(s) that fall under the standard (Figure 2). The standard defines the expected concept and can be made up of one or more clusters. A domain is comprised of one or more standards. While the standards do not provide methods of teaching to instructors, some examples are given to illustrate what is an expected result from the student. For instance, a 5^{th} grade math CCGPS standard will say:

> MCC5.OA.2 Write simple expressions that record calculations with numbers, and interpret numerical expressions without evaluating them. *For example, express the calculation "add 8 and 7, then multiply by 2" as 2 × (8 + 7). Recognize that 3 × (18932 + 921) is three times as large as 18932 + 921, without having to calculate the indicated sum or product.*

The standards do not make specific allowances for students who are English language learners or who have special needs. However, they are written broadly and meant to be interpreted with the largest number of student participation in mind –

including those with special needs. This includes saying that these students should be given “appropriate accommodations” stating, for example, that “students with disabilities reading should allow for use of Braille, screen reader technology, or other assistive devices” [28].

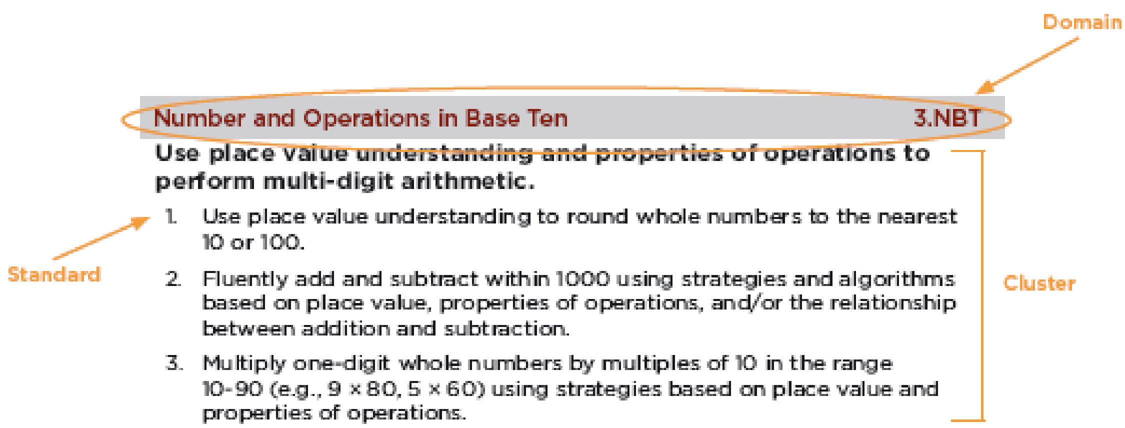

Figure 2. Example of how to read a standard. Image taken from the Common Core State Standards Initiative webpage

The language is vague about what is meant by “appropriate accommodations” and “other assistive devices”. While tools such as graphing calculators and screen readers are common enough to be widely accepted as appropriate, newer software such as the one discussed in this dissertation are not as ubiquitous and thus their status is unclear. This dissertation does not seek to amend the CCGPS, but rather to suggest that audio graphing tools (including but not limited to GNIE) may fall under “appropriate accommodations” for students who have vision impairment.

2.2.1 CCGPS for mathematics 5-8 grade

The CCGPS for math is grouped into eleven domains: counting & cardinality, operations & algebraic thinking, number & operations in base ten, number & operations – fractions, measurement & data, geometry, ratios & proportional relationship, the number system, expressions & equations, functions, and statistics & probability. The number of standards and clusters contained within each domain will vary by grade level. For the purposes of this dissertation, I will concentrate on the CCGPS math standards for the 5th-8th grade.

The first step to determining the utility of an audio graphing tool such as GNIE on math education is identifying concepts in each standard per grade. “Utility” here means that such software should *not* provide assistance that is more than can be expected in tools for sighted students. That is, this tool should not unfairly benefit visually impaired students – these students should still retain the same process of solving math problems as their sighted peers. To understand the role of the Common Core in our research, I have to try to catalogue the skills that are expected of students.

An attempt has been made in previous work [29] to provide a method for identifying and designing tools to meet graphing education standards – called the Standards, Questions, Answers, Reconstruct, and Evaluate (SQUARE) method. This method consists of five steps:

1. Standards. Identify education standards used in graphing.
2. Questions. Find and create graphing questions based on the standards.
3. Answers. Generate a task analysis based on answering the graphing questions.
4. Reconstruct. Build a system that can be used to answer the same questions using the same steps.
5. Evaluate. Confirm that the new system can be used to answer the same questions using the same steps.

The SQUARE method provides a good framework from which to start the identification process, but is too narrow in scope as it was implemented. For instance, researchers who employed this method identified standards by doing a search with the terms “coordinate”, “graph”, and “number line”. This captures all standards that explicitly use the specific graphing terms, but in practice teachers can use graphs to teach standards that do not contain those target words. In other words, math standards and how they are taught is a flexible, not fixed, process.

Many of the standards in the eleven domains in CCGPS involve solving or writing word problems. While these problems do not require a number line or coordinate plane, they may still benefit from the use of auditory software. This is because the software can provide a flexible way for teachers to disseminate information and problems to students, and they can reliably review information once it has been submitted.

2.3 Understanding assistive technologies

Assistive technology (AT) does not exist by itself. It is a device that is used with a human in a specific context to accomplish specific actions. Thus, it must be understood in the context that it will be used. Cook and Hussey created the human activity assistive technology (HAAT) model to provide a framework for identifying and understanding the relationship between an AT and its user(s) [30]. In this model, an assistive technology system is comprised of four components: the human, the assistive technology, the activity, and the context. Each component is a unique part of the system, and the entire system must be evaluated as a whole.

The human in the model is the operator of the system. In the context of GNIE, the human operator would include both the teacher, who uses GNIE to create and review questions, as well as the students, who answer problems. The AT component is self-explanatory (GNIE). The activity defines the overall goal of the system. This will vary depending on who is using the system. The context is defined as the social, cultural, environment, and physical conditions of AT use.

The context portion of the HAAT model is important to expand upon and understand since the educational context can be a unique environment for an AT. Cook and Hussey have identified four types of context that play an important role in the effectiveness of an AT system: setting, cultural, social, and physical. The educational setting for students with vision impairment is typically either: the student is enrolled in a specialized school for the blind (such as for this study) or the student is enrolled in a mainstream classroom. Within these classrooms, the type of interactions between student and teacher (learner-teacher interactions) that occur are also important considerations [31]. The social and cultural contexts described in HAAT include local policies and attitudes toward technology and disabilities by school administrators and social participation and perceptions by teachers and students. Finally, the physical context for educational use of AT involve analyzing the structural and physical components of the classroom. This can include the layout of the classroom and equipment as well as the physical placement of the AT to the user and the users with each other.

Here, I discuss each of these educational contexts as it relates to the current study. First, there is the educational setting where GNIE will be used. The Georgia Academy for the Blind (GAB) is a specialized institution that serves students with vision impairment primarily, but students may have multiple disabilities. The class sizes are small. Most classes have fewer than 10 students, making the student-teacher ratio higher than the average in mainstream classrooms. All the students at the school have some form of vision impairment, and academic expectations are the same for every student. All students are expected to take the standardized exams and taught from the CCGPS standards.

Next, the social and cultural contexts of the classroom play a role in understanding the interaction and acceptance of assistive technologies. At GAB, administrators are receptive to new assistive technologies. Students receive instruction on how to operate any new and existing AT available at the school. Most of the classrooms in the school are equipped with desktop computers and installed with screen reading software such as JAWS [32]. Other AT such as VisioBooks [33] and magnifiers are also available in each classroom. Students take a keyboarding class as part of their curriculum, and learn the key commands for various devices as well as how to navigate and type using a keyboard. The school computers have internet connection via wired and wireless networks.

Finally, the physical context of the classroom is depicted in Figure 3. Desks are arranged in a U-shape in the center of the classroom. Students are seated around the desks facing in, and the teacher typically sits in a chair in the center of the desks. Desktop computers are arranged along one wall of the classroom. During days when GNIE is used for lessons, laptop computers are set up on the desks. Some students sit in the U-desks and some students use the school-owned desktop computers along the wall.

Figure 3. Layout of the middle school mathematics classroom at GAB. Desks are arranged in a U-shape and computers are aligned along the wall.

2.4 System overview

Our software solution began with a general graphing model, with a focus on audio and accessibility. The Accessible Graph Model (AGM) combines graph settings with graph points lines, and canvases, capturing the graph display window, audio settings, visual settings, and a variety of other components. For example, a line could now be set to have not only a certain color (e.g., blue) but also a certain timbre (e.g., grand piano), and that setting was a part of a “graph” object, which could be saved, visualized, printed, heard, or emailed to a friend. Due to early interest in cross-platform compatibility, and interest for the AGM to act as the graph model for the Java-based Sonification Sandbox, the AGM was programmed in Java and intended for desktop purposes.

A complete multimodal graphing program was built in Java on top of the AGM. The final program was named the Graph and Number line Input and Exploration (GNIE) tool (see Figure 4). The first-generation (GNIE 1.0) user interface had three main parts. The first part is a widget area across the top with typical interaction widgets, specifically menu items, check boxes, text boxes, and buttons. These widgets inherit accessibility hooks automatically, and were enhanced with additional accessibility context for screen readers. The second part is a text area, covering the left half of the screen below the menu bar. This holds any non-graph parts of a graphing question, such as the text “Plot the point (−2, 3).” The third part is a graph (or number line), covering the right half of the screen below the menu bar. All accessibility was handled explicitly by GNIE, to control for screen reader effects.

Due to the dependency on existing Java systems, and the portability of Java, the system core is in Java. Later evaluations used two and three sounds in production, and up to four in development (specifically x-axis, y-axis, and either radial point distance or x and y distances each having a sound simultaneous with the others). While the latency remained low on many systems, the load was high enough to crash the system or the Java Virtual Machine. Since Java could not handle the audio processing, Max/MSP was used as an alternative. This program/language has a reputation for low-latency audio processing. In addition, using Maxlink, it was possible to send messages to Max/MSP from Java. The Max/MSP program, ProcPlayer, played sounds based on messages with information about channel, instrument, pan, pitch, pitch bend, rate, and volume.

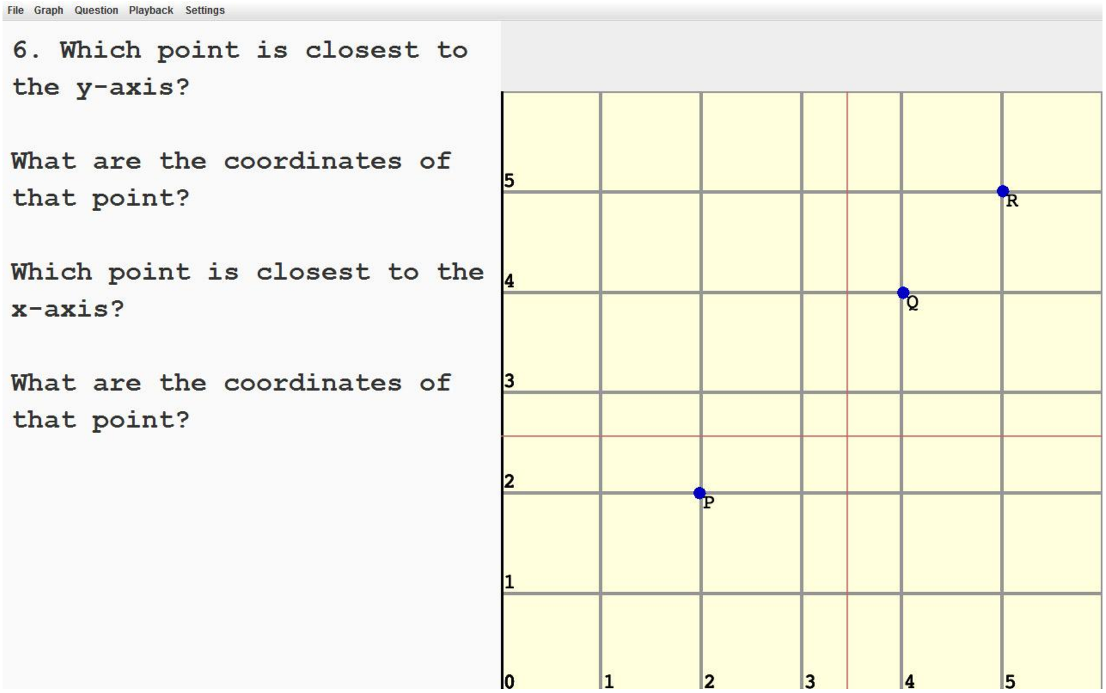

Figure 4 Screengrab of GNIE 1.0 user interface, showing menu bar, single text area (left), and graphing area (right).

Initially, the six channels programmed in Max/MSP were mapped to context sounds for the graph (x and y), the X and Y axes, and the radial distance from a point (in the x and y directions). The sounds relating to the distance from a point begin when the cursor is within a five tick-mark radius. Each point has the same mapping, which means that every point has the same sounds associated with it - i.e. if there are two points graphed (A and B) - being at a distance of 3 from point A sounds the same as being that distance from point B. The context sounds for the graph relate to the overall position of the cursor within it; this was done as a way to help give the boundaries of the graph a distinction from the middle portion. When passing over a tick-mark, the context sounds' tempos speed up, so that when the mouse is on an intersection of the marks (e.g., (4,3)) it is fastest; and when exactly between two tick marks it is slowest. These notes also utilize the mapping of pitch to provide information about the location of the cursor. Positioning the cursor near maximum for the x or y values on the graph results in a higher pitch; being near the minimum for them results in a lower pitch. Finally, the axis notes are specific noises related to crossing the x or y axis. A timbre mimicking a drum was used for the X and Y axes, to distinguish when the cursor was on the axis. In addition to sonifications alone, a text-to-speech (TTS) engine was implemented to read out the x and y tick-mark values when exploring the graph. The TTS helped provide concrete orienting information about the cursor location, to aid in exploration of the graph.

During Fall 2013, the development team began implementing a major new feature for the system - support for lines. It is a feature that the teacher has requested multiple times. This version, GNIE 2.0, allows for a line to be drawn between two points in the graphing area (see Figure 5). While basic line functionality existed in previous versions of GNIE, it was still experimental and thus was not made available to the teacher or students. The experimental version of line-drawing created lines as a series of points plotted within the range of two endpoints. It was not enabled for school use because there was concern that this implementation would cause confusion for the students due to the resulting auditory output. For users, a line would sound like many points plotted simultaneously. We decided that it was important to differentiate between the sonifications mapped to the end points versus other values on the line segment between them.

To begin creating a new sonification for lines, GNIE 2.0 updated the sound mappings from version 1.0's Max/MSP programming. Based on observation conducted during the deployment at GAB, we determined that students mainly relied on the TTS X and Y-values to orient their location on the graph Thus, the pitch-specific context sounds depicting the location of the cursor on the graph were removed. Using tempo to reference when the mouse was near or on an intersecting tick-mark remained unchanged. Additionally, the sounds mapped to plotted points on the graph are the same, except that the distance threshold for the radius was changed to four instead of five.

A majority of the sonification changes made revolved around the way lines were represented to the user. It was important to show the continuity of the line segments, therefore the sounds initially mapped to the X and Y axes were changed to map onto each line. The dimension of pitch was used to represent the x and y-values, and to mitigate any confusion which may arise from hearing both values' pitches at the same time (both the X and Y mapping), the graph must be locked on either the X or the Y axis. When locked on the X axis, the y-values of the line segment may be explored (and vice versa). For all of the values, a higher number is represented by a higher pitch. Therefore, when exploring in the Y direction from y = 5 to y = -5, the pitch at y = 5 will be the highest and the pitch at y = -5 will be the lowest. The same concept applies to the x-values, as well, when the Y axis is locked. To determine the location of the cursor when locked on either the X or Y axis, a distance algorithm from linear algebra was applied to calculate when the mouse was within the two end points (this is to keep the graph from playing line specific sonifications when the cursor is not within the length of the line segment).

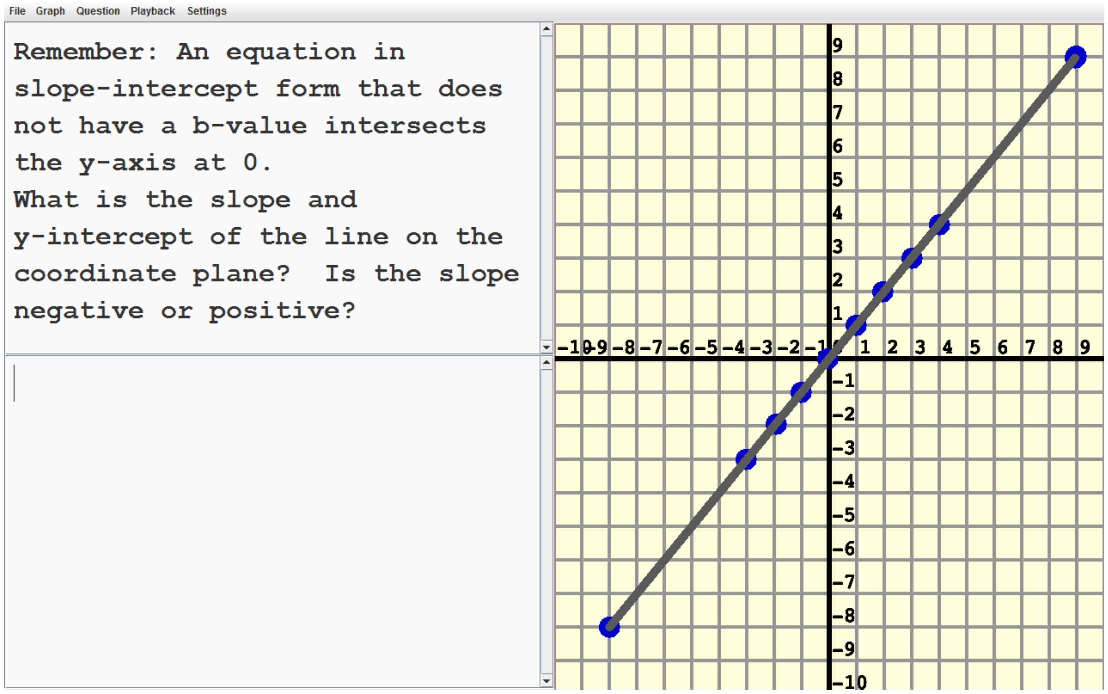

Figure 5 Screengrab of GNIE 2.0 in Student mode. The graph supports drawing of lines between points.

Multiple lines may also be created in the same graph. A line can be drawn from a series of two previously plotted, consecutive points, or when an endpoint of a line is selected, a new line can be drawn at the location of the cursor. This means that a user has the option to draw a single line, multiple lines, or draw any number of polygons within the graph area, as long as points are plotted (or selected) in pairs to form the end points. This version of GNIE was deployed at GAB for Spring 2014 and feedback for this version is discussed in the following chapters.

2.5 Methodology Overview

The purpose of this research is to understand and assess the impact of introducing a computer-based auditory graphing software to a vision impaired classroom. The overall study took place over the course of two-years at the Georgia Academy for the Blind (GAB) where GNIE was deployed in a middle-school mathematics classroom. My user populations are the middle-school mathematics teacher and her students at GAB.

To help answer our research questions, a variety of qualitative and quantitative data was collected during the study. The emphasis of this research is on deploying the system in a realistic setting and allowing the users of the system to decide how they would interact and use the technology. Because of this, a bulk of the data relies on video-recording classroom activities and minimizing interference with lesson plans. Nevertheless, it is still important to gather feedback from the stakeholders and employ some type of assessments, so in addition to video data, interview data, focus groups, and survey data were collected as well. The general overview of the data sources are discussed below and are expanded in detail in each chapter.

Video Data. Video data were collected during each visit to the school (approximately 4-6 weeks apart throughout both years, specific details are in later sections). The video recordings are used to document teaching practices for middle school math during tactile days and compare them to GNIE days. The data were coded for intervals of interest or activities of interest such as lecture time during a lesson vs individual student time.

Interviews. Interviews were conducted periodically with the teacher. This is in order to collect qualitative feedback on GNIE. The interviews focused on system use and the teaching process in general.

Focus Groups. Focus groups were conducted at the end of every semester with the students. The purpose of holding focus groups was to facilitate brainstorming activities with the students about GNIE. I also asked general questions about our system and feelings toward using the system.

Surveys. Surveys were verbally administered to the students after the focus group. The survey measured attitudes toward computer graphs and attitudes toward paper graphs. There were Likert-type items for computer graph use.

Think aloud protocols. The think aloud protocol was employed during SY2013 in combination with the focus groups and surveys with the students. The purpose of the think aloud is to examine the underlying cognitive processes for executing certain graphing tasks in GNIE and compare them to executing those tasks using tactile graphics.

The combination of the above listed methodologies allowed for a well-rounded repository of data and holistic view of the system deployment. The video data provided a natural framework for how the system was used and the focus groups, interviews, and surveys probed why the system was used and why the system did (or did not) work.

CHAPTER 3

THE TEACHER'S PERSPECTIVE: EXPLORING GNIE

In this chapter, I examine the challenges faced specifically by teachers in lesson planning, execution, and review, and compare how this changed when GNIE was introduced in the classroom. I will give an overview of my methods and major themes that resulted from my interview with a teacher at GAB. These themes focus on the major concerns as they relate to the three stages of instruction: lesson planning, lesson delivery, and lesson review. I will also discuss how the results can inform the design of GNIE going forward and accessible auditory graphs in classrooms where there are visually impaired students.

Tactile graphics, as mentioned earlier, are the traditional assistive technology tool for teaching graphs to students who are visually impaired. While these graphs are widely used, they have some limitations such as being bulky and hard to carry around, difficult to change once created, and requiring specialized equipment, making them not as flexible as digital representations of the same graphs. Thus, the unique factors required for creating and using tactile graphs make it necessary for teachers to take more time to prepare and give lessons and also make it harder for students to do work independently and at home.

Auditory graphing systems, such as GNIE, that use sound to convey information are another assistive technology option for addressing graph literacy in individuals with vision impairment. GNIE was originally created to align with the 6th grade Common Core [1] graphing standards to ensure that it was practical and useful for teachers and students. GNIE is implemented in Java and will run on both Macintosh and Windows computers. The basic layout of the interface consists of separate text and graphing areas. Users are allowed to find, plot, and label points by navigating with a mouse or keyboard along the x- and y-axes. The system reads out text and tick marks, and maps horizontal and vertical axes to pitch. There is a separate sound for points, alerting users when they are near or on a point. For a full technical report, please see [34]. The system was tested with students in a small-scale pilot, and results showed that subjects performed similarly using GNIE when compared to their normal graphing medium [35].

3.1 Methods

For this portion of the study, I examined a teacher's perspective and role in teaching middle school mathematics (including but not limited to graphing principles) to students with vision impairment using traditional tactile methods and our auditory graphing software (GNIE). Additionally, I am interested in gaining a qualitative understanding of how our system is used in the classroom and the perceived benefits and disadvantages of our system. This study takes place at the Georgia Academy for the Blind (GAB) over the course of two years – school year 2012 (SY2012) and school year 2013 (SY2013). In Fall 2012 before the beginning of the semester, GNIE was installed on four school-owned desktop computers and three laptops provided by Georgia Tech. In order to allow for a more realistic usage scenario of GNIE, I opted for a more ethnographic approach and left it up to the teacher to decide how she would use and incorporate the software into her class. This means that the teacher decided how to introduce and instruct her students on GNIE use and what lessons given.

The teacher's perspective and data gathered relating to the teacher's role in the classroom is only one part of the two-year deployment study of GNIE. For this component, I chose a mixed method methodology, including both video and audio recordings of classroom activities and interviews. The teacher I interviewed is responsible for math instruction for middle school, science instruction for 7th grade, and abacus instruction for middle school and high school based on need. The teacher had some familiarity with GNIE from working previously with researchers from Georgia Tech to pilot the software during several after school sessions [35]. However, SY2012 is the first time GNIE is used during her official class time as part of her lesson plan. I chose the semi-structured interview as a methodology because I was interested in understanding the experiences of the teacher prior to and during use of GNIE in her classroom. Additionally I wanted to gain insight into the challenges faced by teachers of students with special needs and the role technology might have in this environment.

In SY 2012, I asked the teacher to speak with us in three approximately 45 minute semi-structured interviews. Each conversation was audio recorded and transcribed. The interviews were spaced at approximately the beginning, midpoint, and end of the school year with the first interview taking place 2.5 weeks before the first in-class use of GNIE, the second interview 2 weeks before the end of the Fall semester, and the third interview at the end of the Spring semester. In SY2013, I conducted six interviews with the teacher. The interviews were approximately 15-20 minutes each and were conducted about 6-8 weeks apart during each visit to the school. Rather than interviewing at the beginning, midpoint, and end of the school year, I opted to perform more frequent interviews that were shorter in length in order to gather feedback on opinions and events that transpired between each visit. This allowed me to ask more specific questions relating to our research goals and made it easier for the teacher to recall and aggregate events from shorter time intervals during the interview.

All interviews were conducted in the teacher's classroom during her break period on a school day. During the interview, I asked questions about technology use in the classroom, expectations for GNIE, outcomes and experiences from using GNIE, and general questions about lesson planning, execution, and review. For data collected during SY2012, an inductive coding scheme was utilized. The interview transcripts were analyzed by creating themes from extracted statements of interest [36]. Statements of interest were extracted from each interview transcription, discussed, and grouped together by theme. This was done by two independent coders. For data collected during SY2013, a deductive coding scheme was used. Transcripts were uploaded to Dedoose [37] and statements were coded according to the pre-determined set of themes from the previous year.

I also conducted a series of classroom observations in order to document the use of GNIE during class and to have a comparison for when lessons are given using tactile graphs. Each visit to GAB lasted for two days and the interval between visits was about one month. During the first day of each visit, lessons were conducted using traditional tactile mediums, and GNIE was used for the lesson during the second day. Lessons given on the second day covered the same or similar concepts that were presented on the first day. The lesson was video recorded and coded using the software Elan [38]. I used this software to determine the distribution of the teacher’s time during a lesson with traditional tactile methods compared to the auditory graphing software, and the data was annotated for time spent lecturing all students and time spent per individual student.

3.2 Results

I begin by presenting our interview themes and the supporting evidence in topical clusters. First I consider how instruction for visually impaired students differs from instruction for sighted students. Next, I describe the challenges in providing instruction for visually impaired students, and then I discuss the initial reception of GNIE in the classroom from the teacher’s perspective. I will also go over the results from my classroom observations over the year and present data about how a typical lesson time was split between lecturing and individual time spent with a single student.

3.2.1 General teaching challenges

Our teacher participant explained that instruction for students with vision impairment differs from instruction for sighted students mainly in the required training for teachers of this population and in the medium in which class material is presented. Tactile graphs, as mentioned before, are the most common traditional way of presenting graphical information to students. In addition to creating these graphs to depict things such as number lines, bar charts, and coordinate plans, math equations and scientific notations must be printed and read using Nemeth Code. Teachers use Nemeth Code to write questions and students use it to answer them in Braille. There are specialized software such as the Duxbury Braille Translator [25] that will help with this. The teacher uses both Duxbury and the word processing program Scientific Notebook [39], as well as the Common Core GPS Coach series textbooks [40] to prepare her lessons. External specialized equipment such as an embosser is also needed.

Another tool that is gaining popularity in mainstream classrooms is the subscription-based academic software Study Island [41]. Also available at GAB, this tool contains lesson objectives that are in line with the Common Core curriculum. Lesson problems are given typically in multiple-choice format over a variety of different subjects and it tracks students' progress over time. This commercial software, like ours, does not require any external equipment other than a pair of headphones but must rely on a screen reading software such as JAWS [32]. It has seen minimal use in our teacher's classroom, however, because "it won't read the question to them and even JAWS won't work well with it so it's for the visual. The diagrams they have on there, there's no way."

Consideration should also be given to how students can demonstrate their knowledge of the material (e.g., by answering problems correctly in class or during a test). To answer problem sets, students in the class have two options: low-vision students can write their answers on the large-print handouts given to them by the teacher; blind students type their answers using a mechanical brailler. Note takers, with refreshable Braille, are another option for recording answers. Its drawback is that:

> *"Note takers have refreshable Braille on there that you can write [on]. You could use it for word processing and all that but they only see one line*

at a time. To do a math problem and only see this much and then you've got to write, you're not gonna see what's up there. I tell them no, don't do it."

Being able to "see" and feel a graph was perceived to be an integral part of the learning process according to the teacher. She explains,

"I kept saying but we need a grid right in front, along with that, you know they can hear it, they can see it! That's ideal for me…they've got to see it, feel it, see what they've written on the paper."

Some of this can also depend on the personality traits of the students. Each student has their preferences, and according to the teacher, some of them "want to touch, they don't care what they hear or even see, they want to touch it".

3.2.2 Lesson planning challenges

Lesson planning describes the period prior to class instruction where the teacher prepares material for a class. This includes checking lesson plans, researching and creating any digital copies of the lesson, and preparing physical class materials for the students. The main challenges during this phase are time management and mobility.

3.2.3 Lesson planning time management

When trying to gather materials for a lesson, the teacher expressed the desire to be afforded more time to prepare for classes. She describes a typical week:

"I have so little time. I have only 1 hour of planning and that's not every day. I have maybe 3 hours a week so I have to just wherever I am during my lunch break, during my if I had my lesson plan that's when I do it. … And the fact that I have to constantly, I'm constantly looking for 4 different classes. All the information every class needs and that's not real easy to do."

This is a sentiment that is repeated several times over the interviews. She describes how she used to copy terminology from the Common Core curriculum by the week, but has switched to doing the entire year at once since “it takes time to do that when I could be planning…”. Lesson planning is time consuming for most teachers, but those who have students with vision impairment have the additional requirement of making sure that the upcoming lesson is in an accessible format for their pupils. The teacher has to prepare two versions of the lesson – one large-print copy for low-vision students and one Braille copy for students who are blind. Even preparing these copies can be challenging because of the limitations of tactile graphics. The teacher gives an example:

> *“If the number span is very long then you can’t do it in Braille. That’s another reason why I use the board sometimes is because I can’t you know – and to me, it just does them no good if they have it in the book two or three pages.”*

3.2.4 Lesson planning mobility

Due to the materials required to prepare a traditional tactile lesson, the teacher is often unable to take preparations outside of the classroom and equipment. For each class, the teacher must prepare two types of learning materials – one for low-vision students and one for students who need Braille. Preparing tactile graphing and math lessons requires equipment such as an embosser to be available and accessible. The teacher affirms that “I usually do it here [the classroom]. I do some of it on the laptop but I usually do it here because that's hooked up to my embosser”. Aside from the embosser, lessons prepared for low-vision students must be magnified and copied using the school printer.

Additionally, licensing costs for specialized software to translate typed math symbols into Nemeth Code prevent the teacher from creating lessons easily from her laptop. A commonly used translation software is the Duxbury Braille Translator [25].

GAB holds licenses for Duxbury, and it is installed in the teacher's classroom computer. The license does not extend to personal computers, such as a teacher's laptop, making it expensive for a teacher to prepare lessons away from the classroom.

3.2.5 Lesson delivery challenges

Lesson delivery describes the period of official class time when the teacher discusses material with a class. This includes ensuring that the students have the necessary equipment to complete and understand a given lesson. During this time there is typically social interaction between teacher and student, and student and student, which I will discuss below. Time and mobility are again main concerns in this area.

3.2.6 Lesson delivery time management

It can take students with visual disabilities longer to go through a set lesson plan. Some of this delay stems from the time it takes to set up the materials and assistive technology required to complete the lesson – for instance, setting up magnifiers for low-vision students and Perkins Braillers for note-taking and answering questions. Nevertheless, teachers must still cover a large amount of material required by the state and school, and time is an important resource. When discussing the amount of time it takes to cover material with her students versus a mainstream classroom, the teacher has this to say:

> *"…and it was so hard because ...well...you've probably seen this from working with our kids...what you think might ordinarily take this much time [holds hand about a foot apart] takes this much time [holds hands about two feet apart]. Just because it takes that much time just to get going, to get things set up, and, you know, get into class."*

The teacher also expressed frustration with not being able to reach set objectives in lessons. She says, *"We're never exactly where that [the objective] is and then I usually get to the endpoint which is a little bit unclear endpoint where they're not really quite ready but I have to go onto this."*

3.2.7 Lesson delivery mobility (i.e., homework)

Despite taking longer to cover set lessons, the teacher felt it was difficult to assign material for students to do on their own because of availability of assistive technology equipment and the need for guide or helper. Assigning extra practice problems or work to students to reinforce classroom lessons is a fairly common practice, but can be challenging for students with visual impairment. Boards are bulky to carry around and can often only be used to display one problem at a time. Additionally, it is unclear whether students own equipment such as boards and Braille blocks at home.

There are also concerns about students needing a guide to help them with assignments. The teacher comments,

"It's difficult for me to assign them something that they have to do tactily [sic]. That's hard to do because I need to give them instruction and so they don't usually have a lot of homework".

She clarifies by saying, "We usually do most of our work in class."

3.2.8 Social interaction during lessons

The teacher encourages social interaction and collaboration between students during lessons. Typically she spends the beginning of class giving an overview of the lesson. Due to the small class sizes, she is then able to walk around to each student to help them with any individual questions. During this time, she might pair up students, allowing them to go over concepts with each other. According to the teacher:

"...both respond well because one loves it because they can show somebody something and the other loves it because they're gonna listen to

them probably better than they listen to me. And the thing about 'you learn more when you teach it', that works for them too."

She emphasizes that collaboration between students when learning math is "most definitely" something that she tries to encourage in her class. One reason for promoting co-learning is so that the teacher can spend more time with individual students who need extra help. She explains that,

"Often it'll be all the kids and I have to be with you and you and you and it's kinda hard to decide 'OK wait just a second, I'm working right here"

She also says, *"One time or another someone will be a helper"*, and this is a good thing.

3.2.9 Lesson review challenges

Lesson review is the period after instruction where teachers review work that has already been presented in class. This includes any work that students completed in class and any assignments that were completed at home. This period can overlap with the time spent in lesson preparation, but does not look at future lessons. This does not occur every day because of time constraints. The teacher explains,

"It would be a great idea to go back and look at their answers and see how they did cause I didn't really see what everybody did. But I haven't had time to do it."

As before, time remains a premium resource.

3.2.10 GNIE reception

In the first interview before deployment, the teacher was asked questions about how she expected GNIE to work in relation to her lesson plans and what she felt the role of this software would be in her classroom. In subsequent interviews, she was asked questions about whether or not GNIE met her expectations and general questions about her perception of GNIE after having used it. In SY2013, I asked questions about how she planned on using GNIE during that school year and, later, whether or not she was able to follow through with her plans. The main perceived benefit of using GNIE was the savings in time during lesson preparation, and GNIE was used mainly as a supplement to tactile graphing lessons.

3.2.11 GNIE feedback

There have been both challenges and benefits to the introduction of an auditory graphing tool to a classroom as perceived by the teacher. Benefits of using our system over tactile graphics were: 1) perceived efficiency (time savings) and materials preparation for lessons; 2) increased collaboration opportunities between students; and 3) a straightforward medium for writing creative problems for the students. The challenges were mostly technical in nature that resulted from: 1) the beta-level software experiencing system crashes; or 2) problems with students or the teacher remembering the proper procedures for using the software. Examples include statements such as “I don't know how to change the order”, “I told you the major frustration is when I use it I feel like I'm using it for the first time again”, and “I don't know how to go in there and change it”.

In practice, the main perceived benefit of using GNIE is the savings in time during lesson planning. The teacher explains that:

> *“…all I have to do is enter it [lesson questions into GNIE] and entering it is easy so that's easier than when I have to translate stuff and even when you scan it and translate it, it still takes a little time. Nothing like it used to but it takes more time than using GNIE.”*

And:

> *“When I'm doing coordinate plane and coordinates and so on and number lines even the traditional way it can take more time you know 30 minutes*

> *to an hour to do some of those lessons. Whereas on the GNIE it is a lot quicker – you know a LOT quicker."*

Overall, she says she likes it because "It's quicker. It's quick. It's quicker than the tactile graphs". The teacher also feels that the students have generally positive reactions to the tool. She says, "They enjoy locating the points and I think they feel good about being able to use a computer to do a lesson".

During the first year, a few feature requests were brought up in the interviews. The first was the ability to expand the range of graphs that can be produced. The teacher mentioned during our interviews the limited range of values that the number line and coordinate plane could represent in our system (GNIE could only count by ones and could not handle decimals). The second was the ability to support line drawing. Lastly, there appeared to be a need to rework the architecture of the system to recognize hierarchical folder structures and load questions from different files so that students' work could be saved efficiently and multiple lessons for several grades and dates could be created at once.

3.2.12 GNIE as a supplemental tool

Before using GNIE as part of her class routine, the teacher expected that the software would be used as a supplemental tool for her lesson plans. She did not plan on using GNIE as the only medium of data presentation when going over an objective. She said, "…when I'm first teaching something I would probably be doing this [tactile grid] mostly, but then I would be moving towards GNIE…". She projected that the tool would act "like a supplementary type thing and something to just sort of drive it on home" and that, "it will just be another way of getting at what they need to know and perhaps help them understand". She added that this technology would enable the students to have "a new way to look at it".

Once the students had gained experience and familiarity with GNIE, the teacher said she would be open to the tool having a more prominent role in her teaching. She said, “I mean once they're all used to GNIE and know what to do I may or may not decide hey, we can go right on into using GNIE”.

After using GNIE in her classroom I asked whether GNIE met her expectations from the start. The teacher affirms this and explains:

> *“I think that they saw how it tied in and how you know, it made sense to them. I made sure that we had already had lessons on whatever we were going into so they would have a basis so I think it made sense to them.”*

However, she still did not feel that GNIE can be used *exclusively* as the medium for teaching graphing principles:

> *“I'm not convinced that it can only be GNIE. I think it has to be GNIE with, I think it's a wonderful addition, but I think it needs to be with something else - especially when I'm introducing something.”*

She also mentioned that while GNIE was helpful for lessons that involved number lines and coordinate planes, for lessons that dealt with graphs outside the scope of plotting points, it remained a challenge for her to adjust problems so that they could be integrated into the system and utilized more often into her daily lesson plans. She admits that,

> *“I didn’t get to stretch my mind to the point where I could say ‘Yeah, I could do it like this’ with other things. You know, three-dimensional figures, in 7th grade they do cross-sections.”*

For now, GNIE is used a tool to be used to reinforce ideas that have already been introduced (e.g., the y-axis is explored vertically and x-axis horizontally) rather than the first point of introduction for a new concept.

3.2.13 GNIE for creative expression

A unique benefit of using our system compared to traditional tactile graphics is the relative ease of question creation and answering. One of the ways that this has been used to increase engagement during lessons was by the teacher creating questions that included names of students in class as a word problem or asking an open-ended question that could be answered in multiple ways (see Figure 6 for example). For instance, even though a particular word problem for a lesson may be taken directly from a textbook, the teacher might change the character names in the problem to a name of a student in the class. The teacher said that she really enjoyed being “able to tailor it” to the students in her class.

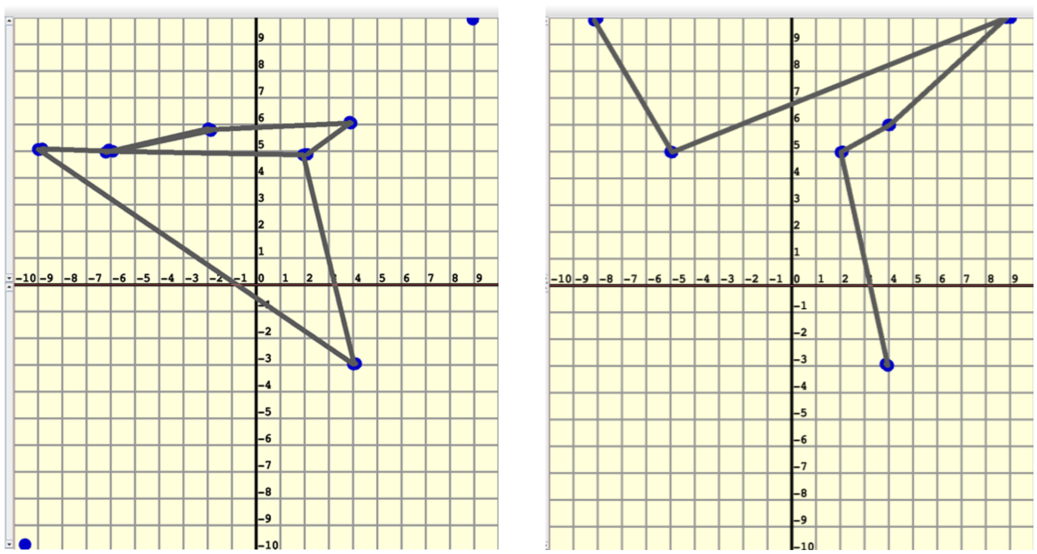

Figure 6. Example of student work for a lesson. The problem asks students to plot points on a graph and then connect them in whatever way they prefer. The two graphs are from two different students.

3.2.14 Classroom observation results

Time series data were generated using Elan and synchronized with the video data. I defined intervals of interest based on the teacher's speech and attention. In the system, I created several rows – one to account for when the teacher addressed the entire class (T-

All) and one for each student to account for individual student attention. An example is shown in Figure 7. Each student's interval was annotated according to when the teacher was addressing them or helping them with the lesson. During class discussions, an individual student's response to general questions and the teacher's acknowledgement were counted towards that student's time. Periods when the teacher was conducting non-lesson related activity, such as talking with another teacher, were not used in the overall time tally. The total annotated amount for each row was summed and the aggregate of each student's individual time spent with the teacher was compared to the teacher's overall lecture time.

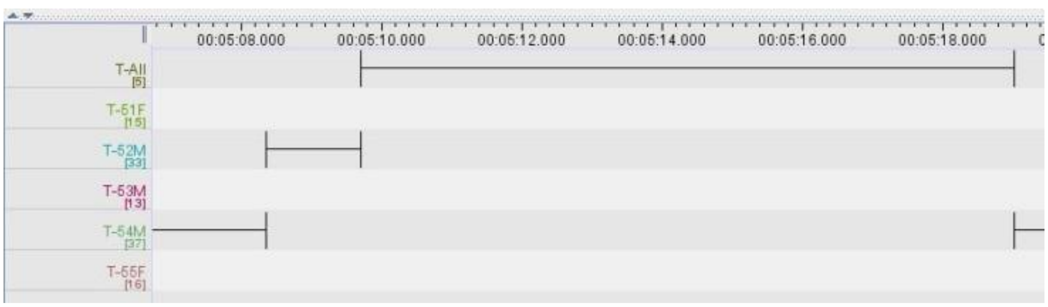

Figure 7: Elan time series data with annotations

In order to determine the effect of GNIE on how the teacher apportioned her time between class lectures and individual student attention, two analyses were conducted. A paired-samples t-test was done in order to determine GNIE's effect on the amount of time the teacher spent speaking to the class as a whole. Results demonstrated that she spent significantly less time addressing the class on days when GNIE was deployed (*M*=611.91, *SD*=320.02) compared to those days in which tactile/paper graphics were utilized (*M*=3895.19, *SD*=1583.89), t (5)= 5.048, *p*<.01(Figure 8).

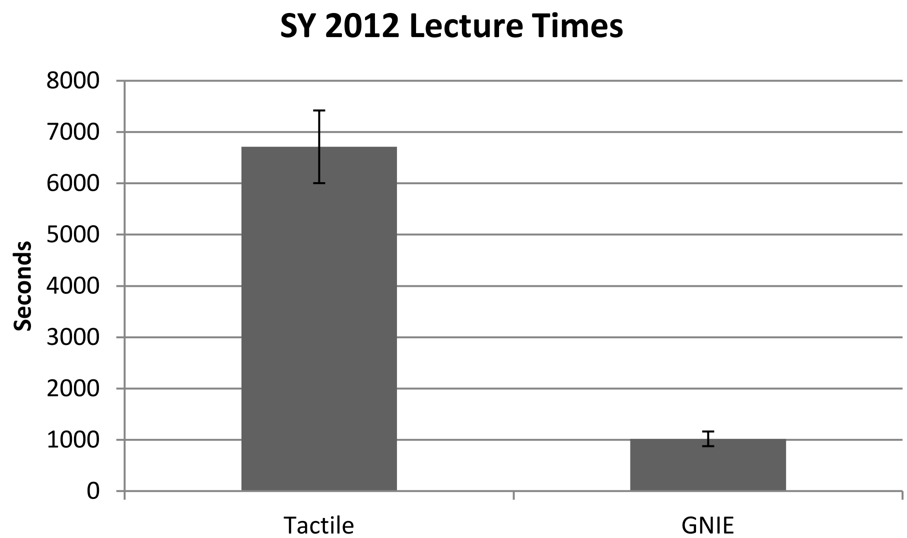

Figure 8. Lecture time means when the teacher is using tactile graphs versus GNIE. Results are based on 10 days of observation - 5 days of tactile lessons and 5 days of GNIE lessons.

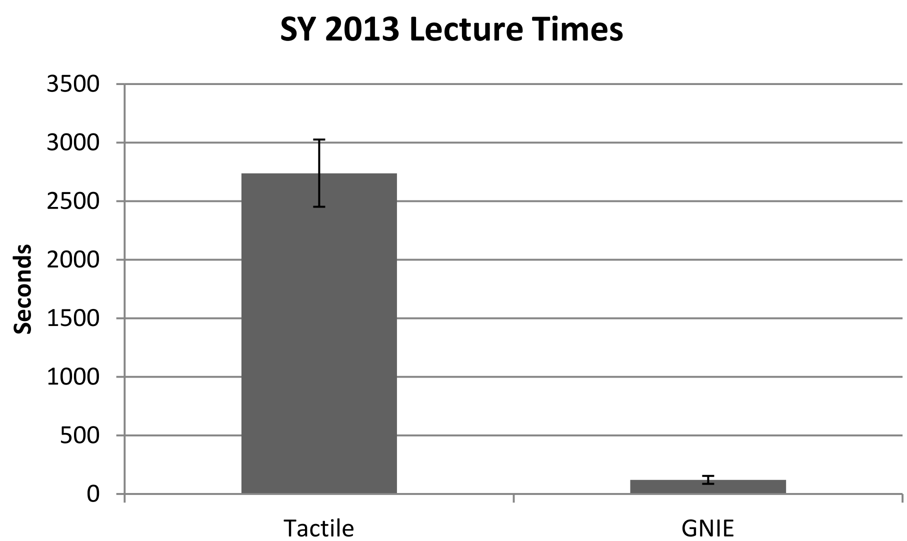

Figure 9. Lecture time means when the teacher is using tactile graphs versus GNIE. Results are based on 14 days of observation - 7 days of tactile lessons and 7 days of GNIE lessons.

In order to determine if this decrease in lecture time led to an increase in individual student attention, a 2 (Presentation modality: GNIE or tactile graphics) x 5 (Session: 1, 2,…5) x 3 (Grade level of questions: 5th, 7th, or 8th) mixed model ANOVA was then conducted on the time spent with individual students (with Presentation Modality and Session as within subjects variables and Grade level as between subjects). The overall omnibus ANOVA yielded a significant effect of modality (F(1, 10)=18.663, p<.05), which demonstrates that the teacher spent significantly more time with individual students on GNIE days as opposed to tactile days. There were no other significant effects in the omnibus test (which included grade level and session).

During SY2013, class times differed between 6th (60 minutes) and 8th (120 minutes) grade. For my first analysis, a paired-samples t-test was done in order to determine GNIE's effect on the amount of time the teacher spent speaking to the class as a whole. I compared the total time the teacher spent lecturing for 6th and 8th grades and results demonstrated that she spent significantly less time addressing the class on days when GNIE was deployed (M=120.72, SD=89.73) compared to those days in which tactile/paper graphics were utilized (M=2738.85, SD=759.30), t (7)= 8.816, p<.01 (Figure 9).

For my second analysis, first I converted our time series data into a percent of the total class time. Then, I conducted a paired-samples t-test in order to determine GNIE's effect on the amount of time the teacher spent speaking to the class as a whole. In order to determine if this decrease in lecture time led to an increase in individual student attention, a 2 (Presentation modality: GNIE or tactile graphics) x 7 (Session: 1, 2,…7) repeated measures ANOVA was then conducted on the time spent with individual students. I did not include Grade level in this analysis since it did not yield significance in the previous year. The overall ANOVA yielded a significant effect of modality (F(1, 10.309)=415.617, p<.05), which demonstrates that the teacher spent significantly more time with individual students on GNIE days as opposed to tactile days.

In light of this result, I wanted to know whether or not the teacher perceived a difference in the amount of time she spent with individual students between tactile days and auditory graphing days. I asked which day she felt she was able to spend more time with individual students or whether she felt it was about the same. She responds “I think probably more on GNIE days”. When asked to elaborate further, she says it’s because “when I’m doing the tactile I go toward the Braille students because I feel like the print students can see more of what’s going on”. It seems that not only is the teacher spending more time with each student when our software is used, but the difference is great enough to be noticed.

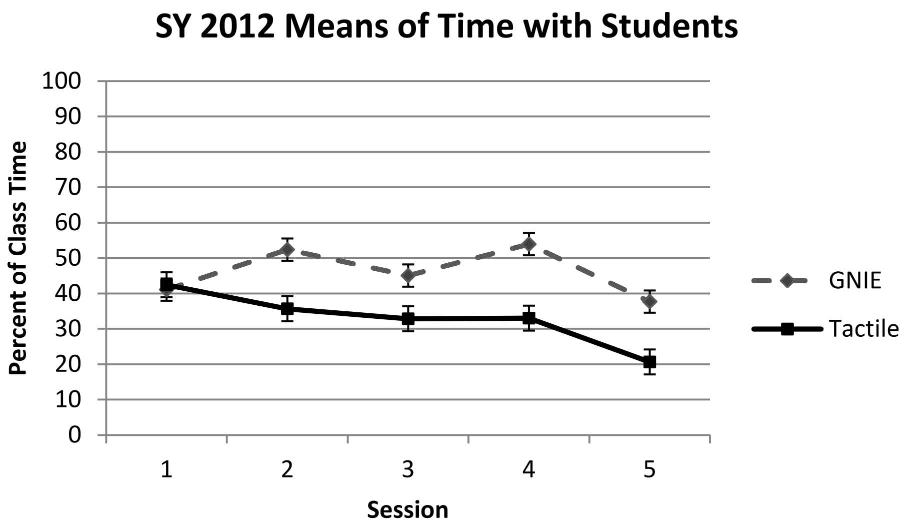

Figure 10. Graph of means of time spent as a percentage of total class time helping individual students for tactile and GNIE days in SY2012.

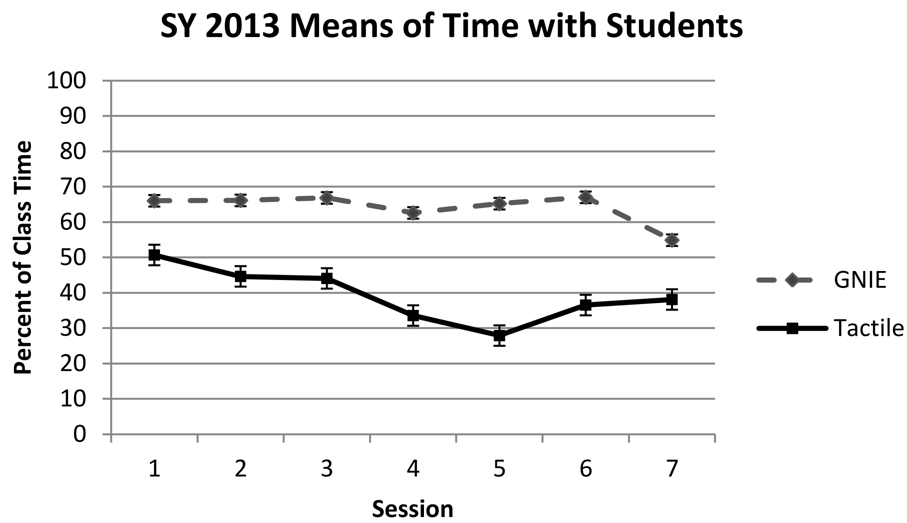

Figure 11. Graph of means of time spent as a percentage of total class time helping individual students for tactile and GNIE days in SY2013.

3.3 Discussion

In this section, I review my findings and identify strengths and weaknesses of an accessible auditory graphing tool as developed and deployed in a real classroom. Then I present the implications for design the emerged from this work.

3.3.1 Impact on lessons

The themes I identified from interviews suggest that of the three phases of instruction, lesson planning is the most time consuming aspect of teaching visually impaired students. A variety of factors, including materials access and ensuring that lessons are tailored to each student's degree of vision, often necessitate multiple preparations of the same lesson (e.g. Braille copies for blind students, large print for low-vision etc). Data in section 3.2.10 on GNIE reception seems to indicate that the teacher perceives a noticeable positive difference in lesson preparation time using GNIE versus tactile lessons. Auditory graphing software can cut down the time-costs associated with this phase by allowing the teacher to prepare a lesson once instead of multiple times. The trade-off for using our software in particular is the limited types of problems that the program can represent (e.g., problems involving shapes).

Mobility is another area where GNIE differs from traditional mediums. Once the software is installed, the teacher is free to create lessons away from the classroom, and once lessons are created they can be distributed to student workstations via a network drive or USB device. Indeed, our teacher participant mentioned that she often takes her laptop home to create lesson plans and works on the problems by “grabbing little snatches of time” whenever she could. Finally, the potential for mobility on the student-side is also increased because the teacher can assign homework for students provided they have access to a computer.

There are also savings in materials-cost when using computerized software. Other than headphones (which are optional), there is no additional hardware that is needed to use GNIE as it can be navigated with or without a mouse. Delivering electronic lessons can also cut down on physical resources such as Braille paper and external hardware such as an embosser.

3.3.2 Impact on class time distribution

The data in section 3.2.14 suggests that the introduction of GNIE into the classroom has a significant impact on the amount of time the teacher spends on lecturing versus individualized attention for students. When executing a lesson using traditional tactile mediums, the teacher spends more time addressing the class as a whole and less time one-on-one with a student. One explanation is that the teacher expects the class to always be working on the same problem during tactile lesson days. Since it is difficult to change an answer once it is embossed and impossible to answer several questions at once if the student is using a board, there is a higher cost for students who wish to “skip ahead” or work independently. During tactile lessons, the teacher will normally guide the students one question at a time and ensure that each question is answered correctly before moving to the next problem. This means students who finish their problem early must wait for their classmates to finish the same problem before moving on to the next question. Our software addresses some of these issues by providing flexibility and allowing for exploration of problems which students can do themselves.

The results from Figure 10 also suggest that, after the first session, there is a large increase in individualized student attention on days when our system was used. I hypothesize that there was no difference in session 1 due to the novelty of introducing this software for the first time. I believe that after gaining familiarity with how to use the tool, students were more comfortable with working independently. GNIE saves all of a student's work and makes it relatively easy to undo mistakes and refer back to previous questions. This greatly decreases the cost of working ahead for both student and teacher. A student can work on several problems while waiting for the teacher to make her way around to check finished work for accuracy. Answers can be checked by the teacher quickly, and work done in class can be saved for review at a future time.

Spending more time with each student is a desirable outcome for the teacher as indicated in results from section 3.2.5 on lesson delivery challenges. The teacher reports that some students benefit from having more guidance and individual attention and GNIE allows for much more of this type of interaction. Additionally, students who do not need as much oversight can now work at their own pace instead of waiting for their classmates, and those students who need more help can receive guidance without slowing down their peers. A combination of these factors may allow the teacher to cover more material in a given class period, though further evaluation must be conducted to determine to what extent this is true.

3.3.3 Design implications

The three main qualities that I see as important in order for auditory graphing tools to be adopted in classrooms are its compatibility, distributability, and flexibility. The first quality, compatibility, means designing software to work with existing tools and standards that are already in place. In order for auditory graphing software to be considered for core curriculum use, it should be compatible with other tools and equipment that are already part of traditional tactile lessons. For example, if the teacher still wants to print a Braille copy of the lesson, the auditory graphing software should provide a mechanism to do so (e.g., by translating questions directly into Braille to be embossed when needed or perhaps by allowing for files to be exported in formats readable by Braille translators). While GNIE has benefits that were discussed in earlier sections, I recognize that some students will still prefer traditional tactile mediums. Designing a tool that is already compatible with existing software lowers the threshold for adoption and allows the teacher to decide which medium is best suited for individual students.

The second feature, distributability, refers to the ease of distribution of lesson material between the teacher's copy and the student's workstation. The current practice for our system is for the teacher to first create the questions for each class on her computer, and then transfer the files to each of the workstations in the classroom. With an average of five students, the time-costs for this step are minimal but would become problematic quickly if the number of students in a class increases. Eliminating this step, perhaps by implementing a central database, would allow for a more seamless transition between lesson preparation and execution. Additionally, having a repository or database for finished work would make it easier for the teacher to assign homework and review finished work that she otherwise would not have time for.

Finally, auditory graphing software should be flexible to use for both the teacher and the student. A survey on the implementation of assistive technology with students who are visually impaired indicated that most teachers do not have training specifically in using an AT [42], so any software that will be used in the classroom should be flexible and intuitive. Affording the instructor the opportunity to generate her own graphs and questions allows her to create problems that are relevant and tailored to her students. After all, the Common Core standards do not dictate specific lessons plans for instructors, and it is instead up to the teacher to determine how best to teach concepts to students and assess whether or not they understood that concept. Flexibility also means allowing for students to experiment with the system with minimum penalty. The student should be allowed to make mistakes and explore different ideas while still easily undoing errors and saving progress. This enables students to work independently.

3.4 Limitations

By working specifically with one teacher from a local school for the blind, I can gather a large amount of information from the participant and also track changes and use over time. However, there are some limitations to this methodology that I will discuss below.

First, I only interviewed one teacher at the school. While her views are insightful and speak to her many years as an educator, it may not be an accurate representation of the views of other teachers and as a result are difficult to generalize. It is likely her experiences are similar to other teachers at schools for the blind, but may not extend to teachers at mainstream schools. To address some of this problem, I have taken care to document the interview results and present findings from observation in enough detail that other researchers who have experience with mainstream schools and educators can distinguish patterns and draw their own conclusions about whether or not the results can be generalized to other populations.

Second, conducting a classroom observation is a key component of my methodology, but my presence in the classroom during the observations may have an impact on the behavior of the teacher and students – something like the Hawthorne effect [43]. It is possible that the differences that I see in the data are a result of my presence in the classroom. However, the study was conducted over the course of two-years, with multiple multi-day visits to the classroom. Any changes in behavior would have to be robust enough to manifest during each visit. Instead, what we see is that the distribution of lecture-time versus student-time varies over time, but the distribution of time proportionally remains constant over two-years.

Finally, I only studied the behavior and interaction of middle-school students at a particular school for the blind. Many students with vision impairment are enrolled in a mainstream classroom [22], and data collected from the population of students I studied may not generalize to other schools. Further research is needed in this area.

3.5 Conclusion

In this section I examine the challenges encountered by a teacher for students who are visually impaired and how some of these challenges may be overcome by using an accessible auditory graphing tool. Through interviews, I found that throughout the course of the teaching cycle, time is considered by the teacher to be the most limiting resource. While this can be true for most teachers of mainstream schools, it is especially an important issue in cases where the students have a disability such as vision impairment. This is due to the extra equipment that must be prepared and guidance that must be given before, during, and after a lesson.

Another factor that affects an instructor's teaching is how new tools change the way the instructor diverts her time during a lesson. A tool that allows a teacher to spend more time with individual students during a lesson can be beneficial to both the teacher and the student. Increased time per student means that the teacher can more effectively guide students who require additional help and students have more opportunities to ask detailed questions about assignments. What is not discussed in this work is whether or not the extra time spent with students results in differences in student achievement or an increase in the amount of material covered in a given period. This warrants exploration in future research. However, anecdotal evidence already suggests that the use of our software has helped students understand some types of problems more quickly and has also helped them during standardized testing by triggering mental reminders of how to navigate around graphs.

There is some evidence [44] that students are more likely to collaborate on days when GNIE is used (discussed in detail in the next section). This might be because all students, regardless of degree of vision impairment, now share the same medium for a lesson, it is possible that a change in the type of social interaction and collaboration between students can be observed.

The cultural context as described by HAAT is highlighted by the classroom observation results. In this setting, what stands out in the findings is the attitude of the teacher and how it shifts between days of tactile instruction and days of GNIE instruction. Using GNIE in the classroom demonstrates acceptance and support for new assistive technologies and a willingness to experiment with different modalities of information presentation – an attitude that students will hopefully emulate.

I do not argue for auditory graphing tools to be the only tools used for teaching middle school math. Rather, I assert that there are many benefits from using such a tool in the class – such as savings in lesson preparation time and resources as well as an increase in teacher-to-student time. And, though there are still challenges that remain to be addressed, an auditory graphing tool such as the Graph and Number line Input and Exploration (GNIE) software, can be an appropriate supplement for traditional tactile techniques for teaching.

CHAPTER 4

Collaboration

Bone-conduction headphones ("bonephones") operate by generating direct vibration to bones in the head (in our case, the condyle), which results in sounds being transmitted directly to the inner ear. This method effectively bypasses the typical air-conduction pathway for sound perception, and leaves the ear canal unblocked by headphones or earpbuds, allowing users to continue to hear environmental sounds. Research in this area includes studies on different bone locations for speech intelligibility [45] and the performance of bonephones when used for wayfinding [46]. They have also been looked at as a type of assistive auditory device [47] in the classroom, but in the context of children with hearing impairments rather than visual impairment.

With students with vision impairment, communicating through speech is often the primary method for teachers to administer a lesson. This is why it is important that auditory channels are not blocked off during classtime. This becomes an issue during computer lessons when regular air-conduction headphones are used along with screenreading software. Over-ear headphones and even earbuds can be cumbersome because either users must talk louder than normal in order to be heard or headphones must be taken on and off in order to communicate with others. This has the potential to create unnecessary noise in an already noisy environment. In contrast, bone-conduction headphones allow students to listen to auditory software tools while remaining receptive to any teacher instruction or communication with peers.

During Fall 2012, students used school-owned air-conduction headphones with the software, and starting in Spring 2013, we provided bone-conduction headphones manufactured by AfterShokz [48] along with 2 or 3-way audio splitters to use. We provided these headphones for each student and the teacher, as well as an audio splitter for each computer (Figure 12). The splitter was plugged into the computer's headphone jack, and the student's bonephones were plugged into one of the splitter jacks. If another student wanted to listen to the same audio, he could simply plug his headset into the second splitter jack. When the teacher came around to check on progress on assignments, she could quickly plug in to the third jack, listen in for a while, then unplug and move along to the next student group.

Figure 12. Image of the AfterShokz bone conduction headphones used in the school.

To study the impact of introducing bonephones and splitters to the classroom, I looked at video data, asked questions during semi-structured interviews with the teacher and asked questions about bonephones as part of the focus group discussions with the students.

Overall, I found that compared to air-conduction headphones, students were more likely to keep the AfterShokz headsets on throughout the entire lesson, and a majority of the students as well as the teacher preferred using the bone-conduction headphone over the air-conduction headphone. I also discovered that providing the audio splitters allowed the teacher to more quickly assess where a student was experiencing difficulty. Finally, I observed that the teacher was more likely to pair students to work together when audio splitters were provided. Here, I present the results of our observation and qualitative interviews with the students and teachers grouped by device: audio splitter and bone-conduction headphones.

4.1.1 Audio Splitter

Figure 13. The teacher is shown helping a student who is using auditory graphing software. Both are wearing bonephones plugged into the computer via an audio splitter cable.

I decided to connect audio splitters to each computer after observing the teacher in the beginning of the semester and noticing that she often "took over" a student's headset in order to troubleshoot a problem they were having. Providing the splitter allowed the teacher to plug-in quickly to a student's computer and immediately share in the same audio environment with the student (Figure 13). This led to more efficient instructing, and the teacher says of the splitters:

> *"[the splitter] was priceless. I like that a lot. Because, the problem was I would forget that I had that option and then I go "duh", plug in, and of course I could see right away the problem they were having. So it was just like it explains everything so much better when you hear what's going on there. So that was just great."*

Additionally, I did not observe any instances where students were paired to work together when there were no splitters; however, I observed seven instances of paired work (pairs assigned by the teacher) when audio splitters were connected. The teacher also says of pairing students together:

> *"One of the things I loved is if one student finished – finished an assignment – and asked, sometimes they would ask if they could help other students, they could easily go and connect with the other student using the bonephones, using the connectors, and help each other out and I thought it was wonderful. I thought it was – I loved to be able to go and help them that way, but I think it was even more effective when one student helped another. So, I liked that a lot."*

This paired work is in contrast to tactile days, where I observed only two instances of the teacher pairing students together.

4.1.2 Bone-conduction headphones

During the Spring 2013 focus group, I asked the question "What do you think of the new bonephones?" Of the twelve students who participated in the discussion, eleven students expressed positive attitudes toward the use of the headphones. Some opinions include:

> *"I think it's cool 'cause if your teacher says "It's time to go [to the next class]", you can still hear them. And then, it's still kinda in your ear so you can hear that [the computer audio] at the same time, and it makes it a lot easier."*

The teacher also had a positive reception to the headphones, claiming that:

> *"I love them. I like them a lot. I like them because they can hear me even when they're listening on that – to GNIE… Anyways, I like them a lot. I think they're much much better than anything else we've had."*

One student expressed a mixed reaction to bone-conduction headphones. She says:

> *"They're easy for me to put on, but they kind of distracts you because you can't – because you want to block out the sounds people make – people around you because sometimes people are loud and you can barely hear what you're doing 'cause they're loud."*

During my observations, I noted that once the bone-conduction headphones were put on, students did not fidget and remove them during class unless they were leaving their seat. This was not the case with the air-conduction headphones, where I observed that many students would take them on and off repeatedly. Some students were also observed using air-conduction headphones with one side over their ear and the other side off. The following is a recorded exchange between a student and the teacher about wearing the air-conduction headphones.

> *Teacher: Now why don't you have these [headphones] on?*
>
> *Student: Because I had to ask you the question, I couldn't hear you.*

I also asked students how they felt about using bonephones during the focus group discussions in SY2013. Students who had used it in the previous year said they enjoyed using the bonephones and all new students also said they enjoyed using the bonephones.

During SY2013 discussions, I asked students how they felt about collaboration using GNIE. All the students asked, who had the opportunity to collaborate with another student at some point using bonephones and GNIE, agreed that they enjoyed the experience of sharing an audio environment and helping their peers. One student said:

> *"I don't think paper gives you the same advantage because if you were looking on paper you would have to try and get that person to move over and try and find what they're looking for and it would make it harder. But when you're listening on GNIE with your – with the person you're helping, you can hear where they're at and help them find them and*

instead of making them move and losing their place and you trying to find their place and whatnot."

A key advantage of GNIE collaboration is that it supports the same interactions for all users regardless of level of vision loss. As mentioned in the previous chapter, students with low-vision and students who are blind typically use different copies of lessons – large print paper for low-vision and Braille copies for the blind. This means that during tactile lesson days, it is not typical for students who have different levels of vision loss to collaborate together. Normally, paired work is done with students who have the same level of vision impairment, and this is what was observed during the times we were there. Since GNIE is the same for everyone, students can work with any of their classmates without needing to consider whether they should be concerned about understanding the lesson presentation material. One student perhaps sums it up best by saying this:

> *"Say there's like a totally blind person and a person that could see and the paper was print, it wasn't Braille, and they were trying to find a point on the graph, well that blind person won't know what you're doing. I mean, he or she cannot tell what you're doing or anything like that. I mean they can't tell where you're going or where you're going to place the point at or anything. But on GNIE you can hear what they're doing so it's kind of a bigger advantage for visually impaired people and for people who are non – not blind."*

4.1.3 Discussion and conclusion

This section will briefly discuss the results from interview analysis conducted so far and how collaborative work is supported by GNIE, limitations of the study, and conclude with future work. I will begin by discussing the introduction of new periphery equipment to our existing system. Audio splitters and bone-conduction headphones are not normally considered assistive devices, though when used in a classroom for the visually impaired, they offer many benefits. The main benefit of audio splitters is to quickly allow pairs (or even trios) to share the same audio environment. This is helpful for a teacher who is helping a student and also for students who are working together on the same problem. Bonephones do not block the ear canals, an important route for receiving information by visually impaired students. With bonephones they can listen to their screen reader while also being receptive to environmental input. Though this also means being exposed to irrelevant data, as one student noted, this can be overcome with time and practice.

I believe that after gaining familiarity with how to use the tool, students were more comfortable with working independently. GNIE saves all of a student's work and makes it relatively easy to undo mistakes and refer back to previous questions. This greatly decreases the cost of working ahead for both student and teacher. A student can work on several problems while waiting for the teacher to make her way around to check finished work for accuracy. Answers can be checked by the teacher quickly, and work done in class can be saved for review at a future time. Working independently also means that sometimes students can finish the day's lessons ahead of their classmates. This is the typical scenario that I saw when observing collaboration instances between students. Because GNIE supports independent work and allows students to work at their own pace, it is an impetus for pair work between two (and sometimes more) students.

GNIE primary method for supporting collaboration is by providing a single-source display for information and allowing students to work independently. As mentioned in earlier sections, there are some interactions that GNIE does not currently support (such as circles and 3D objects). It is possible, then, that when lessons are given that involves exploring those topics, tactile graphics are better for collaboration. In other words, GNIE is used for lessons that involve points and lines. For lessons that involve other concepts, tactile graphs may be better and collaboration may occur between students during those times. But, because those lessons are not observed during my visits to the school, I cannot compare those instances.

Supporting collaboration by allowing one student to be the "teacher" and another to be the "student" only encompasses one type of collaboration between peers. This is the scenario that appears at GAB because there are ample resources for each student – every student had a computer that they could work on, so students worked together when one was finished with the lesson. This may not be true for other classrooms, such as in mainstream schools and other countries, where computers are a limited resource. It would be interesting to see if other types of collaboration between peers, such as when two students are both learning together on a problem, can be supported through our system and what types of interactions are unique to each type of collaboration.

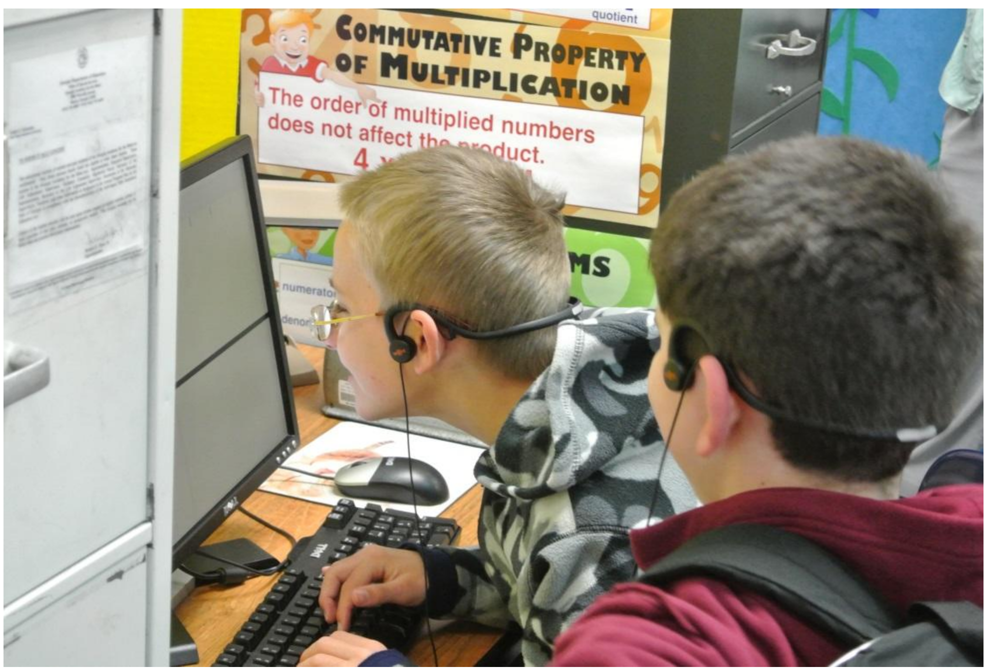

Figure 14. Two students are wearing bonephones and connected to a school desktop while working together on a problem during class.

Feedback from the teacher and students indicate that collaboration is a desirable component of learning math. HAAT also agrees that the social context in which an AT is used should be given consideration. Our results suggest that GNIE supports these opportunities by lowering the cost of working through a series of problems and presenting problems in a single-source display. Future work in this area can explore the use of GNIE in mainstream schools between sighted students and students with vision impairment. Also, while two and three-way audio splitters were provided in the classroom, I did not observe any instances of three students working on the same problem. A next step would be investigating situations that necessitate multiple users working with the same display, such as places where computer resources are limited, and how collaboration can take place in these environments.

CHAPTER 5

SUMMER 2013 ITERATION

The last school visit for Year One occurred on April 29, 2013. Over the summer, laptops were taken back to Georgia Tech, where we worked to implement changes to the system based on feedback given by the teacher. The following section details the features that were changed or added to GNIE.

First, we introduced two new modes for accessing GNIE – GNIE Teacher and GNIE Student. GNIE Teacher is a teacher mode that allows the teacher to create lessons for her students and does not include the answer area. This interface does not have an answer area since the teacher does not need it. This view provides more space for question text and for reviewing questions created for the lesson (Figure 15).

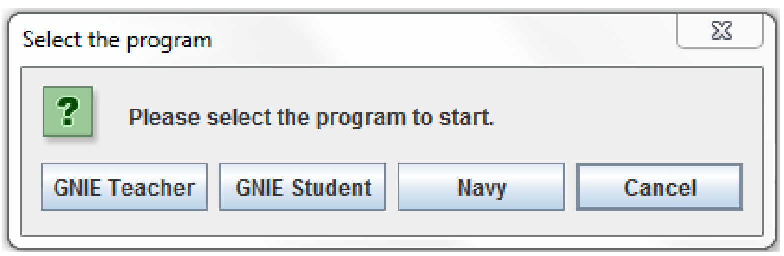

Figure 15. This dialog displays the two new modes of accessing the system: GNIE Teacher and GNIE Student.

Inside GNIE Teacher, we implemented the most requested feature based on our interview and expanded the range of graphs that could be produced. One of the major hurdles the teacher mentioned during our interviews is the limited range of values that the number line and coordinate plane could represent in our system. GNIE could only count by ones and could not handle decimals. In the second iteration, we included the option to specify the interval of the number line thus allowing for both decimal and larger interval representations (Figure 16).

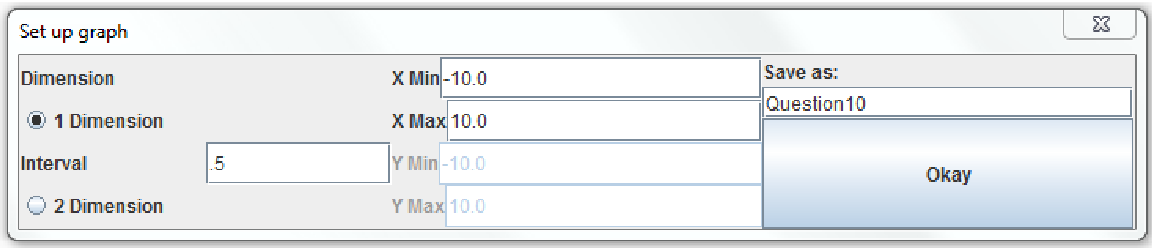

Figure 16. This is a dialog box for setting up the graph for a question. GNIE allows users to specify the interval to be displayed.

We also changed the architecture of the system so that it behaved analogously to software the teacher was already familiar with. The system did not recognize hierarchical folder structure in beta, so we added support for different folders for lessons. This change allowed the teacher to create multiple folders for lessons and for classes. This feature will be useful to help with planning future lessons and also for keeping track of old lessons (for things such as review or for the next school year). Additionally, we created a "student" folder where students' work is saved. A dialog is triggered when students select "GNIE student" and they are prompted to enter their name and select their lesson folder for the day (Figure 17). All progress is saved in the student folder under the student's name which provides quick retrieval and review of lessons.

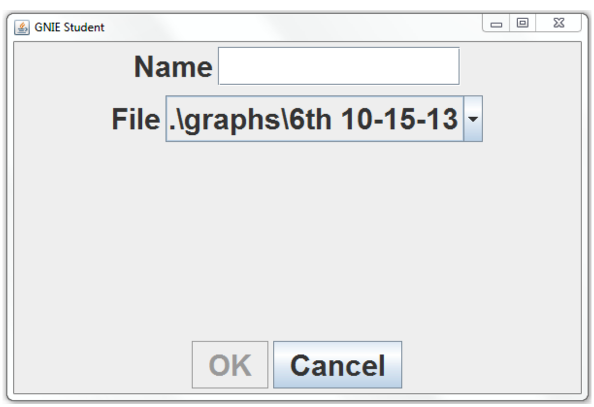

Figure 17. This is the dialog for bringing up and saving student work. The student name is typed into the first field and the lesson selected under "File".

During classroom observations I noticed that some students had difficulty determining where they should type their answer. Not only that, but there were instances where the teacher had problems finding the location of student answers. The main cause of this problem was that the system only had one text area. The question and any answers were located in the same pane, and there were no cues for the students or teacher to differentiate question text and answer text. This led to answers being typed into unexpected places (such as before the question or at the end of a multiple choice selection) instead of at the end of the question. To address this issue, we divided the right pane horizontally into two text areas, and the bottom pane was designated as the answer area. Delineating the text areas also had the secondary benefit of reducing text-to-speech time for reading questions or answers. Before this change, students would be forced to listen to the entire right pane even if they only wanted to check their answers which might be located at the end. Now students will be able to tab between question and answer easily. The teacher will also be able to quickly determine whether or not the student answered the question correctly.

Finally, we changed the way GNIE saved and ordered questions for presentation. In the first version, questions were assigned a random number ID by default. This number was used to randomize question presentation which may be helpful in a testing situation. However, when GNIE is used for class, it is important that questions are ordered sequentially, since some questions may have multiple parts and concepts may build on each other. The teacher was frustrated when she could not understand why her questions were being displayed out of order. She says, "I mean I get the feeling even still that I put a question into GNIE and I'm really not sure where it is. You know, I quit numbering them. I quit numbering them because it's like 'what for?'" In this iteration, we eliminated the random number assignment and incorporated a naming scheme that made more sense – a timestamp marked by when the question was created.

The changes made over the summer are part of the iterative process of creating a system of features that are useful in the real-world. These changes will help streamline the lesson preparation process and save time for the teacher. The design decisions were guided by our experience during the deployment and feedback from our users.

CHAPTER 6

THE STUDENT PERSPECTIVE: FOCUS GROUPS AND SURVEYS

Introducing a new educational technology for learning into a classroom is exciting but often comes with a set of challenges, including how to evaluate the impact of the technology. These tools are difficult to study because the technology themselves have many attributes, their outcomes affect many domains, and standardized measurement instruments are few [49]. And, as technology use becomes increasingly widespread in schools and more integrated in education, it is apparent that there is a need to understand the integration process and its relation to existing practices. If possible, the new technology is compared to existing practices and a better understanding is reached on how the technology fits into the flow of the learning environment.

Educational technology has been shown to offer many benefits and promises of improving and enhancing learning experiences for students [50], [51]. Assistive technology (AT) for education is one category of tool that has shown an increase in distribution and bears promise for young learners [52]. Specific interfaces for blind users have been developed, such as the Integrated Communication 2 Draw (IC2D) drawing tool based on a grid and keyboard [53].

This section looks at how users interact with our system and how they feel about the utility of the technology. I seek to understand their attitudes toward GNIE and graphing, highlight some differences between our system and the traditional tactile graphing tools, and gain insight into what features of the auditory tool worked and what could be improved in the future from the students' perspective.

6.1 Methods

To collect student feedback on our system, I conducted four focus group sessions over the two-year deployment of our system. I was interested in how the system functioned without our oversight and wanted to see how the users' experiences with the system would naturally evolve. As such, I only collected data from students and teachers when they were not using the system, and performed classroom observations periodically throughout the academic year (a two-day visit to the school approximately every 4-6 weeks) to document how GNIE was being used for lessons. I left it solely up to the teacher to decide how and for what lessons to use GNIE. I did not interfere with the lesson planning, and the only intervention I conducted was to take the system back to the lab over the summer after school year 2012 (SY2012) and implement new features based on feedback collected from interviews with the teacher and focus groups with the students.

Each focus group took place at the end of the semester with the middle school students at GAB. The primary purpose of the focus group was to gather qualitative feedback from the students using our system, engage in a conversation about the things GNIE did and did not do well and brainstorm ideas on how we can make the system better. I also collected demographic data and deployed a survey about paper and computer graph attitudes after each discussion.

6.1.1 School year 2012 (SY2012)

The first focus group was held at the end of the Fall semester after school and the second was held at the end of the Spring semester during school. Of the 17 total students in middle school during SY2012, 14 participated in at least one focus group.

The Fall session lasted for about one hour and was split into three parts. Seven students (5 female) participated in this session – 2 students from 5^{th} grade, 3 from 7^{th}

grade and 2 from 8th grade. For the first 20 minutes, participants were separated by grade (5th in one room and 7th with 8th grade in another) and asked questions about their technology use and their initial feelings about using our system. I did this because during our classroom observations I noticed that students tended to respond differently to GNIE, and this difference was roughly correlated with grade level. I wanted to ensure that the younger students did not feel pressured or hesitant to speak up about their opinions and thus decided to separate them from the older students initially. WI brought both groups together for the second part of the focus group which consisted of 20 minutes of questions about what could be improved with GNIE and brainstorming ideas on new features they would like to see implemented. I also asked questions about graphing in general and what challenges they encountered when trying to understand graphing principles. We spent the remainder of the time collecting demographic data and asking survey questions.

The Spring focus group session was conducted during the school day at the end of each class period. Therefore the groups were already separated by grade. Twelve students (8 female) participated in the Spring session – 5 students from 5th grade, 5 students from 7th grade, and 2 students from 8th grade. During the discussion portion we asked questions again about their use of our system and what could be improved. We spent the remainder of our allotted time collecting demographic data and administering survey questions.

6.1.2 School year 2013 (SY2013)

Two focus groups were conducted during SY2013 with students from 6th-8th grade (there were no 5th grade students during SY2013). Both focus groups were held during the day at GAB at the end of Fall and Spring. Eleven students (5 female) participated in the Fall session and 10 students (4 female) participated in the Spring session. All students who participated in the Spring had also participated in the Fall. Almost all students experienced vision impairment since birth and 9 consider themselves as “low vision” and

2 students consider themselves to be “blind”. Each session lasted for approximately 15-20 minutes. A majority of questions that were asked during the activity were the same as SY2012.

We made a few changes to the system during the summer between school years based on feedback that we received from our participants (discussed in the previous chapter). To assess the effectiveness of these changes, for those participants who had used GNIE during SY2012, we also asked how the system this year compared to the previous year. The same survey tool was administered to each student individually after the focus group. One student joined in the group discussion in the Spring session and elected not to participate in the survey afterward.

All of the focus group sessions were audio recorded and transcribed. Then, statements of interest were extracted and coded starting with pre-existing codes from the overall study deployment. Statements that did not belong in a pre-existing code were set aside and discussed before a new code was created and assigned. This process was done iteratively until all extracted statements were categorized into themes that are discussed in the results section below.

6.2 Results

A majority of the students had positive reactions to using our system and there is some evidence that using the system had added benefits outside of structured lesson time (such as during the end-of-year standardized exams). GNIE supports two different types of orientation processes that students use for navigation and supports independent work. GNIE also incurs lower cost in setup and reports higher engagement from users. Some students expressed frustration about not receiving enough feedback from computers (our system as well as others) and had some difficulty remembering procedural actions in GNIE during the first year. Finally for those students that used the system for two years, all but one student felt their experience of using GNIE improved during the second year.

The results below are an aggregate of feedback from SY2012 and SY2013 focus groups, and the following sections discuss each theme in turn.

6.2.1 Orientation

Orientation and learning to orient spatially is an important and crucial skill to learn for a person with vision impairment. Not surprisingly, comments about orientation and localization were common among all students. Students talked about two different types of orientation processes using GNIE and tactile graphs – orientation for searching and orientation during tracking.

6.2.2 Orientation for search

Orientation for search refers to the situation when users gather information about the graphing environment with the goal of locating a specific target. This type of orientation involves using information to move *toward* a destination on the graph and is generally a linear process. When asked about what they found hard about graphing in general, students responded with varying degrees of complaints about the difficulty or challenge in being able to locate landmarks such as the major axes or the origin (0, 0). One student described her difficulty:

> *"Finding where things are. Like if it's a big graph, with the squares, and then things are so close together, it's hard to find – like if it's a line graph, or if it's a [big] graph, it's kind of hard to find where things are. And it's kinda hard to feel the– sometimes the Braille too is kind of hard."*

For these students, tactile graphics are sometimes challenging for graphing lessons and for demonstrating graphing knowledge. Also, tactile graphics are difficult to change once created and can be unwieldy to navigate if the range of the axes are too large (difficult to remember locations on a large plane) or too small (tick-marks, numbers, or points are too close together to discern).

Orientation in our system, though not without challenges, was considered by students to be one of its strengths. They found the auditory cues provided by GNIE to be enjoyable and useful because it would inform them immediately of their cursor location on the graphing area, by reading out the x and y-axis coordinates. This enabled users to quickly tell which direction they should be moving on the graph. Students were also able to determine the general location of any nearby points. When asked if there was anything GNIE does well, participants said things such as "I like the part where the sounds would help you locate things" or "I like that … I could pinpoint where the positions are on the graph."

6.2.3 Orientation during tracking

Orientation during tracking refers to location information that is used as a reference point to return to or marker that is used to keep track of a particular starting point. Orientation during tracking is used when users move *back and forth* in the environment and is generally an iterative process. Students utilize this process when working through problems that require multiple steps, and state that it can be a problem when using paper graphs. For instance:

> *"…on GNIE you can just like put down something like, and like, so for the Braille students, like they have to go look at the sheet then have to go back to the paper and then sometimes they have to go back to the sheet and go back to the paper…"*

Students stated that it can be easy to lose their place when using tactile graphs, which often has the question and graph as separate pages or detached components such as a board with pegs. In contrast, GNIE's integrated interface segments a problem into three distinct sections on the screen – question (problem), answer, and graph area. Users can press "tab" to navigate between these areas, reducing the time and steps it takes to go between the problem and graphing area. This functionality has the additional benefit of allowing the user to quickly and efficiently navigate within and between questions and assess the status of a particular problem being solved.

6.2.4 Independence

Becoming independent is a skill that students work toward during their formative years. Part of this learning takes place in the classroom and begins with the ability to work on lessons with minimal guidance. It is especially true for tasks that the student already has the skill to do (such as reading), but cannot do now because of problems with accessibility. Multiple students commented on the general lack of accessibility in programs, websites, and software that could potentially benefit them. For instance, when referring to a specific web-based science and math subscription software already available at the school, a student says, "See, I like it, but I'd rather like it when I do it independently without someone reading it." That software is compatible with screen readers and able to read text questions, but is inadequate for displaying graphs and images. The students need a sighted helper to read or explain any graphics that are embedded in the software in order to answer questions.

During the group discussion, I asked students whether or not they felt they were able to use GNIE independently and why. I also asked if they felt they were able to use GNIE independently when compared to paper/tactile graphs and why. The responses I received were mixed, with a majority of students saying "yes," "yes" with a qualification, or "it depends." The reasons given for why students felt they could or could not use GNIE independently also changed between SY2012 and SY2013.

As expected, when learning a system for the first time, users will encounter occasional barriers to using the system. This will lead to some frustration, and I saw this with our student participants. Sometimes they could not understand the question being read or they could not remember the controls to move on to the next question. If they were stuck, students expressed dissatisfaction in waiting around for help to complete a task. One student says:

> *"I'm getting tired of asking…like if your teacher is helping other people and you need help really really bad, and you won't be able to get help. And it drives me crazy when I have to ask."*

This is an issue with both tactile graphs and GNIE. Students wanted the option to be able to work on problems at their own pace while receiving enough feedback to feel confident about moving on to the next question. While GNIE allows users to work on any number of problems that are available to them, it does not currently provide any checks to see if a question was answered correctly or skipped.

I received responses from students who have used GNIE for a year about perceived issues or barriers to using the system independently. In the first year, three students (of eight) who cited hesitations about using GNIE independently noted issues with procedural actions of using a computer and challenges in learning the meaning of output signals. They claimed that they needed more practice to interpret the sounds of the system and to remember the function command keys. These concerns are discussed in more detail in the following sections.

By the end of SY2013, almost every student I asked felt they were able to use GNIE independently. When asked why, students said that they were able to overcome the initial barrier of remembering the procedural actions of using the system (i.e. "because I finally figured out how to use it like I remember how to do some of the stuff"), although one student still cited the controls as a reason she was not able to use GNIE on her own. Another interesting remark from a student who stated in SY2012 that she was not able to use the system independently was that, after extended exposure to GNIE, she still did not know everything about the system, but trusted that she would be able to figure it out. She says:

> *"I'm learning myself how to do it. Because with the tactile graphs, I am learning but not by myself, but when on GNIE it feels like I'm learning how to do it all myself. Sometimes I can figure out ways to get my answer."*

6.2.5 Students' GNIE Reception

Another goal of this study is to better understand how our student users feel about GNIE after using the system for a year or longer. As part of the discussion, I asked questions about what they liked about the system, what they did not like about the system, and what suggestions they had to make the system better in the future. I also administered a survey during each focus group session to gauge their attitudes about paper/tactile graphs compared to computer graphs.

6.2.6 GNIE Advantages

One of the primary advantages of our system is the relatively low cost of setup to get started. During a normal lesson, groups of students (depending on whether they preferred large-print or Braille) would have to take time to gather the necessary equipment to participate in class. Compared with days when GNIE was used, students liked that they did not have to prepare multiple resources to use the system. One response, for example,

> *"I think it helped me with graphs because instead of writing and worrying if the pencil gets broken, then all you have to do is press a button and it's quick and easy."*

Three students mentioned during the discussion how they enjoyed using a single combined system (computer) rather than a system with multiple disparate parts – for example using a sheet of tactile graphing paper and a Perkins Brailler as well as tactile marking tools like sticky dots. One student even suggested he did not even need the screen because of GNIE's audio interface, saying, "You don't have to worry about the screen. You can just like turn the screen off and you know what to do."

Another aspect about using a computerized tool in class that was revealed in our findings was the engagement that some students experienced when using our system. These were coded as statement of varying valence and refer to utterances that used emotional words to describe their perceptions about a system. Students looked forward to working on the computer, and claim that it helped them stay awake during a lesson compared to tactile graph lesson days. For one student it helps him, "'cause it has noise! And it will wake you up." Another student remarked, "when you're looking down at paper, I'd be getting kind of sleepy. On a computer, I may stay excited and stuff like that." The word "fun" was often used when asked about what they liked about using GNIE.

For some of our participants, using our system provided unexpected benefits outside of a regular lesson. Four students claimed that it helped them on the annual Criterion-Referenced Competency Tests (CRCT) given at the end of the semester. One student said, "There were a lot of graphs and knowing we did GNIE helped a lot." When asked to elaborate further, the student went on to say:

> *"…because they asked a lot about number lines and graphs and when they did and the number lines had points, I remembered GNIE had a lot of points and I could imagine hearing it ding every time you got it right or something so it helped."*

Here, the benefit of auditory cues from GNIE apparently persisted even though the system was not used during the examination. Another factor that was beneficial in our system was the ability to control question reading. As one student mentions, "just, the reading like, if you were taking a test, the teachers might just read it twice, but GNIE can go back and read it for you," which indicates that having this autonomy is helpful during testing situations.

6.2.7 GNIE Concerns

There were several things that students said were issues they had with using GNIE. These issues are all related to how the system is controlled and how the system provides feedback rather than issues with understanding graphing concepts. If a student understood how to do a particular type of problem with paper/tactile graphs, they also understood what needed to be done using computer graphs.

Understanding what needs to be done to answer a graphing question, and possessing the procedural knowledge to execute on it, are different abilities that may be challenging initially. When using GNIE, a user must learn the actions that must be taken in order to produce a desired result. When there are many such actions that must be remembered, it can cause difficulty in using the system effectively and efficiently. For instance, some of the younger students had difficulty remembering the short-cuts used for proceeding to the next question or for navigating between the graph and the text-input area. In cases such as these, there are no guides or prompts to help or remind them of the proper controls.

There was also some disagreement between students on the utility of some of the sonified elements of the graph. Some students felt that, although the reading of the tick-marks was necessary, the rhythmic pulsing noise and pitch may not be as useful. One student said when asked if the sounds were annoying “Sometimes, but not all the time” to which another student responded “I don’t find it much annoying because it helps me. If they took it off then I would be very angry.” These differences may stem from vision ability (low vision vs. blind) and may be worth exploring in the future to determine what auditory cues are most helpful when navigating a sonified graph. For instance, one possible method of presenting the information each user wants could be through customization where they are able to select/deselect which sonifications and other orientation information are presented.

6.2.8 Survey Data

At the end of each focus group, we verbally administered a 24 question survey individually to each student who participated. The survey consisted of 14 Likert scale questions about attitudes toward computer graphs versus paper graphs and 10 Likert-type questions about general ease-of-use and opinions about graphing and computer graphs [54]. The tables in the appendix show the recorded responses to the survey questions.

In order to determine if students' attitudes toward computer graphs and paper graphs changed between Fall and Spring, a 2 (Fall or Spring) x 7 (for each type of question by sensory modality) repeated measures ANOVA was conducted for questions about computer graphs. A significant interaction was found between ratings and question type, $F(2.203, 31.650) = 5.126$, $p < 0.05$. Another 2 (Fall or Spring) x 7 (for each type of question) repeated measures ANOVA was conducted for questions about paper graphs but no significant effects were found. To determine which questions about computer graphs had significant changes in ratings, a post-hoc paired samples t-test was done on the computer graphs questions for Fall and Spring.

The results suggest that there is a positive shift in attitude for the statements "Between the paper/tactile graphs and the computer graphs, I think I had more graph questions correct on the computer" and "Computer graphs were annoying to use." For the first question above, students thought they performed better during the second semester with computer graphs over paper ones [$t(6) = -2.569$, $p < 0.05$] (first semester: M = 2.14, SD = 1.464; second semester: M = 3.71, SD = 1.113). For the second question, students thought that computer graphs were less annoying after the second semester of using them [$t(6) = 3.603$, $p < 0.05$] (first semester: M = 3.29, SD = 1.254; second semester: M = 1.14, SD = 0.378). Students were more likely to believe that they had more questions correct on the computer compared to paper graphs and also felt that computer graphs were not annoying to use. There was no significant interaction for questions about paper graphs, which indicates that student attitudes toward paper graphs did not change demonstrably between Fall and Spring, which is not unexpected.

To determine if there were changes in ratings for the 10 Likert-type questions, a paired samples t-test was conducted between the Fall and Spring ratings. Though no significance was found, the ratings themselves may be interesting, and are reported in the appendix.

For data collected during SY2013, a 2 (Fall or Spring) x 7 (for each type of question by sensory modality) repeated measures ANOVA was again conducted for questions about computer graphs and paper graphs, but no significant interaction was found in either condition. We also performed a repeated measures ANOVA for attitudes toward computer graphs and paper graphs between Spring 2013 and Fall 2013 and again no significant interaction was found, indicating that after the initial exposure to the system, students' attitudes toward computer and paper graphs did not shift significantly.

I also wanted to examine any changes in ratings for the 10 Likert-type questions and a paired samples t-test was conducted between the Fall 2013 and Spring 2014 ratings. No significance was found. However, when I compared ratings for Fall 2012 and Spring 2014 for each of the questions using an independent samples t-test, results indicate a positive shift for the question "I can see myself using computer graphs outside of school" [$t(15) = -2.139$, $p < .05$] (Fall 2012: M = 2.43, SD = 1.254; Spring 2014: M = 3.70, SD = 1.252). This result suggests that, after a period of time potentially longer than one year, students feel comfortable and confident enough with their skills to envision themselves operating a computer graph outside of the classroom.

6.2.9 GNIE Suggestions

During the group discussion, we led conversation about what could be done to improve our system as well as what kind of system (not necessarily an auditory tool) would be their ideal tool for learning math and graphs. A majority of the students said that they enjoyed using the tool. Most of the suggestions involved providing users with more control over what auditory cues were generated by the system as well as providing an explicit notification for giving the correct answers or inputs.

Many students wanted more control over the auditory aspect of GNIE. They suggested allowing users to choose what sound was made when a point was plotted and enabling them to choose whether it was a male or female voice reading the text and numbers. Students say the voice was "Monotonous. It needs to have expression" or "The voice sounds a little robotic to me." Others thought that the system read the question and numbers too quickly. The speech rate for the text-to-speech (TTS) was initially set to 200 words per minute, and the voice was a male voice ("kevin16") from the java freeTTS library [55]. This was an issue that we addressed over the summer after receiving feedback from students that the rate was too fast to comprehend, and thus we slowed it down to 115 words per minute.

When asked to brainstorm ideas for a system that they would enjoy using, many students wanted a system that provided concrete feedback for correct answers. One student suggested, "I know! Every time you get a question right, the computer can give out candy!" or "Like if you get it wrong [buzzer sound] and if you get it right [ringing sound]." Students did not want to rely on the teacher to let them know whether or not a problem was answered correctly, but would rather have system-generated feedback about their work, which would give them the opportunity to continue to work independently and at their own pace.

Some unconventional ideas from students for a graphing system involved creating a system that utilized combination of tactile and auditory cues. For instance, "I want to have a Braille paper that changes! I want a Braille notes that can actually show a picture of a graph" or "a talking graph like a graph that runs on batteries." Another idea for a graphing tool involved bypassing the keyboard and mouse altogether and communicating directly to the system through voice commands or brain waves. This system, according to the students, “can just listen to what you want to write, and you can just tell it what you want to write and it will just pop up.” Taken a step further, it could also “make this little pin into some Braille and you could write squiggly lines and it connects to your mind and it comes out in Braille!” This feedback seems to indicate that there are many positive aspects of an auditory graphing tool, and with implementation of features that provide more autonomy and control over the system, auditory graphing software can aid in understanding graphing concepts while being fun and enjoyable.

To summarize, our findings suggest that, for most of our users, any graphing tool they use must have good markers that allow for orientation on the graph and any features that allow them to do work independently is an asset. Using our tool also did not change perceptions about paper/tactile graphs, but using computer graphs over time can lead to a positive shift in attitude toward these types of systems. Students preferred to have more control in adjusting some auditory features of GNIE, such as the type of voice and speed of reading. Our system was perceived to be better at providing cues about user location on a graph and localization of points, but users still favor a graphing environment that uses a combination of paper/tactile and computerized mediums.

6.3 Discussion

The qualitative focus group and discussion method allowed me to gather valuable insight and feedback into how students with vision impairment feel about using an auditory graphing tool for learning and demonstrating knowledge of graphing concepts. The first goal of this study was to investigate how introducing a new tool into the classroom impacts existing practices and learner interactions. The second goal was to better understand the relative strengths and weaknesses of our system compared to traditional tactile tools in order to create design guidelines to inform future versions of this system and other similar systems.

Users described various challenges in graphing and learning graphs in general, most notably in being able to orient themselves on a graph and locating starting points and landmarks, a skill which has been widely explored through sound [56], [57]. GNIE addresses some of these issues, but some of the auditory cues may need to be calibrated to the individual preferences of the student. The sounds used by the system are unique and persist for some students outside the use of the system, enabling them to recall information during an examination setting. Thus, care should be taken if the sounds are to be changed such that they still retain that unique quality and can also be heard above the typical noise level of a classroom.

A key aspect in this educational setting requires consideration of the level of engagement a student experiences while learning. Our results suggest that students are paying attention during lessons when the computer is used as a teaching medium and the sounds help keep them awake and attentive. Students at the school have regular keyboarding lessons and have regular interaction with computers (though not necessarily in math class outside of GNIE), so it is unlikely that this engagement stems from a novelty effect.

Results also indicate that using a single medium rather than multiple resources to conduct a lesson has advantages in time and resource savings. Students do not have to take time to gather materials and teachers only need to create a single copy of the lesson to distribute to the class. Previous findings also indicate that using a single teaching medium for everyone can encourage collaboration between students even if they have different vision abilities [58].

While the system was being developed, the overall design and requirements gathering involved both groups of users (the teachers and the students). There had not been a longitudinal study of this particular AT or this type of AT and its impact on classroom dynamics, or an opportunity to gather assessment from users. Through the first year of deployment at GAB, we received helpful feedback from both the teacher and students, and were able to modify and improve the system based on their needs and evaluation.

The focus groups and surveys provide valuable information about what features of the system are practical, appropriate, and liked by the users. Some of the feedback was useful for informing future versions of the system, even if other features were modified or added. One of the most important features noted during the focus groups was the ability to orient within the graph. It is important to include the ability to orient within the system and to provide contextual information to the user. Currently, a majority of the auditory orienting details are in the graphical portion of the interface. GNIE's users include students with varying levels of visual impairments and their math teacher who has corrected-to-normal vision; if the user group expanded to include teachers with visual impairments, as well, the system would need to be adapted to include the same type of orienting information for teacher-specific portions of the program (e.g., adding a new question). There is no orienting information during the "Add a new problem" pop-up window, and it is not optimized to work with a screen reader such as NVDA [59].

There was some debate over whether GNIE should operate with its own reader or if it should rely on a user's screen reading software. Ultimately, I believe that for a standalone desktop application, using its own reader is a more efficient solution. While some elements of our system were compatible with conventional screen readers such as NVDA and JAWS, an issue that arose from user testing was the number of quick keys that the student would need to use to navigate in-between questions. The menu system at the top of the graphical interface was not self-reading within the program and students did not know how to access them using the conventional screen reading software. Having a system which works independently of a screen reader can attempt to mitigate potential problems which may arise from using a screen reader and a self-voicing AT at the same time (which may lead to confusion for the user). This design decision would also allow us to have more control over adjusting the auditory outputs of the software and would permit the distribution of this software without requiring users to own a screen reader to use the system.

Although the sound design for the system is not discussed above (that was not the focus of this paper; see [60] for more information on the technical specification of the system), an important consideration for any type of auditory graphing software is the amount of information contained within the auditory feedback of the system. GNIE included unique sounds for overall graph context, the points, intersections of tick marks, the numbers for the x and y position of the cursor, and the x and y axes. Presenting this amount of information at once could lead to confusion and increase the time it takes for the user to become familiar with the system. If a teacher is not helping students use the software initially, help documentation about the auditory cues in the system would be necessary to mitigate initial confusion. Providing either written or in-software guides would afford the user several benefits. It would increase autonomy (students would rely less on the teacher when getting started), reduce teacher load, and serve as a prompt if a user needed a reminder of the functions of various controls or meaning of auditory inputs.

Our results therefore emphasize the importance of deploying potential assistive technologies in the environment they will be used and assessing adoption over time to gain a holistic understanding of these systems since I found that attitudes and perceptions do change over the school year. For instance, while the sounds of GNIE seemed complex at first, the students supported the wide variety of auditory feedback and ultimately think it is an important feature of the system. Students' also had very strong views about the ability to orient and understand the layout of the graph from the auditory cues, demonstrating that using sonification can accurately represent and replace visual cues in AT for students with visual impairments.

Numerous studies have shown the benefits of using technology as a tool inside the classroom to promote engagement with the material, cooperation and collaboration between students, additional modes of presentation for materials, and a method to more easily connect learning at school with learning that takes place outside of the classroom. As technology becomes adopted in classrooms and utilized to support learning, especially in STEM curricula, a focus on universal design and AT design principles are important considerations during requirements gathering, development, and evaluation. Student engagement and the extent to which the AT is able to foster the independence of the students are particularly important factors to investigate. These are important considerations when working to develop a technology for use in the classroom.

6.4 Conclusion

The data gathered through focus groups and surveys indicate that students had an overall favorable impression of GNIE. Some of this is due to alleviating physical environment constraints, such as not having multiple physical components to navigate between or not having to set up additional outside AT, which is a notion supported by the HAAT framework. Additionally, while deploying an educational technology in the classroom, it is important to consider the individual experiences of the students and the teachers. That said, it would be necessary to investigate the impact of the GNIE system in multiple classroom environments. I explored its use at one school, the GAB, over the course of two years with a small group of middle school students. It would be important to extend the number of classrooms where this is deployed, to gain a more cohesive idea about the impacts of AT on supporting mathematics classes. Further classroom observations and focus groups with more students would be the next step necessary to explore the system's ability to support and enhance the student experience in the classroom.

Table 2 SY2012 and SY2013 responses to the 14 Likert scale questions addressing attitudes toward computer and paper/tactile graphics

#	Statement	Fall 2012		Spring 2013		Fall 2013		Spring 2014	
		Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
C1	I understood the graphing problems with computer graphs.	2.71	1.50	4.09	1.21	4.18	0.98	4.20	1.03
C2	Between the paper graphs and the computer graphs, I think I was faster on the computer.	2.29	1.25	3.73	1.38	4.09	0.83	3.60	1.17
C3	Between the paper/tactile graphs and the computer graphs, I think I had more graph questions correct on the computer.	2.14	1.46	3.82	0.94	4.09	0.94	3.80	1.03
C4	I think I do better with computer graphs.	2.57	1.51	3.73	1.06	4.18	0.98	3.40	1.26
C5	Computer graphs were helpful in solving problems.	2.43	1.27	3.64	1.07	4.09	0.94	3.80	0.92
C6	Computer graphs were fun to use.	2.71	1.50	3.82	1.11	3.82	1.08	3.80	0.92
C7	Computer graphs were annoying to use.	3.29	1.25	1.82	1.11	2.45	1.29	1.70	1.06
P1	I understood the graphing problems with paper/tactile graphs.	4.00	1.53	3.73	1.06	3.36	1.36	3.60	1.26
P2	Between the paper graphs and the computer graphs, I think I was faster on paper.	3.14	1.35	2.73	1.15	2.55	1.37	2.90	1.45
P3	Between the paper/tactile graphs and the computer graphs, I think I had more graph questions correct on paper.	3.71	0.95	2.55	1.07	2.73	1.56	3.10	1.29
P4	I think I do better with paper/tactile graphs.	3.57	1.27	3.00	1.08	2.18	1.08	2.80	1.40
P5	Paper/tactile graphs were helpful in solving problems.	4.29	0.76	4.00	0.74	2.45	1.13	2.90	1.20
P6	Paper/tactile graphs were fun to use.	3.43	1.40	3.55	1.44	2.55	1.29	3.00	1.41
P7	Paper/tactile graphs were annoying to use.	2.86	1.77	2.18	1.40	3.00	1.67	2.90	1.45

Table 3 SY2012 and SY2013 responses to the Likert-type items about computer graphs and graphing in general.

#	Statement	Fall 2012		Spring 2013		Fall 2013		Spring 2014	
		Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
1	In general, number line questions are difficult.	2.00	1.73	2.58	1.08	2.45	1.37	2.10	0.88
2	In general, graph questions are difficult.	2.57	1.27	2.50	1.17	2.91	1.38	2.40	1.26
3	I needed the sound to use the computer graphs.	3.86	1.46	4.08	1.00	4.27	0.90	4.00	0.67
4	I needed my vision to use the computer graphs.	2.43	1.62	3.42	1.51	3.64	1.21	3.10	1.29
5	I needed my vision to use the paper/tactile graphs.	3.14	2.04	3.33	1.23	3.82	1.40	4.40	0.70
6	I preferred to be able to hear the sounds with the computer graphs.	3.86	1.46	4.33	0.98	4.27	0.90	4.10	0.74
7	It was easy to understand the meaning of the sounds on the computer graphs.	2.29	1.60	3.75	1.22	4.00	0.77	3.50	1.08
8	I had to concentrate on the sounds on the computer graphs.	3.71	1.60	3.75	0.87	3.73	1.19	3.80	1.03
9	I can see myself using computer graphs outside of school.	2.43	1.13	3.17	1.27	3.09	1.14	3.70	1.25
10	I feel comfortable using computer graphs by myself without any help.	2.14	1.07	2.17	1.03	2.55	1.13	2.70	1.34

CHAPTER 7

THE STUDENT PERSPECTIVE: THINK ALOUD

As part of a larger study assessing the impact of introducing GNIE into the classroom, I already have some data directed at questions answered during a lesson by students. In order to achieve a more comprehensive picture of the interfaces, however, here I am focusing on understanding the cognitive process and procedures used by students to arrive at these answers. Others have argued that the degree of transfer between tasks is a function of the cognitive elements that are shared between the tasks [61]. Building on that, my goal for this activity is to outline how students perform basic graphing operations using two different mediums. For instance, do students plot points on a coordinate plane with the same method when using GNIE as when using tactile graphics? The results may look the same, but the process to achieve the results may differ. Therefore, I opted to use a modified version of the think aloud protocol [62], [63]. The think aloud protocol is a popular methodology in part due to its simplicity and low-cost set-up and has shown to be an effective way to probe at underlying cognitive processes [64], [65]. Having students describe their thought process and actions taken to answer graphing problems is an important step toward mapping the task flow of GNIE along with tactile tools and uncovering any differences between the two.

The basic structure of a classic think aloud protocol involves having a participant articulate their actions and reasons for completing actions while simultaneously interacting with an interface and being observed by a researcher [63]. There is still some debate over guidelines for conducting a think aloud and how much interaction a researcher should have with the participant [66], [67] though a relaxed protocol allowing more interaction between researcher and participant seems to have minimal impact on the quality of verbalization [55].

A majority of think aloud protocols are conducted with participants who do not have specific disabilities such as vision loss [68]. Some studies have been conducted to evaluate the feasibility of tailoring the protocol for persons with disabilities such as vision or hearing impairment [68], [69]. For participants with vision impairment, interfaces that have an audio output such as screen readers, can interfere with verbalization [70]. Thus, think aloud studies used with this population often require the researcher to pause the interface to gather think aloud information from the user or wait until the end of the study and then conduct a traditional retrospective think aloud [70], [71].

I, however, decided to do both a concurrent and modified retrospective think aloud protocol. I first did a retrospective think aloud because I was interested in what students perceive they do with each interface, without interference and without the potential distraction of simultaneously using the interface. I then used a concurrent think aloud because I wanted to see if the perception differed from the reality of using the interface. These methods are appropriate because I am not testing for specific usability issues of our system and the tasks I chose (discussed below) are not tasks of high complexity [72]. However, I had to get creative in order to conduct a concurrent think aloud with an auditory interface.

7.1 Method

This study was also conducted at the Georgia Academy for the Blind, a residential school that serves 4^{th} through 12^{th} grade students. Participants were middle school students from 6^{th} – 8^{th} grade who were also part of a larger study investigating the impact of using auditory graphs for teaching and learning middle school math. The study took place after school at the end of the Fall and Spring semester during school year 2013 (SY2013).

Each session lasted between 60-90 minutes and was split into three main segments – group discussion and survey/demographic questions (discussed in the previous section), and individual think aloud activity. The group discussion lasted about 15-20 minutes. The think aloud and survey questions were conducted one-on-one with a student and researcher from the lab. Each think aloud and survey lasted approximately 15 minutes per student. Students were allowed to talk quietly amongst themselves or work on homework problems while waiting their turn for the think aloud activity.

7.1.1 Fall 2013: Retrospective Think Aloud

Eleven students participated in this activity. Students who participated in this session were already familiar with using GNIE. Most had used it for one and a half academic school years since the start of the larger study, and two students had started using the system since the beginning of the current school year.

A modified retrospective think aloud protocol was utilized in the Fall 2013 session. Similar to a standard retrospective think aloud, students were asked to verbalize their thoughts about a particular graphing process without concurrent interaction with a graphing medium. Students did not perform the graphing problem immediately prior to the think aloud, in either tactile or computerized form. I decided to include this delay because the goal of this protocol is not to explicitly uncover usability flaws in either tactile or auditory graphs, but to compare the mental processes and procedures for the same problem using two different mediums.

I incorporated a relaxed protocol where both researchers and participants can ask questions and interact with each other. This decision was made because I wanted our younger participants to feel more at ease during each task and less like they were being tested. Researcher interruption was limited to reminding students to think aloud if they fell silent or asking them to elaborate if their verbalizations were unclear.

The think aloud tasks chosen for this study were familiar tasks that students would have to do every time they used GNIE. I chose graphing questions that were simple and required minimal mental calculations. The first task was to describe the process of *finding* a point using GNIE and then describe the process using a tactile graph. The third task was to describe how to *plot* a particular point [we used the point (3, 2)] using GNIE and then using a tactile graph. Prior to the start of the session, the retrospective think aloud protocol was explained to the students along with an example. They were given the opportunity to ask any clarification questions before the start of the first task and were allowed to ask questions during the tasks. The entire session was audio recorded and transcribed.

7.1.2 Spring 2014: Novel Concurrent Think Aloud

Ten students participated in this session. One student's data were not included in this analysis because she was unwilling or unable to verbalize her thought process during the task. All the participants were familiar with the usage of bone-conduction headphones and had worn them for at least one-year prior to this session. The bonephones were used whenever students worked with GNIE during the school year, so any novelty effect of using this type of headphone during the think aloud were minimal. Before the start of the task, they were reminded of the procedure of a think aloud protocol. Every student who participated in the Spring session had also participated in the Fall session.

For the Spring 2014 session, I tested a new method for conducting a concurrent think aloud with an auditory interface. Previous methods have found it necessary to pause auditory interfaces periodically because the audio outputs tended to interfere with user verbalization of thoughts [71]. Additionally, over-the-ear headphones or earbuds have typically been worn during the task, making it difficult for researchers to ask clarification questions or communicate with the participant. To address some of these issues, I incorporated the use of bone-conduction headphones by AfterShokz [48] during the think aloud task. Bone-conduction headphones (bonephones) allowed the students to listen to both GNIE and the researcher at the same time and allowed the researcher to ask questions, provide instructions, and address any concerns the student might have during the task without having to pause the interface or remove headphones.

The Spring session included four main tasks. In addition to performing the two tasks of finding a point and plotting a point repeated from Fall, students were also asked to *label* a point and *draw a line* between two points. They were asked to do these tasks using both GNIE and a tactile board with pegs and rubber bands. Four students were presented with the GNIE task first and five students with the tactile task first. For each medium, students were ask to find a pre-placed point on the coordinate plane, plot a specific point, label the new point, and create or draw a line between the two points. Students were asked to think aloud while they completed each task.

Speech during each of the eight tasks (four for each medium) was audio recorded and, when possible, the computer screen was also video recorded. The audio recordings were then transcribed for analysis. A tally of completeness was logged for each student for each task, and presented in the following section. All speech was recorded during each session and then transcribed afterward. The transcriptions were then uploaded to the qualitative analysis website Dedoose [37] for coding. I decided to use context-appreciative coding [73] for analysis because some students' utterance data were sparse and having the context in which the verbalization occurred would allow us to make more accurate interpretations of verbal data through contextual checking.

7.2 Results

The aim of the analysis was to establish the common cognitive steps and physical actions that students took when performing the graphing actions of finding a point and plotting a point on a coordinate plane. I was particularly interested in how these steps differed between GNIE and traditional tactile graphing mediums. While I collected and transcribed think aloud data for the other two tasks of labeling a point and drawing a line between two points, since these tasks were explored in Spring 2014 and not Fall 2013, I concentrated on finding and plotting points when comparing utterances between mediums.

I began with three main groups of codes for each task – starting phase, action phase, and solution phase. The groups correspond to the flow of the tasks from beginning to end. Within each group are categories and subcategories that describe actions or processes that occur during each phase. These are listed in Table 4. Each transcription was segmented into individual utterances. The utterances varied in length, but contained a single idea and were coded to either a main or subcategory underneath a main category.

Table 4 Utterance categories, subcategories, and their definitions.

Categories	**Definitions**	**Examples**
Action description	Describes what they were planning on doing, currently doing, or just finished doing	*" now I'm going to the y-direction"* *"I'm trying to put the line on the thing right here"*
Counting *	Counting aloud	*"So, 1, 2, 3, 4."*
Orientation *	Statements about orienting on the graph/statements about starting or moving from a specific location	*"like I said, I'll start with zero"* *"Probably start from the y-coordinate"*
Movement toward destination *	Describes a movement toward a location/destination/goal	*"Well – yeah, go to the right 2 and then up 2"*
Action explanation	Provides a reasoning for why they executed or will execute a particular action	*"I'm going to go down until I hear something."*
Task Uncertainty	Statements indicating confusion or uncertainty about the task or action	*"And this is "p" or is it "ctrl + p" to point?"*
Observation	Statements about the state of the problem or task	*"Um, here's the zero."* *"it's now y."*
Search *	Describes a searching action	*"now I'm going to find the 'y'"*
Procedure *	Describes a procedural action	*"I'm going to push the 'x' to find the x-value."*

Problem solution statement	Statement indicating the solution has been found	*"And the point is (2, 2)."*

*: indicates an utterance subcategory

The number of utterances in each task was calculated for each medium. From there, a paired samples t-test was conducted to compare the number of utterances in the GNIE/tactile conditions, retrospective/concurrent think aloud conditions, and the find a point/plot a point conditions. The results revealed that there were no significant differences in the number of utterances produced between the retrospective and concurrent think aloud conditions or the find a point and plot a point conditions. However, there were significantly more utterances in the GNIE condition (M=41.25, SD=12.63) than in the tactile condition (M=29.5, SD=6.95) conditions; $t(3)=3.062$, $p=.05$.

Next, working from the codes, I created a flowchart for each of the processes based on the steps that a majority of the students took for each task (Figure 18, Figure 19). The diagram is a basic outline of the actions required to find and plot a point on a tactile board and GNIE. Overall, *finding* a point on GNIE requires more iterative steps than when using a tactile graph. In contrast, *plotting* a point on a graph using a tactile medium or GNIE incur roughly the same number and type of steps.

For all tasks, another measurement I recorded was a tally of task completion by medium, observed during the concurrent think aloud. As one of the study goals was to compare graphing actions conducted using tactile and GNIE, it was necessary to keep a tally of which tasks, if any, students struggled with when given a graphing task. I should note here that all students were able to verbalize the process for each task during the Fall retrospective think aloud, and no one said "I don't know" or gave up.

Table 5 This table shows a tally of task completeness for each concurrent think aloud task activity conducted during Spring 2014.

	Find a point			Plot a point			Label a point			Draw a line		
	C	*IC*	*P*	*C*	*IC*	*P*	*C*	*IC*	*P*	*C*	*IC*	*P*
Tactile	9	--	--	9	--	--	--	9	--	9	--	--
GNIE	6	2	1	9	--	--	2	4	3	1	4	2

*C: complete, IC: incomplete, P: partial

Table 5 shows the completion rate of each of the eight tasks. A task was marked "complete" if the student was able to finish the task without help. A task was "incomplete" if the student gave up or said "I don't know" and did not ask for assistance or clarification to finish the task. A task was marked as "partial" if the student finished the task, but required help from the researcher. Examples of help included a reminder of what point(s) they were looking for or plotting or what key-commands were associated with desired actions (e.g, "p" for plotting a point). Assistance was not given to the student unless they specifically asked for it. As indicated in the table, while all students were able to outline their process for finding a point on GNIE (Fall 2013), some students were not able to complete the task of finding a point on GNIE during the concurrent think aloud. No student was able to demonstrate labeling a point using a tactile board, though one participant claimed that he made a mental note in his head that the point was there. Students across all grades performed consistently using a tactile graphic.

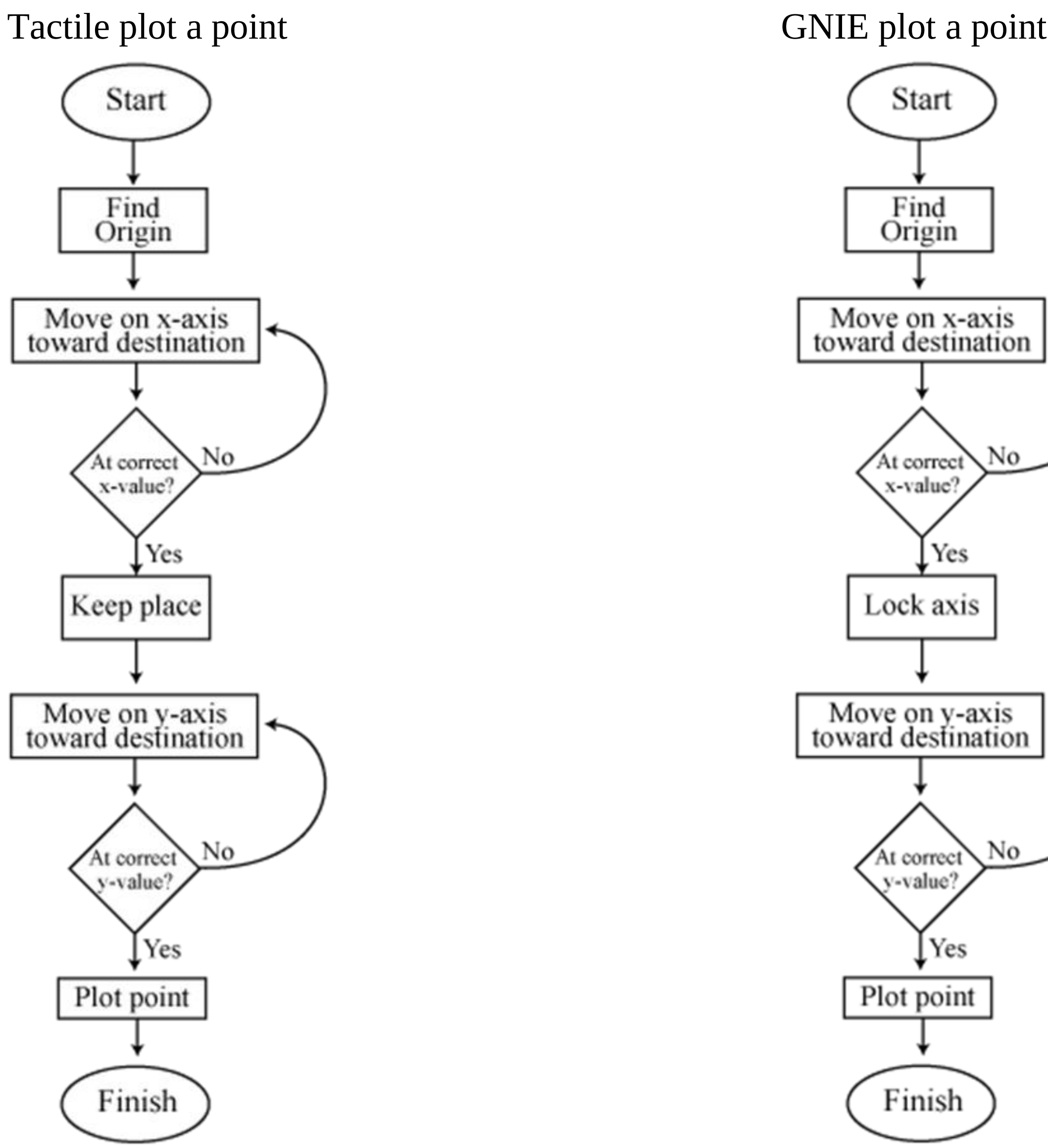

Figure 18 A flowchart depicting the actions taken by students to plot a point on a tactile graph and on GNIE

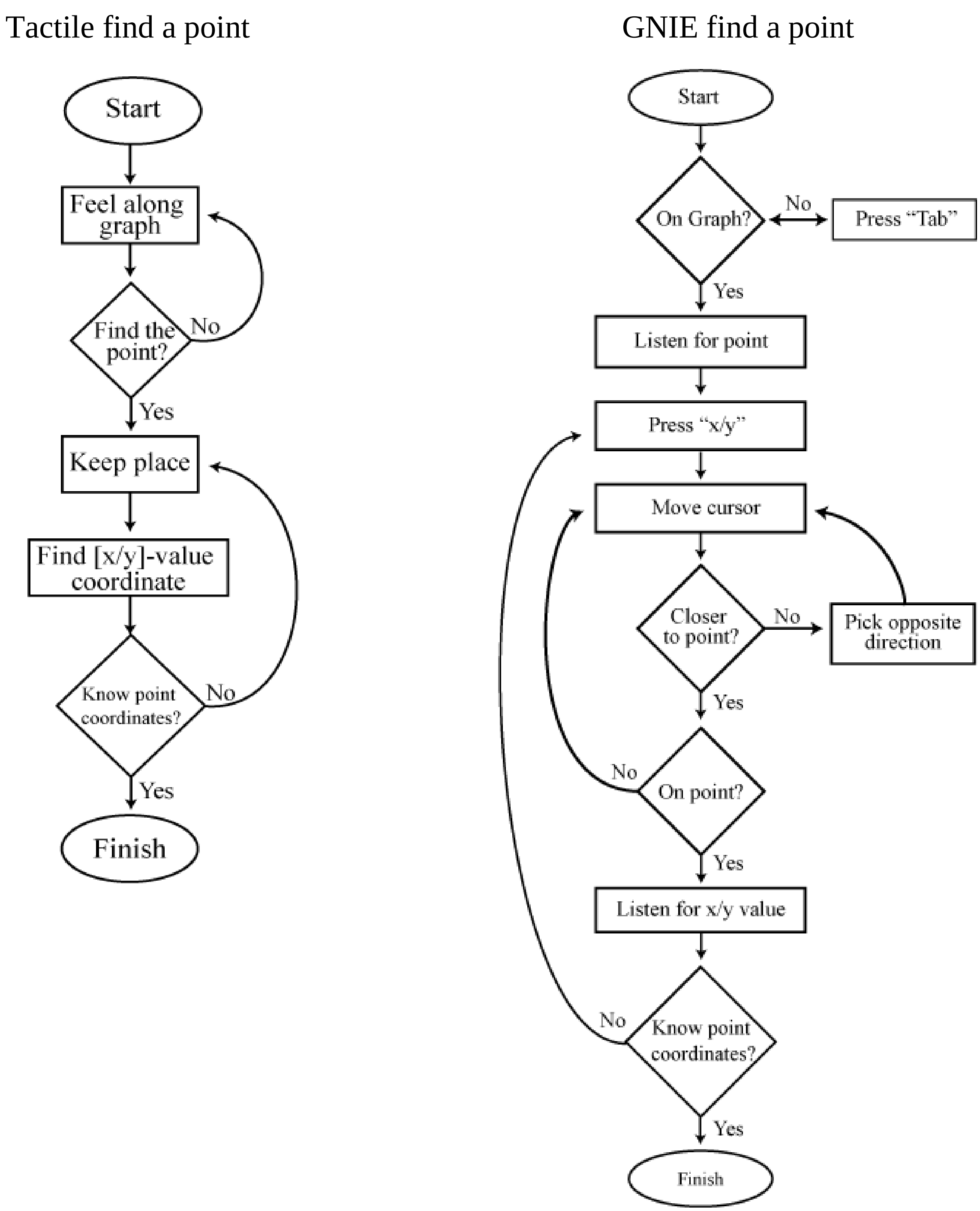

Figure 19. A flowchart depicting the actions taken by students to find a point on a tactile graph and on GNIE

7.3 Discussion

Overall, results suggest that there are qualitative differences in the way users approach finding a point on the coordinate plane on our system versus a tactile graphic, and this may have an effect on task performance. However, when it comes to plotting a point on the coordinate plane, users do not demonstrate any differences between using a tactile graphic and GNIE, and task performance remains the same.

I found that there were more distinct verbalizations from students when reflecting on tasks done on GNIE than on a tactile graphic. Given that students have less experience with GNIE than with tactile graphics, some actions may not have yet become subconscious and students are more acutely aware of each individual step required to achieve a goal. These actions (e.g. pressing "x") can be indicative of a novice learning to use a system and may fade into the background over time [62].

In addition to comparing utterances between GNIE and tactile graphing mediums, I also found that there were no significant differences in the number of verbalizations between the two think aloud methodologies. This finding indicates that my method of conducting a concurrent think aloud protocol using bone-conduction headphones is a viable alternative to the modified concurrent think aloud method that is commonly used in testing with users who have vision impairment. Employing bone-conduction headphones during the task allows researchers to assume an interactive role during the think aloud while enabling the participant to remain receptive to verbal prompts and questions without disabling or pausing the interface.

Results from the task completion success rate suggest that users perform more consistently (i.e. all successes or all failures) using a tactile graphing medium than when using our system. One possible explanation for this result was that participants felt that they had to arrive at the solution quickly and thus gave up or asked for assistance in order to move on to the next task. Alternatively, it may be that the workflow between an existing and new system will affect performance on the systems. For instance, when workflows are similar between GNIE and tactile graphs as in the case of plotting a point on a coordinate plane, every student was able to successfully plot a point. When workflows are different, as in finding a point, some students have difficulty with the task. When designing systems in the future, it might be useful to examine the framework of the existing system to see how it compares first.

There are a few limitations to my approach in this study. First, my sample size was small and highly specific. I have taken care to document the process and utterances so that inferences can be made to other populations, but there is still a chance that the results obtained from my subjects are atypical. Also, I deliberately chose tasks that users were familiar with. Choosing a familiar task can help make verbalizing the actions taken to achieve a goal easier because it is something that is repeated often. It can alleviate some of the cognitive load involved in trying to understand a new process. While this decision was based on what I wanted to study (i.e. how students achieve typical graphing goals), results may be different for usability studies that attempt to uncover problems with a specific interface.

7.4 Conclusion

When designing a system that serves as a supplement or alternative to an existing method of completing a task, it is important to examine the cognitive process of the current method. To make the transition more seamless, designers might want to establish a workflow that takes advantage of existing workflows. This is especially important in math, where steps needed to complete a problem are explicitly and rigidly laid out.

Although my sample size was relatively small, using bone-conduction headphones in place of regular headphones to conduct a concurrent think aloud protocol yielded positive results. Participants still provided utterances that were on-par with the retrospective think aloud protocol. This suggests that bonephones can be used to conduct concurrent think aloud usability tests without a degradation in data gathered while preserving the option for researchers and participants to interact with each other during the study.

CHAPTER 8

DISCUSSION AND CONCLUSION

The research presented in this dissertation serves two purposes. The first purpose is to understand the impact of introducing an auditory graphing software (GNIE) into a classroom for students with vision impairment. This aim is a practical step toward helping practitioners and researchers understand the role of assistive technology in education today. The second purpose of this work is to contribute to the HCI community by investigating the role of technology in learning environments. This work is done through a mix of qualitative and quantitative methods. In the following paragraphs, I begin with a discussion of the overall advantages and disadvantages of our system, followed by a revisiting of my research questions and assessment on how I answered them. Then I finish with a summary of my contributions to the HCI community and directions for future research.

When choosing research methods for this study, I needed to consider what techniques were appropriate for my goals. I wanted to understand how GNIE evolved with minimal outside intervention, so a bulk of my methodology relied on qualitative approaches. In doing so, I had to consider whether the results from the study and the analysis I conducted were trustworthy. To evaluate trustworthiness, I will discuss the four criteria of a trustworthy study as posited by Lincoln and Gruba [74]: 1) credibility; 2) transferability; 3) dependability; and 4) confirmability.

Credibility refers to the degree to which researchers can say that the data collected accurately depicts the phenomenon being studied. Two techniques to establish credibility is through the researcher having prolonged engagement and persistent observation with the research subjects. Prolonged engagement is essential because it allows the researcher to become orientated in the setting, build rapport and establish trust with subjects and rise above any preconceptions coming in to the study. Persistent observation then allows researchers to identify important elements that relate to the problem being studied and focus on them in detail. Lincoln and Gruba state that, “if prolonged engagement provides scope, persistent observation provides depth" [74]. These two evaluative techniques are applicable to this dissertation’s study. I have made multiple trips, during each trip staying for multiple days over the course of the two-years of deployment at GAB. During that time, I have established a solid relationship with the administrators of the school as well as the teacher. Being present at the school constantly means watching students progress in their studies and move on to higher grades and getting to know and understand their personalities and preferences for math and technology. It also means that I have a baseline of knowledge to draw from to know when something deviates from the norm.

Transferability is concerned with the degree that findings from a study can apply to external situations. A technique for establishing transferability is by using thick descriptions – describing the phenomena in enough detail that others can determine the extent that the conclusions drawn and patterns established can be applied to contexts that are outside the scope of the original setting. This dissertation document is my attempt at transferability. My sample size and population is small, and that comes with the benefit of gaining a deeper understanding of individuals in the study. And while the numbers are few, the experiences of my participants may not be unique to them. I have described the frustrations and expectations of the teacher and students and observed how attitudes and technical familiarity with GNIE have changed over time with exposure to the system.

Dependability is showing that results from the study are consistent and can be repeated, and a technique for evaluation is by conducting an inquiry audit. An inquiry audit is done with a researcher that is not involved with the research process and they perform checks to ensure that the process and product of the study are accurate and that the conclusions are supported by the data. Inquiry audits take place in my dissertation in several ways. First, another coder is used for the qualitative data collected from interviews with the teacher. Relevant statements are extracted and examined, then discussed and catalogued. Second, at least one and sometimes more researchers are present in addition to myself during focus groups with the students. When preliminary findings are presented, these researchers provide a sounding board for discussion. Finally, my advisor provides oversight on the entire research process and serves as an important external source for quality control of the study.

Lastly, confirmability refers to the degree to which the results and conclusion of a study are neutral and non-biased. A common evaluative technique for establishing confirmability is through triangulation – using multiple data sources in the investigation. I attempt to do this through a combination of qualitative and quantitative techniques that are discussed in the introduction. The quantitative techniques help establish a pattern and the qualitative help explain those patterns.

I have attempted to establish the trustworthiness of this study by examining the four criteria developed by Lincoln and Guba. While not perfect, the research methods I chose and research process I took meet the criteria discussed above. Thus, this strongly suggests that the results and conclusions posited in this dissertation are valid. Additionally, this work provides evidence to support the HAAT model established by Cook and Hussey. While the model was not explicitly used when designing the study, HAAT was used as a framework for understanding how the different contextual components of the system worked together when GNIE was introduced to the classroom.

8.1 Overall GNIE discussion

The primary purpose of my dissertation is to understand how a computerized auditory-based graphing system would impact a classroom for the blind. However, in order to understand the impact this system has in the environment, I must also examine the performance of the system in the wild – what it does well, what it does not do well, and what can be done better in the future. The following section discusses these findings.

The primary benefits of using a dynamic computerized system rather than a static tactile system is that it lowers the costs associated with creation and exploration. For teachers, this means that they can create questions on the fly and they do not have to worry about external hardware or equipment. For students, this translates to being able to move through a series of questions without losing their place, and being afforded the ability to save their work between problems and between lessons.

An area for improvement for GNIE can be made in how it conveys and reads text to the student. As the system is currently programmed, GNIE will read out typed problems in standard English, not accounting for mathematical expressions. For instance, what appears visually as an absolute value expression (e.g., |-7|) would be read instead as "bar minus seven bar". A workaround that can be used is to type out the word "absolute value" followed by the number, but this is a short-term solution and only viable when expressions are short and simple. Typing out the pronunciation of symbols is also problematic because it does not teach students how to identify and interpret mathematical expressions – an important component of learning math. One of the reasons that this issue did not surface as a problem during the course of the deployment is likely because the level of complexity of mathematical symbols covered by the teacher is still relatively low at the middle-school level. If this system were going to be used for advanced math at the high-school level and beyond, it is critical that this issue be addressed in future versions.

Another area worth exploring in GNIE is looking at what types of interactions should be used when graphing content becomes more complex. For instance, as a sighted user, when I look at a coordinate plane with a triangle plotted on the graph, I first understand that it's a triangle I'm looking at, and then look closer to see each of the triangle's vertices. It's unclear whether GNIE supports this type of interaction. While users can plot points and draw lines between points (such as for a triangle), it remains to be seen whether the user can "hear" the triangle and then move to explore its components. Our system assumes that the user explores the graph in a linear fashion (e.g., up and down, left and right). GNIE also does not currently support curves and circles, which leaves out a portion of the curriculum.

Lastly, GNIE can improve the experience for both teachers and students by providing more support and guides when using the system. We bypassed the "up-and-running" experience for the teacher by installing the software on the school computers prior to the start of the school year. There are multiple system checks and requirements that are needed to ensure that GNIE is installed and running properly, and a consolidated installation wizard would be beneficial for others who want to use the system. A tutorial or help guide would also help with first-use of the program and help students who have difficulty remembering the procedural actions required to answer problem sets without help from the teacher.

8.2 Research questions revisited

I conceived of my research focus before the beginning of the first deployment after meeting with Dr. Ben Davison and the teacher at GAB. While Dr. Davison's dissertation was focused on developing the system and pilot testing the software, I was committed to taking what he had created a few steps further and seeing it perform "out in the wild". A longitudinal study of this length was the only way that I could adequately explore the evolution and impact of using this system over time. The main question that guides my dissertation research is that of understanding the overall impact of using GNIE. The different parts of that question emerged over time through my interactions with the teacher and students – much like the system itself.

R1 How does introducing auditory graphing tools to the classroom affect classroom dynamics?

I wanted to understand what happens to interactions in the classroom when an auditory graphing tool is used during middle school math class. I examined these questions through an ethnographic approach of classroom observation and supplemented with teacher interviews and student focus groups. I found evidence that overall, the role that auditory graphing tools play during class time is a tool used to reinforce ideas and present them in a different context.

R2 How will the use of GNIE affect time spent one-on-one per student?

I was interested in examining what affect auditory graphing tools have on structured lecture time versus time spent helping individual students. I observed the teacher during days when she used tactile graphics and also on days when she used GNIE. I annotated video data according to lecture and student time and it appears GNIE has an effect on how a teacher directs her attention during class. I found that the teacher does make adjustments to her how she conducts a lesson when using tactile graphics and when using GNIE as the primary teaching medium. This results in increased lecture time during tactile lesson days and increased time spent with individual students during GNIE lesson days.

R3 How will the use of GNIE affect student collaboration among themselves?

Another aspect of classroom dynamics is the relationship and interactions between the teacher and students and students with each other. To examine this further, I relied on classroom observations of collaboration between students, discussion with students, and interviews with the teacher about collaboration. I found evidence that students were more likely to collaborate when GNIE is used than on days when tactile graphics are used. Students reported enjoyment in helping their peers with lessons and liked the fact that their level of vision loss did not impact their ability to collaborate with others using the computer. The teacher also reported the desire and usefulness of having students work on problems together

R4 How do auditory graphing tools differ from traditional tactile graphing tools?

I also wanted to look at the ways in which auditory graphing tools differed from traditional tactile tools. I was interested in how lesson preparation using both were different for the teacher and also in how underlying cognitive processes differed when students executed graphing actions using both tools. I used interview data to understand the lesson planning process from the teacher's perspective and conducted think aloud activities with students to understand their cognitive processes. I found that aside from the medium of presentation, auditory graphing tools are different from traditional tactile graphing tools in a few main ways: 1) they have fewer components and thus are easier to set up during lessons 2) when used in the classroom, they enable students to work independently and support collaboration between students and 3) require procedural knowledge that may be difficult at first for users to learn.

R5 How do auditory and tactile tools impact the lesson planning process?

Through repeated interviews with the teacher, I discovered that computerized software has the ability to reduce lesson preparation time and materials for the teacher. The teacher consistently reported that lessons took less time to prepare when using GNIE compared to tactile graphics. Additionally lesson preparation was more likely to take place outside of the classroom context when using our system. However, not all lessons were able to be incorporated in GNIE because the system does not support complex mathematical expressions or curves and 3D objects.

R6 What mental procedures do students employ to interact with GNIE and does this differ from what they use for tactile graphics?

The purpose of R6 was to examine whether GNIE supports desirable interactions when answering graphing problems. I used bone-conduction headphones to conduct a concurrent think aloud protocol and compared results to a retrospective think aloud condition with students about specific graphing problems when using a tactile graphing and when using GNIE. Results indicated that students use the same steps to arrive at answers when *plotting* a point on a coordinate plane, but different steps to arrive at answers when *finding* a point on a coordinate plane. The differences between these two procedures could explain performance inconsistencies in the two tasks that I observed.

The role of technology in a learning environment is a complex and nuanced one, and GNIE is no exception. I did not come into this research area with a specific target for GNIE to achieve (for instance, a higher standardized testing score for users of the system), but rather wanted to observe and document how the system can be used in the classroom and the features that can be improved. I came away with a model for how this system was used in the classroom and recommendations for future iterations of the system. Other contributions to the community include: an assessment on how auditory graphing tools compare to traditional tactile tools and a novel method for conducting concurrent think aloud protocols with users who have vision impairment.

8.3 Future work

There is still much research to be done in the area of auditory graphs research for math education. I examined GNIE in a particular school for the blind for two-years. This research is a good reference for what to expect when these systems are used in a classroom, and future work involving expansion to mainstream schools or other schools for the blind would be the next logical step for this project. To facilitate this expansion, researchers can consider moving GNIE to an online platform to make distribution easier – both for the teacher to create and deliver lesson plans and for research teams to be able to troubleshoot remotely any issues that may arise.

Another avenue of exploration would be to examine and test the boundaries of auditory graphical representation for more complex concepts such as 3D objects and pair them with standards learned in the classroom. Researchers could then again assess how the system performs. More research can be done to study the most effective way to present such information such that it allows for exploration of the data rather than just passive receiving of information.

Additionally, studies can be done to replicate conducting a concurrent think aloud protocol using bone-conduction headphones. Examining whether this method can consistently yield good quality results with users with vision impairment and also testing whether this method can be used with any user and interface with auditory output will help expand the toolkit of methods for all user experience practitioners.

Finally, in Fall 2014, after the conclusion of the two-year deployment of GNIE for this dissertation, an informal phone conversation transpired with the teacher at GAB. The teacher mentioned that she had not had a chance to use GNIE in her classes this semester and did not really know why. The teacher also stated that she would use GNIE in her 8^{th} grade class when they reached the lessons covering transformations on the coordinate plane. Checking in on the teacher periodically could provide additional insight on the long-term use of GNIE in the classroom.

APPENDIX

Demographics/Focus group survey

Experimenter: Please fill out this top portion
Study: ________________________________

Date: _________________________________

Participant Number: ____________________

Experimenter Name: ____________________

General Demographics

1. What is your gender? **Male** **Female**
2. What year were you born? _____________________
3. What grade are you in school? ________________________

Impairment

4. Do you have normal hearing or corrected-to-normal hearing? **Yes** or **No**
5. What would you consider to be your current level of visual impairment?

   Sighted **Low Vision** **Blind**
6. When did you become low vision? ______________
7. When did you become blind? __________________
8. Do you have mobility impairments in either arm, including hands?

   Neither Arm **Left Arm** **Right Arm** **Both Arms**
9. Which is your dominant hand? **Right** **Left**

Computer/Technology Access

10. Do you have access to or own a computer at home? **Yes** or **No**
11. What other technology(s) do you own (e.g., smartphone, tablet, etc)?

12. What (if any) technology(s) do you use for schoolwork/homework?

GNIE Feedback

Over the past few weeks, we have explored visual, tactile, and auditory graphs.

- "**Computer graphs**" are the graphs, with sounds, that were completed on the laptops or desktops.
- "**Paper/tactile graphs"** are the graphs that were enlarged or made out of tactile graphics.

This section asks for your feedback. Please answer with a scale of 1 to 5, where 1 is strongly disagree, 2 is somewhat disagree, 3 is neutral, 4 is agree, and 5 is strongly agree.

1. ___ In general, number line questions are difficult.
2. ___ In general, graph questions are difficult.
3. ___ I understood the graphing problems with paper/tactile graphs.
4. ___ I understood the graphing problems with computer graphs.
5. ___ I needed the sound to use the computer graphs.
6. ___ I needed my vision to use the computer graphs.
7. ___ I needed my vision to use the paper/tactile graphs.
8. ___ I preferred to be able to hear the sounds with the computer graphs.
9. ___ Between the paper graphs and the computer graphs, I think I was faster on paper.
10. ___ Between the paper/tactile graphs and the computer graphs, I think I had more graph questions correct on paper.
11. ___ I think I do better with paper/tactile graphs.
12. ___ Between the paper graphs and the computer graphs, I think I was faster on the computer.
13. ___ Between the paper/tactile graphs and the computer graphs, I think I had more graph questions correct on the computer.
14. ___ I think I do better with computer graphs.
15. ___ It was easy to understand the meaning of the sounds on the computer graphs.
16. ___ I had to concentrate on the sounds on the computer graphs.
17. ___ I can see myself using computer graphs outside of school.
18. ___ I feel comfortable using computer graphs by myself without any help.
19. ___ Paper/tactile graphs were helpful in solving problems.

20. ___ Computer graphs were helpful in solving problems.
21. ___ Paper/tactile graphs were fun to use.
22. ___ Computer graphs were fun to use.
23. ___ Paper/tactile graphs were annoying to use.
24. ___ Computer graphs were annoying to use.
25. What are some of your favorite things to do on the computer? What games, programs, or websites do you visit for learning/education? Why do you like them?

26. Do you have any comments about computer graphs or paper graphs?

27. Do you have any other comments?

Thank you for completing this survey!

Focus Group Transcripts

Focus Group 11/28/12

R: When you have some extra time during class to use the computer, what do you normally use it for? What games or websites do you visit?

75F: When I was in ECC, I would normally use it for, like, they would ask me for certain websites like my favorite websites. I don't know. I like Nickelodeon. So I use it for Nickelodeon – and that's probably it. Or if they want me to go on some specific websites like math or

85F: Georgia 411.

75F: What?

85F: Georgia 411. It's like college planning and figuring out what career you want to do.

R: Okay

75F: I don't even know what that is.

R: What about the others? What games or - ?

71F: Fun with TypeAbility

75F: Oh yeah! Fun with TypeAbility!

85F: Oh no! That game is annoying!

71F: It's the only thing I can get on.

83M: That's the only thing I'm able to use.

71F: I ignore the jokes because the jokes are stupid.

83M: That's the only thing I can

75F: The jokes are hilarious.

R: Can you elaborate further on that?

85F: It's like a typing program that –

71F: - teaches you keyboarding and skills

75F: yeah it teaches you how to sit up straight

71F: And then if you're done with it, instead of giving you candy, they give you a joke. I wish that – yeah, can you make computers that pop out a candy every time you get something right?

R: That's great. It teaches you keyboarding

71F: I would use a computer everyday if I had that.

R: So I hear you also have a game called "Study Island"?

Class: Yeah

71F: Ms. Pope I never got on that

R: [75F], you want to talk about it – Study Island?

T: You all. Pretend I'm not here. Say whatever you believe okay? I'm not judging or listening to anybody in particular, so just say whatever you think.

R: So Judy, you have something to say about it?

71F: I didn't really do that. We did it last year –

T: Some classes did it and some classes didn't

75F: I did it last year

R: Did you like it?

75F: N – I did like it…sometimes.

R: Why not the other times? What did you not - ?

75F: Cuz it was kind of choosy.

R: Choosy? In what way?

75F: When it asks you A,B,C,D questions like.

R: So you think it's restricting your answers?

75F: Sometimes it restricts the long answer and I'm thinking – why? And then they give you the next question. And I like, I don't really – and that's why – some teachers that actually get it every single day. And I don't really – you know – cuz I don't use the computer that much. I only use it like once upon a – once in a blue moon. And that's really it. I'm not going to say nothing else.

R: And none of you have played it?

85F: See, I have played it, but it reminds me too much of the thing they made us get on when I was in elementary school. And it was [help with the SAT?] and Study Island feels like the same thing.

R: Okay, so you think it's kind of repetitive?

85F: Yes. And I didn't like it then and I don't like it now.

71F: See I like it, but I'd rather like it when I do it independently without someone reading it.

R: Okay. So you like to play on your own and use it on your own?

71F: yes

R: Anything to add to that – [73F] and [83M]?

71F: But the problems are hard.

83M: I don't really use it much so I really don't have anything to add.

71F: Can you make it easy lik 2 + 2?

83M: Yes, please!

73F: The thing can't do JAWS so – I mean – I wouldn't mind if it was read to me but I'm tired of it. When I hear question 1, question 2, question 3, question 4 I'm like – done – question 5 – done. And they have a lot more than 5. And I'm done when I hear 5.

R: So do you people use computers much outside of school?

Students: no, not really.

71F: Sometimes. I always use my Braillenote because I love the tool even though sometimes it doesn't…

R: What tool was that again?

71F: it's a braillenote. I don't have it.

R: So you don't use computers much at all outside of school?

73F: I mean I use an iPad but not a computer.

85F: You have an iPad?

73F: Yes, I do.

85F: I have an iPad too.

75F: I use a tablet though. I have this tablet and I use it sometimes.

R: Do you use it for homework? Or - ?

75F: Nah, I just use it for games.

R: You too [73F]?

73F: Yes. I go to YouTube for me, check my emails, go to iTunes. I can download games from somewhere. I can do games too.

75F: I love YouTube. It's my favorite. YouTube! I go to Youtube and watch videos.

85F: But you got money for

71F: You got money for iTunes?

73F: I got $10. Yeah, I have music stuff somewhere, I just haven't played it yet.

R: [75F], what kind of games do you download?

73F: um….

R: Are they games like "Study Island"?

73F: nope. They're different.

85F: They're more fun.

71F: Yes, they're more fun.

75F: I love basketball.

85F: They have like cooking games and stuff.

83M (to 75F): You and [name of teacher] would get along great.

R: You think you would use such games if they were existing? Educational games on your iPad or computer?

71F: I would use those games if they were so much fun. You have to make it fun – like Battleship.

83M: Yes, you have to actually make it fun.

85F: Battleship? I've never played that.

73F: I've never played it on the computer.

R: Do you use other technologies?

85F: Are you talking about to understand schoolwork?

73F: Braillenote, my writer.

75F: Pencils. Okay, I'll stop.

R: And you also said that you learned keyboarding right? Was that good? Did you like that?

71F: I liked it sometimes. I have to be in the right mood.

83M: Sometimes I do, sometimes I don't.

R: Why don't you like it [83M]?

83M: Because sometimes I end up…uh…they start repeating the same things.

R: So they're repeating the same things, okay.

71F: It's pretty hard to balance computer too because I play piano, so it's kind of hard.

R: It's hard to balance the computer?

71F: It's hard to balance computer, piano, and homework.

R: Oh, okay. So that's what you're saying. So now let's talk a little bit about GNIE. Are you guys familiar with that?

[group]: I do not like GNIE.

R: Okay, so each one can take your turn and tell me why you don't like… yes [73F], you can start.

73F: Okay, here's the reason I don't like GNIE. IT NEEDS TO READ THE QUESTION TO YOU.

R: okay, so it needs to give you audio feedback right?

73F: Yes. And it needs to tell you when you're on the question side or if you're on the graph side.

71F: Well actually, you could know if you're on the graph side cuz it makes the sounds.

85F: Those beeping noises get annoying.

R: Sorry…what?

85F: Those beeping sounds on the graph? It gets annoying.

83M: It only needs to be done at certain times.

R: Yes [75F]?

75F: Listen. I would tell you, but everyone is gonna get mad.

83M: Say it.

71F: Go ahead and say it. We know you like GNIE.

83M: This is why we're here. So you can say what you think.

R: So you like using GNIE?

75F: Well okay, I'm going to start with I do like it sometimes. But, I don't like it a lot. Or I do like it sometimes, but I like it when I'm in the mood for it. But, everybody's gonna get mad when I say it!

85F: No. You just said it!

R: It's okay, you can just tell whatever you want to say.

83M: This is why we're here.

R: So what don't you like about it…sometimes?

75F: Sometimes? I don't like it when…they're monotonal *(sic)*.

R: you think it's monotonous?

75F: Monotonous. Yes. Monotonous.

R: So [83M], what was your impression of GNIE? You can just say what you liked about it or what you didn't like about it. Did you also think it needs to read the question out…?

83M: Yes. I think that would be good.

71F: It also needs to have JAWS. It needs to tell you when you're typing the right answer. Or, when you type in the answer, it should tell you the letter you typed.

83M: or whatever you're typing.

R: And did you also find the sound to be annoying sometimes?

75F: Sometimes, but not all the time.

71F: I don't find it much annoying because it helps me. If they took it off then I would be very angry.

R: Okay, so you think it should be there and it helps you?

71F: yes.

83M: But I think it should be done every once in a while instead of all the time.

R: So the sound is only made when you go out of the graph, is that what you're talking about?

73F: no, when you're finding the point and everything.

[group makes beeping noises]

83M: and then it keeps going for a long time.

R: So do you think the GNIE software will get more useful once you get used to it? Or do you think that it still needs to be improved?

Group: it needs to be improved.

R: So you guys did not get used to using it.

83M: I barely ever used it.

71F: The first time I used GNIE, I wanted to pick up the computer and throw it out the window. I didn't care if it was Georgia Tech's or not.

85F: That's the same thing I wanted to do too the first time I used it.

R: So what happened the second time you used it?

71F: Still the same thing.

73F: I felt like…I didn't want to do I anymore.

R: Do you think you could ever get used to using GNIE?

85F: Yeah, I do. If it got improved.

73F: If it improved.

R: What do you think would improve it?

73F: Like the question to be read. And when you type a letter something it will tell you if you type the wrong letter or anything.

75F: Monotonous. It needs to have expression.

71F: All these big words! I used to be the kid that used to speak big words at school.

R: [85F], do you think there's other improvements? Other than of course the sound?

85F: uh-uh (no).

R: So it needs to read out loud, and maybe you guys will have more confidence for the point of the game?

[group]: yes

71F: Like if you get it wrong [buzzer sound] and if you get it right [ringing sound].

83M: That would be cool.

R: How many of you got a chance to play the navy ship game?

75F: Oh, the battleship game with the boats? I did! I got to 59 on that game. I got a 59!

85F: Can I say something? It needs a pause button. Because…if you have to go do something, and you're not playing the game, it will just bring your score back down to zero.

R: Oh, so it doesn't stop so it needs to be paused. And did you play too [83M]?

83M: Oh, I never played it. I've actually never played it.

71F: How do you play battleship?

R: [73F] and [71F] haven't played it either?

75F: You press the key and the sound goes kind of like *whish-whish*.

73F: Sweetie, it doesn't have 9 people.

R: So can you tell me if you liked playing the game?

75F: Okay, let me tell you something. I loved playing the navy ship game. Because…I thought my high score was 59, I was not so happy with my score at all. My score was kinda low. It was supposed to be 143 or something.

R: What did you like about it?

75F: I liked the game cuz I liked the way the sound was going and it was so fun! It was exciting.

R: What did you not like about it?

75F: the score. The score was kinda…

R: So you didn't know why your score was ..?

71F: My score was a 59, and I don't like…

83M: you may have had to do…something to…

R: So what do you guys think can make this navy ship game better?

71F: Teach me how to play it? That would make it better.

75F: I love the game, and it should tell you why your score is always 50-something

71F: if you get a bad score, you get a bad score.

[group]: yeah

75F: I really don't want to get a bad score. I seriously don't

83M: it's not the game's fault…

71F: …it's a way of life.

R: So was there anything that you liked about GNIE?

83M: not really. I never could get used to it.

71F: I like the part where the sounds would help you locate things. But the rest of it…nah.

R: So the only part you thought was helpful was it gave you some sounds to know…

71F: It also told you numbers sometimes.

R: Why do you think you could never get used to it?

71F: Cuz it’s so hard!

R: It’s hard how?

71F: Because it’s so hard to navigate to points and stuff and I’m getting tired of asking…like if your teacher is helping other people and you need help really really bad, and you won’t be able to get help. And it drives me crazy when I have to ask.

R: you said you need to ask more help? What about you [83M]?

83M: I don’t really ever use it much.

R: what about you [73F]? what was the one thing you liked about GNIE?

73F: I agree with GNIE for one thing. It did help me find the stuff and it did say the numbers and places sometimes, but it didn’t say it too much.

R: so it just told you where the point was, and it didn’t give you enough information right? And it never reads questions. Anything else that you guys can think of? So if GNIE had all these things, these reading questions and everything, then you guys would use it yeah?

[group]: yes.

R: Thanks a lot guys.

[5th grade joins focus group]

R: So now we’re going to have a bigger group discussion about how to make GNIE better, and remember it can be any crazy idea.

71F: I know, every time you get a question right, the computer can give out candy. [group laughs]. You said crazy idea!

83M: The candy would never be able to come out of the computer.

R: So you think GNIE should be able to tell you when you have a question correct or incorrect?

[group]: yes

52M: Something that you can go back to change your answers, instead of the teacher having to waste her time.

75F: Yeah right! I elect. I elect.

R: So what else did you think [83M]? Something that you could improve so that you would start using it because you said that you could not get used to it. So if we add these questions reading and eliminating all these sounds, you think you would use it more?

[group]: yes

75F: I elect. I agree.

83M: Not all of them, but some of them.

R: What is that [71F]?

71F: Well, I don’t really like…well the thing that I want. I like the bell part actually.

R: What about the keyboard and mouse part of GNIE? Like would it be helpful if there were fewer keys to press? Or if they were closer together?

71F: I like the arrows.

73F: The mouse would be hard. The mouse is hard.

83M: Yes, the mouse is very hard.

73F: it's hard for me to navigate with the mouse, but I don't even use the mouse anyway.

R: because you guys generally don't use a mouse and that's why you find it hard?

71F: The reason we can't is because we can't see the screen.

73F: I can see the screen, but, I mean, it's just too hard.

R: can you talk about why it's so hard to use the mouse? Is it because it moves too fast?

73F: The mouse is too small. And it also moves too fast, you're right.

71F: Maybe it's because they don't teach us to use the mouse. They teach us to use the keyboard. They say "don't use the mouse". They want us to learn short commands.

85F: Short cuts, and everything like that.

83M: So complicated.

R: So any other ideas?

55F: Like, using the arrow keys more.

R: Would you also like it to read you the questions aloud? And also to tell you where your pointer is?

[group]: yeah.

71F: it already tells you where the pointer is at. You just may not hear. The thing needs to be a little louder. The speaker needs to be a little louder.

83M: yeah, the voice.

52M: And it talks to fast.

71F: It needs to be slowed down cuz it's like [says numbers rapidly].

83M: The voice sounds a little robotic to me.

52M: Can you make it sounds like…

83M: …a regular person?

75F: …not monotonous?

52M: …like a 35-year old?

83M: not a 35-year old, just a regular person.

R: So what do you guys think about what [83M] said about being able to go back and change your answers?

[group]: yeah

75F: That would be exciting

52M: that was me who said that.

R: Anything else? Any other ideas…the keyboard, the mouse, the sounds, or the voice, anything?

52M: Like a little bit better sound.

75F: Cuz the sound is…freaky.

71F: it sounds like a robot.

55F: Yeah, it sounds like a robot. I think it is a robot. It is a robot.

R: So you want it to sound more like JAWS?

[group]: NO!

71F: I'm getting tired of JAWS.

85F: JAWS is just annoying.

R: so what would you make it sound like then?

83M: Just a regular person!

52M: Just like a regular person.

75F: make it sound like a "valley girl"

71F: make it sound British.

R: what if you were able to customize the sounds that GNIE makes?

[group]: oh yeah!

52M: then you could change it to be really high and really low like [high pitch number] and [low pitch number].

R: so you think the voice should also vary in pitch?

[group]: yeah.

83M: why? No, no, no.

75F: it needs some expression.

85F: it needs to be a little louder, cuz sometimes I can't hear the numbers.

R: Aside from GNIE, kind of taking a step back, what do you find hard or confusing about graphing and learning graphs in general?

73F: Finding where things are. Like if it's a big graph, with the squares, and then things are so close together, it's hard to find – like if it's a line graph, or if it's a this graph, it's kind of hard to find where things are. And it's kinda hard to feel the– sometimes the Braille too is kind of hard.

71F: and don't GNIE have so many questions?

83M: I thought that was Study Island?

R: Well, your teacher made the questions. I have no control over that. What else about learning graphs or graphing principles can be confusing or hard?

71F: Don't let the teacher control our questions.

R: other than finding points on a graph, what else do you think is hard to do on the graph or while learning graphs? Do you guys learn about curves or lines?

73F: Those are hard too. Sometimes you don't know – I mean sometimes, the line is easy but you don't know if it's gonna curve or whatever, if it's a line graph, you don't know what's gonna happen in a line graph. Sometimes it needs to go up or down.

R: So it's hard to find patterns or trends in graphs?

[group]: yes.

R: Anything else you can think of that's hard?

[group]: no.

R: so if you could have any tool to help you learn graphs – it doesn't have to be GNIE – it can be anything, what would it look like and what could it do?

75F: I know! Math Flash!

[group]: nooo

52M: Study Island.

R: it doesn't have to be something that exists, it can be made up. Like, I want to have Braille paper that changes

71F: I want to have a Braille paper that changes! I want a Braille notes that can actually show a picture of a graph.

52M: You wouldn't have to Braille all of it.

75F: You can color the graph…

83M: How is coloring going to help?

71F: …and also a tracing one that you can just make graphs.

R: so are you saying it would be nice to be able to really easily put points in - plot your own points in your own graph?

[group]: yes

71F: I'd rather have a talking graph.

75F: A talking graph! Yes.

R: we were trying to do something similar with GNIE – with talking.

71F: No I mean a talking graph like a graph that runs on batteries.

83M: Like a graph in a box.

R: So then you would be able to take it with you wherever you go?

[group]: yeah!

71F: And then everytime you get ready for a new graph, you can just put it in that little device and it can just scan the graph for you.

52M: And then it can just listen to what you want to write, and you can just tell it what you want to write and it will just pop up…like the iPhone 4S or the iPhone5.

73F: that way you don't have to do all the typing.

R: So you would like to not have to type a lot?

73F: Right, I mean, after you just type one answer to a question your hands are tired.

71F: Or why don't you have a machine that connects to your mind

83M: haha, the mind-machine is a little freaky

52M: That'd be cool – like you put it in your ear like a headphone

83M: that's freaky

R: so you guys want to be able to talk to it?

75F: I know! That would be exciting!

71F: You could have this thing – like a psychic machine.

83M: Um, elaborate on that please?

73F: it would just type what you're thinking about

71F: actually, the talking one would work, because I don't think they could make that.

52M: you could just say "pause" if you want it to stop.

73F: or you could just take it with you and then –

71F: or you could should make this little pin into some Braille and you could write squiggly lines and it connects to your mind and it comes out in Braille!

R: Well, if you remember, in GNIE, all you had to do was press 'P' to put a point on the graph and it was there. Did you think that was - ?

75F: that was exciting.

55F: Sometimes it was hard when you didn't want it to be there. And then you tried to mash backspace but it didn't do it

R: So you want to have sort of a 'undo' button?

73F: yeah

R: so you just press this button, and it undoes the last thing you did?

52M: yeah

75F: yay! A 'z' button

83M: in case you make a mistake.

R: so like "ctrl+z" on a normal keyboard?

83M: yeah.

R: Anything else? Besides a brain-braille graph? How do you normally plot – create – your own graphs if not using the computer?

71F: I don't know. [teacher], do you know that?

T: you all have done that before. You know the answer. Think of any type of graph – number line.

83M: the graphing board!

75F: drawing it

71F: putting dots

83M: Braille it?

52M: The coordinate plane thing

83M: yeah, the coordinate plane thing

T: that's most recently, try to think about before.

85F: with pencil and paper

71F: the board?

73F: the Braille writer and paper. 20/20 pencil.

T: what did you do when you were in grammar school?

R: so you would just get paper and pencil and plot points?

T: remember sticky dots?

71F: we used sticky dots. If we wanted to make a picture, we used sticky dots to make the picture.

T: I think in other classes, you also used “wikki stix” right?

[group]: mm-hmm.

R: Okay, that’s all the time we have for the group discussion.

Focus Group 4/29/13

R: Okay. Now we’re going to talk a little bit about GNIE. You had the chance to use it throughout the year and we’d like to get your feelings about it. How do you like GNIE now? Okay, we’ll start with [54M].

54M: I think it’s pretty cool. It allows us to like…if we couldn’t read it, you could just press the down arrow and it would tell us. I think it’s better than JAWS cause JAWS always keeps talking and talking but it’s cool. I like the way it talks and stuff- you could understand it. And it helps us with our work that we usually should do in print but it helps us on the computer. It helps us – GNIE does. I think I like it.

R: What about you [53M]?

53M: I like GNIE. It’s because like it tells you the numbers like JAWS it talks too much and it tells you like the number and it shows the area, and it shows the point and it just says a whole lot. But the GNIE, it’s just like a regular thing. I like how you programmed it to go to the next question by pressing the button and I like how the points are like GNIE just helps us.

R: Alright. It’s your turn [52M].

52M: I think it helped me with graphs because instead of writing and worrying if the pencil gets broken, then all you have to do is press a button and its quick and easy.

R: Do you think you’re able to work independently using GNIE?

52M: Yes

53M: Yes

54M: Yes

52M: Yes

R: What about compared to paper graphs?

55F: They’re kinda hard to see and use sometimes.

54M: yeah.

52M: GNIE is better

54M: Some of us might have to use visiobooks or Braille copies

53M: Or like most people have to – if don’t have like the types of utensils. If we don’t have any magnifiers or anything in our school, GNIE will help. Like we can do all different types of stuff

R: so you think you will be able to work more independently using GNIE than using paper graphs.

52M: Yes

53M: Yes

54M: Yes

53M: cause if we didn’t have magnifiers, visiobooks, CCTVs, GNIE would help.

R: What do you think about the new bonephones?

53M: bonephones?

R: [53M]?

53M: They're cool, because like, you can hear and listen to it at the same time. like, I like how you can connect like say you're listening to music on your phone. like, you can just turn it up instead of pulling the earphone out and just turn it up with the button. and like, say if you're talking on the phone and you're talking with your parents at the same time, and you can just speak to them, hear them and like speak to the other person on the phone at the same time cause you can hear them.

R: What about you [52M]?

52M: I think it's cool cause if your teacher says "it's time to go", you can still hear them. And then, it's still kinda in your ear so you can hear that at the same time, and it makes it a lot easier.

R: [54M]?

54M: I think it's cool because if you are not really paying attention to anything, so for that personal thing, if somebody is trying to tell you something you can hear them, because normally when you have headphones on, say you're doing something on the computer and you have music blasting, the teacher is like "time to go, time to go", you cannot hear that. You're just sitting there da-da-da-da, but with that you can.

R: So can you think of any things that we can do to make GNIE better? Alright, we'll start with [52M].

52M: I think when they say the numbers, they say it too fast because it's kinda hard to understand

R: [53M]?

53M: I don't got anything except like when we move on to the next question, it doesn't like...it just talks really fast and most of the time you just don't understand.

R: [54M]?

54M: It's...cool, like some parts. Like I agree with them, it talks way too fast like [makes noise]. And the repeating, like it'll say one then leave it for a few seconds, then it'll say one. It keep repeating and repeating,

53M: and it interrupting you when you typing.

54M: I know.

R: [55F], you've been pretty quiet.

55F: Yeah, I was waiting for them.

R: So what do you think about GNIE, and what do you think we can do to make GNIE better?

55F: You know like the voice, like it talks like a robot, and it doesn't talk normal like a regular person.

R: So what do you like best about days when you use GNIE? [54M]?

54M: You don't have to worry about the screen. You can just like turn the screen off and you know what to do.

R: [52M]?

52M: It's easy.

R: So do you feel like you get more time with [T] using GNIE?

All except [51F]: Yes

R: Taking a step back, is there anything you find confusing or hard about graphing and learning graphs in general?

All except [51F]: No

R: No? graphs are pretty easy?

53M: Oh! It's one thing like you can't make the thing bigger cause like every time you go to the end, you can't see the numbers even though it tells you. And it talks fast so you can't understand. And it's from 0 to 11 and you'll see 11 but it talks so fast that you don't understand.

R: That is it for the group discussion, what's going to happen now is that the three of us will go around to you and ask you specific questions about paper graphs and things like that and after those things are finished, we'll give you guys your checks and have you sign some papers and get you paid.

4-29 Focus Group 7th grade

R: okay. So now we're going to ask you a couple questions about GNIE. You've had a chance to use it for almost a year now, well most of you, what do you think about it?

74M: it was pretty good.

71F: it was okay.

75F: I don't really like it.

72F: GNIE's good. It just need voice control with JAWS so it would work better, but other than that it's pretty easy to get. Once you get to the question.

R: What do you think of the new bonephones?

74M: oh, I love them.

73F: They're okay, but they're hard to put on.

71F: They're easy for me to put on, but they kind of distracts you because you can't – because you want to block out the sounds people make – people around you because sometimes people are loud and you can barely hear what you're doing 'cuz they're loud.

72F: But they work. They're cool.

R: cool. So do you feel like you're able to work independently using GNIE?

71F: no

72F: yes and no.

73F: it depends. It depends what you're doing.

71F: I can play battleship independently

73F: me too

72F: I could do it independently if there was voice control with JAWS to read it out loud to you. I could do it independently.

R: Is there anything that you like best about days when you use GNIE?

72F: It helped me on the CRCT.

71F: It helped on the CRCT

75F: It did.

72F: there were a lot of graphs and knowing we did GNIE helped a lot.

Class: yes

74M: it did

75F: and it helped a lot doing a lot of things.

71F: It makes me feel bad that I don't have any...

R: yes?

T: You know you need to say what you're honestly thinking, so that's fine. Not everyone's going to be the same.

R: It made you feel bad that you didn't have any -?

71F: I mean it didn't help me – it helped me a little on the CRCT. It didn't help me a lot because I still didn't understand how GNIE worked. I still don't understand it but I guess I'll learn it.

75F: okay, if I say I don't like GNIE, will [T] get mad at me?

Class: no

74M: I liked it pretty good

72F: I liked it.

73F: I mean I liked it when they added JAWS to it to read the question

72F: mm-hmm. That helped.

73F: But, somewhat, it doesn't read the answer.

71F: I was thinking JAWS was too […]

R: So let's talk a little bit more about GNIE and the CRCT. You said it helped you…?

74M: it did

72F: because they asked a lot about number lines and graphs and when they did and the number lines had points, I remembered GNIE had a lot of points and I could imagine hearing it ding every time you got it right or something so it helped

R: Okay, so are there any things we can do to make GNIE better?

72F: JAWS

71F: Start with JAWS. Slow it down because it's so fast, you have to slow it down.

73F: and make it read the answers too.

R: Anything else that you want to say about GNIE that we can help make GNIE better?

71F: nope

R: That's it? Just make it slow down, talking, and read answers?

72F: and some control keys on it - the voice control instead of using the mouse

R: Aside from GNIE and aside from paper graphs and all the stuff, what do you find confusing or hard about graphing and learning graphs in general?

71F: the coordinate planes

R: what about the coordinate plane is hard?

71F: like, finding where it intersects

T: Where x and y intersect?

71F: mm-hmm.

72F: it was hard to tell if they reflected sometimes. When they ask you how it's reflected, it was hard to tell that, but besides that

R: Anyone else? anything hard or confusing about graphing?

73F: I have one. The – what do you call them – the coordinates. Those are hard. Like you gotta find 1, 2, 3, and 4, and it's kind of hard to find them.

R: Are you talking about the quadrants?

73F: yes. It's hard to find them on paper, but it's easy to find them on GNIE

75F: it is easy to find them on GNIE.

R: coordinates or the quadrants? Coordinates are like (x, y) like where points are and quadrants are like the squares

73F: quadrants.

R: okay. So those are all the questions we have for you today.

4-29 Focus Group 8th grade

R: So now we're going to talk a little bit about GNIE. I guess [86F] has only used it this semester, but [82M] you've used it since the beginning of the school year. How do you feel about GNIE?

82M: I think it's a pretty good software for math

R: yeah, you like it?

82M: yes

R: How do you feel about it [86F]?

86F: I like that we could really – that I could pinpoint where the positions are on the graph -to know if it's a slope or not. It really helped. I can actually do it by the computer and actually visually see it

R: did you have any trouble when you first started using it?

86F: it was tricky at first but I just had to learn the keys and that's basically all I need to learn is the keys and I'll be pretty good at it later.

R: what do you think about the new bonephones that you guys tried out? I mean, I guess you don't have anything to compare it to because you didn't use it last semester, but how do you like the bonephones? They're the headphones that go around your ear instead of over your ear and you used them with the graphs. What do you guys think about that type of headphone? Do you think it's good? Do you think it's bad? You don't it? You don't like headphones?

82M: I think it was good.

R: yeah? You guys liked it?

82M +86F: mm-hmm

R: what did you like about it?

86F: I like those headphones. They're more comfortable, more fit, laid back on you and you don't have any wires around you

R: do you feel like you're able to work independently using GNIE?

82M: yes

R: [86F] do you feel like you can work independently using GNIE?

86F: probably – I'm okay with it. I probably just need some more assistance on learning the keys and I'll be good.

R: what about compared to paper graphs?

86F: paper graphs? Paper graphs are hard to see but on the computer I can visualize it better and, of course, probably blow it up and I can see it better and actually visual it on the computer than on paper

84M: So you're saying that the GNIE thing is easier for you than –

86F: very easy. And helpful.

R: Do either of you feel like you get to spend more time with [T] when you're using GNIE versus when you're using paper graphs? Or you can't tell the different between the two?

82M: can't tell the difference

86F: I can't tell the difference at all.

R: okay. Is there anything you can think of that we can do to make GNIE better? That's fine if you can't think of anything. I just wanted to give you an opportunity to give ideas on what you think would help you use – or better use GNIE or make it more something that you would use. So taking a step back, what do you find confusing or hard about learning graphs in general? And it's okay, [T] won't get her feelings hurt. Or do you find graphing and learning graphs easy?

82M: I find learning graphs easy.

86F: at first it was confusing, but I think GNIE's helped to understand it more better. So I can like – at first I didn't really know a lot about graphs and GNIE's helped a lot.

R: can you talk a little more about that?

86F: it helped when – at first I was confused about the slopes, and GNIE's helped with that a lot. I'm not as confused as I was when I – when we first started. 'cause I always got it mixed up, but GNIE's helped a lot with where – to let me know if I'm – if it's the right one or not

R: great

Focus Group 12/9/13

R: okay. Let me ask you a couple of feedback questions. You've had a chance to use GNIE for a while now right?

73F: yes

R: now we just want to know a little bit more about your feelings. How does GNIE this year compare to last year?

73F: it's a little bit better

R: why do you say it's better?

73F: because at least JAWS can read it. But I think on some of them, they need to slow JAWS down.

R: so you want it a little slower?

73F: so you can understand the question because it goes *boop boop boop* umm, what did it just say? And then I have to ask [T] to read it to me.

R: do you feel you get more time with [T] when using GNIE compared to using the paper graphs?

73F: I think so.

R: do you feel you're able to work independently using GNIE compared to paper graphs?

73F: I think I need just a tad bit of help.

R: okay, do you think you need more help on the paper one? Or do you need more help on GNIE?

73F: on the paper one.

R: so you think GNIE is a little bit easier to do by yourself?

73F: right.

R: do you think it would be even easier if the questions were read slower?

73F: right.

R: is there anything you feel GNIE helps you with more than the paper graphs?

73F: could you just press one little key – I mean just hit 'enter' and it'll go to the next question

R: the question is, "is there anything you feel GNIE helps you with more than the paper graphs?"

73F: the numbers and the points and stuff like that

R: is there anything you feel paper graphs help you more with than GNIE?

73F: no

R: no? so you think GNIE is better than paper graphs?

73F: yes. Even though I don't like GNIE, but it's better.

R: what did you like best about the days when you got to use GNIE?

73F: you mean like doing the points that suff?

R: yeah, when you got to use GNIE, what did you like?

73F: I like to play that battleship game. It's interesting

R: what things can we do to make GNIE better for you? So you said slowing down the questions..?

73F: right.

R: anything else you think would be helpful?

73F: that drum noise? I mean it's okay, but when you're trying to hear for one thing when you're hearing the drumming it's kind of difficult for me to navigate especially when it's turned down low. I can hardly hear what's going on.

R: so you think it's a little bit confusing when there's that drum noise?

73F: yes.

R: taking a step back, what do you find confusing about graphing and learning graphs in general?

73F: hard to navigate on GNIE.

R: we're not talking about GNIE anymore. Just graphs in general

73F: I mean, hard to navigate with Braille graphs, put that way. GNIE's fine, but Braille graphs? I always have trouble navigating through them

R: do you think you just lose where you are?

73F: my place? Yeah.

Group answer: 74M, 72F, 76F

R: so, you three. How does GNIE this year compare to last year?

72F: it is better

74M: it is better

R: how or why? Why do you say it's better?

72F: last year it was harder to get to – because last year it didn't really say the numbers when you needed it to. And it really didn't have the right sounds.

74M: right.

76F: mm-hmm. I think it raised it a lot clearer this year.

74M: yeah it raised it clearer – right. And you can understand it better - what it's saying. When you're trying to find the coordinates on the graph

R: okay, sounds good. Do you feel like you get more time with [T] when you're using GNIE?

72F: yeah. I could see how it's easier.

74M: yeah.

76F: mm-hmm. I see how it's easier.

R: do you feel like you're able to work independently using GNIE?

72F: I could if it wasn't so fast.

74M: yeah.

R: what do you mean by fast?

72F: the speed of the reading. It reads the question too fast.

76F: I can't understand it when it's that fast.

74M: that's my main thing.

R: so you want the question reading to be slowed down a little bit. Well, we did slow it down a little from the beginning of the semester.

74M: mm-hmm. Yeah, it's slowed down a lot

72F: but it's still a little too fast though

R: still too fast? Okay

74M: just a little bit.

R: do you feel you're able to work independently using GNIE compared to paper graphs?

72F: yes

76F: yes

74M: mm-hmm. I think so.

R: you think you're able to work independently *more* using GNIE than paper graphs?

All: yes

72F: because you can sit there and mark your spot from where you last was to make sure you're looking at the question too and on paper you always lose your spot trying to look back and forth.

R: is there anything that you feel GNIE helps you with more than paper graphs?

74M: it helps you – okay, in the math book, the graph is like real tiny. I mean, you can barely see the line. But on GNIE, it's the perfect size.

72F: GNIE keeps you occupied. It keeps you awake. It lets you know what you're doing instead of having to struggle to find out what you're looking for. It's easier.

76F: I think it's easier because you don't have to keep looking at your paper if you were doing it in print or braille.

74M: yeah with GNIE it's there for you. You don't have to look back at it a hundred times.

R: okay. Is there anything you feel paper graphs help you with more than GNIE?

74M: I think GNIE's best.

76F: I can't think of anything

74M: I can't either.

R: what do you like best about days when you use GNIE?

72F: you don't have to struggle so hard.

R: struggle so hard doing what?

72F: find what you're looking for.

74M: finding the coordinates

76F: you don't lose your place as easily.

R: lose your place like you're on the coordinate graph and you don't remember what coordinate you're on?

All: mm-hmm.

72F: you always lose your spot

74M: on hard copy you can do that but on GNIE it's there for you

72F: and on GNIE if you mess up, you can delete it instead of having to sit there and constantly keep erasing it. Cleaner.

76F: yeah

74M: that's easier too.

R: is there anything else – I know you mentioned reading questions slower – is there anything else that we can do to make GNIE better?

74M: that's about it.

72F: it's really useful. So far it's good – just the speed.

74M: right.

R: taking a step back, what do you find confusing or hard about learning graphs or graphing in general?

72F: just to remember what coordinate planes go for what.

R: sorry can you say that again?

72F: haha. To tell what coordinate planes need to go with what like if you're on the first quadrant, should you be on that one? Or should you be on the other ones?

R: that's it. Now we're going to ask you some survey questions. Actually, before that really quick, [72F], last year you said that you could hear GNIE sounds when you were doing the CRCT. Did you have a question in mind where you remember that happening?

72F: we were just – what was it. It was asking us to find negative – it was like -4, -6 to 4. So at first I was going to put it on the wrong quadrant and I was thinking "well I hope there's beeping going on". Eventually I just gave up and went "okay" and really thought about it and I remembered it being on the computer and it just helped. They should let us do that on the CRCT.

R: so you wished there was beeping in the question?

72F: yeah.

R: you also said you could hear it a little bit in your head?

72F: mm-hmm. Memory.

R: memory? And you thought that having GNIE to do that problem would be helpful? Like it would help you…?

72F: it made it easier to learn so yeah.

R: and do you think it would help you answer those questions faster?

72F: yeah.

R: okay. Now we're going to talk a little bit about GNIE. How does GNIE this year compare to last year?

54M: I think it's changed a little.

R: changed how?

54M: like the, what's it called, I didn't notice the where you can press 'x' and then 'y' and it reads the question now. And that's it.

R: do you feel these changes are better changes? Worse changes?

54M: better

R: so you think GNIE is better this year compared to last year?

54M: yes.

R: do you feel like you get more time with Ms. Pope when using GNIE?

54M: no.

R: how does it compare to days when you're using Braille graphs?

54M: it's good.

R: I guess the question is, do you feel like the way Ms. Pope teaches class or the attention you get from Ms. Pope is different between the two days? Or you think it's about the same?

54M: it's about the same.

R: okay. And do you feel like you're able to do work independently using GNIE?

54M: yeah.

R: why?

54M: because I finally figured out how to use it like I remember how to do some of the stuff.

R: so you figured out the controls?

54M: yeah.

R: what about doing work independently using GNIE compared to paper graphs?

54M: I think GNIE would be easier.

R: easier and you can do work independently?

54M: I think it'd be easier.

R: is there anything you feel GNIE helps you with more than paper graphs?

54M: where I'm at. You just move it and you know where you are.

R: so it helps you orient yourself better?

54M: yeah.

R: and is there anything you feel paper graphs help you with more than GNIE?

54M: no.

R: what do you like best about days when you use GNIE?

54M: it's easy.

R: easy how?

54M: like, I know what I'm doing

R: any things we can do to make GNIE better?

54M: the voice is kind of hard to understand because it's fast.

R: is there anything else?

54M: no.

R: so you think GNIE is just fine the way it is?

54M: yeah.

R: taking a step back, what do you find confusing or hard about graphs and learning graphs in general?

54M: it's just confusing how there's 4 parts. The negative and the positive and I forgot what the other ones are

R: what do you mean? Four parts of?

54M: like there's the top-left, top-right

R: oh, the quadrants?

54M: yeah.

R: so the quadrants are confusing? What's confusing about them?

54M: I just don't remember like – the top-right I know is the positive numbers and I think the top left is negative but I don't know what the other ones are

R: any other comments you want to share with us?

54M: no.

R: okay. So now I'm going to ask -.

71F: If you're going to ask me how I know, I'm going to cry. Because Braille graphs are not my thing.

R: why aren't they your thing?

71F: they're hard

R: what's hard about them?

71F: well, finding what you need to find.

R: would you say it's harder than GNIE?

71F: no. they're both the same amount.

R: same amount of hard to find?

71F: see I say the Braille is 95 and GNIE is 102

R: in terms of difficulty? With higher numbers being more difficult?

71F: yes

R: so, what's hard about Braille copies?

71F: making sure that you have both hands to figure out where you're going – especially when there's no key on the Braille copy. Because you know the key makes you understand something. Sometimes there's no key and when there's no key, yeah, that's hard.

R: what about GNIE? What's hard about finding points on GNIE?

71F: listening to all the sounds. Like because you know there's other beeps and stuff for – you know how you have the drums and the dinging and all that. It's kind of hard to concentrate on all that while trying to find the sounds

R: so now we're going to talk about GNIE. How does GNIE this year compare to last year?

71F: harder

R: what makes it harder?

71F: because this year we're doing like – like last year we're just doing the negatives and the positives and the number lines but this year we're locating the points on the graph and we're labeling them sometimes. And then you have to focus on training – on tuning some of the noises out so you can focus on that one thing.

R: so is it the concepts that are harder or using GNIE that's harder?

71F: using it.

R: using it?

71F: navigating it. And the concepts I guess.

R: did you notice any positive changes from this year to last year?

71F: you can tell – it's easier to get to the graph and the questions.

R: and it also reads the questions now right?

71F: yes. But really really fast.

R: do you feel you get more time with Ms. Pope when you're using GNIE?

71F: can I be honest? No.

R: no you don't get more time or no you can't tell?

71F: I can't tell really. Because so like you're in class, but when you're with GNIE, everybody's on the computer and you're trying to get help but someone else needs help. And when you try to get her attention and she's basically trying to help other students and it's chaotic. But I like it.

R: you like the chaos?

71F: because I get to be on the computer. But on GNIE days I like it a little. I like it when it's tactile days because it's more fun.

R: you think tactile graphs are more fun than GNIE?

71F: yes. Because we get to make it. And we get to make the dots and the dashes. And I love playing with sticky dots.

R: and you don't get the same sense of satisfaction with plotting points?

71F: nope. Because it's not sticky dots. It's electronic.

R: do you feel like you're able to work independently using GNIE?

71F: yes.

R: what about on paper graphs?

71F: yes. Sometimes.

R: why only sometimes?

71F: I can work independently sometimes on it, but if I get little kinks, I might need help with those. But that doesn't matter because I'm a star anyway, you know.

R: is there anything you feel GNIE helps you with more than paper graphs?

71F: yes. It helps me with learning the number lines. And the graph. It helps me with learning where the coordinates are. It tells me where the coordinates are. Without talking…well, it does talk.

R: it helps you with the number graphs how?

71F: because I'm learning myself how to do it. Because with the tactile graphs, I am learning but not by myself, but when on GNIE it feels like I'm learning how to do it all myself. Sometimes I can figure out ways to get my answer.

R: and do you like doing that? Hacking the system?

71F: yeah. I wouldn't call it hacking, I just call it "finding out ways"

R: well that's essentially what software programmers do. We figure out ways around the system that work for us.

71F: plus I think about ways that it can improve.

R: and I will definitely ask you about that in a few questions. Is there anything you feel paper graphs help you with more than GNIE?

71F: paper graphs? They help me with –hmm. No, they're about the same.

R: about the same?

71F: yes.

R: so what did you like best about days when you used GNIE?

71F: when I get everything right.

R: anything else?

71F: and people are proud of me when I figure it out by myself. They're proud of me more.

R: you mentioned earlier that you thought of things that could make GNIE better. What are some of those?

71F: you know when you log in you have to click "ok"? well some of the kids can't see "ok". So when you type in your name, couldn't you just press "enter" and all's well that ends well?

R: yeah, we did fix that because I thought it was weird too. But that is definitely a good suggestion. Anything else?

71F: you need more games.

R: we are working on a new game actually. A hangman game.

71F: you know that game battleship? Instead of using it with a mouse, could you work it so that you could use it with arrow keys?

R: you can use it with arrow keys.

71F: you can?

R: yeah. Have you never tried it with arrow keys?

71F: no

R: you're actually supposed to use it with arrow keys. You can also use it with numbers.

71F: I did it with a mouse.

R: you can use the number pad too and press the number or spacebar.

71F: I want to learn that.

R: alright, anything else?

71F: nope.

R: just more games and the logging in stuff?

71F: yup. And minimize the drums.

R: taking a step back what do you find confusing or hard about graphs and learning graphs in general?

71F: process – remembering it.

R: remembering the entire graph in your head?

71F: yes.

R: and this is usually hard when you have lots of points?

71F: processing the graph is really hard because you have to try to get it- try to get the graph. Because the first day is paper graphs and it's so easy because you got it on paper and everything works out and all the little anyways – and then you have the computer, you have to imagine the computer pretending the computer's the paper – electronic paper, but it's electronically. And that's pretty hard because you're not in front of the piece of paper, you're in front of the computer and it makes it a little hard. Not too hard. Just a little.

R: okay. That's fair.

Focus Group 4/23/14

R: Let's talk a little bit about GNIE. Most of you have had a chance to use it for almost 2 years now, how does GNIE this Spring compare to the Fall? Remember the thing that's different about this Spring is the whole line-drawing portion that's new. Yes, [53M]?

53M: Um, like, the Spring, like, I like a lot like the Spring. It would… wasn't that bad like the one in the – no – *the one in the Fall* wasn't that bad but I like the one in the Spring better because when you draw the lines like very vision impaired people that can't see stuff, like blurry, but they can see the lines so they can know what kind of comparisons to make.

R: mm-hmm. Anyone else have an opinion about the line-drawing?

73F: They help. Lines help because when you use them, GNIE lets you know there's a line there. It may not say it but it has some cues that will let you know that it's there so you can go straight to the point so you don't have to go all over the coordinate plane to find it.

R: yes [54M], you have your hand up?

54M: she stole basically what I was going to say.

R: okay. [to 53M], yes?

53M: I like GNI – it's another reason why I like GNIE. Like, if I'm on print paper, like if I'm doing like a test, I can't hear – like, I can't hear or like somebody read it to me. Like, I have to do it by myself, but if I have GNIE, like GNIE can read it to me while I'm trying to figure out the problem.

R: mm-hmm. Anyone else we haven't heard from yet? [55F]?

55F: I like, well visually it's good that I can see the lines. And then I like how I can hear it because sometimes my eyes get tired of reading or looking so it helps a lot.

R: [76F], do you have anything to add to that?

76F: just, the reading like, if you were taking a test, the teachers might just read it twice, but GNIE can go back and read it for you

R: mm-hmm. [73F]?

73F: um.

R: did you get to do much line drawing?

73F: it's easy to let me know when I have a point on the – when I have my point or when I'm at – when I'm getting to a point, it will make a special sound that I know where I'm at so I don't have to keep, you know like, "where am I at?" and moving around

R: yeah. [54M]?

54M: I know what she's talking about. Like, whenever you get to a point, like it makes a -

73F: - goes quiet.

54M: - loud beeping noise, but when you get further away from the point it goes slower and slower and slower. But when you're there it's fast so you actually know you're at the point.

73F: yeah.

R: And do you feel like you're able to work independently using GNIE?

Most students: yes

R: yes, no, maybe?

72F: maybe

71F: no

R: no? why not?

71F: well, not “no”. maybe. Sometimes. When I get stuck, I might need help. I guess that’s it.

R: and when do you get stuck?

71F: uh, quite often. I get stuck sometimes, like, if I can’t read the question or something. Or if I’m having trouble finding the – oh, nevermind. I don’t know what I’m trying to say. Can I think about it?

R: sure. [55F]?

55F: oh yeah because sometimes I get confused and stuck on like the commands like how to move it and then, um, placing a point. Sometimes I need some help doing that.

R: remembering what the commands are?

55F: mm-hmm

72F: mine is reading the question. He reads it a little too fast to keep up with sometimes

73F: yeah

71F: it’s slower now

72F: mm-hmm. It is slower.

R: what about working independently on paper graphs compared to GNIE? Uh, I think [53M] had his hand up first.

53M: um, like, on GNIE you can just like put down something like, and like, so for the Braille students, like they have to go look at the sheet then have to go back to the paper and then sometimes they have to go back to the sheet and go back to the paper. And on GNIE you could just like hear it and then it just tells it for you and instead of doing all this [burrow?] you could just go to the point that you need to go to and then it will, um, it will just put it there for you if you hit “p” and “Ctrl”.

R: [54M]?

54M: computer is basically easier if you want to read it for you too. I mean, it’s easy to place points because it tells you the number you’re on. Like if you’re completely blind and you can’t see nothing, it tells you what number you’re on and all that and whenever you get to a point it beeps. But paper graphs, say you’re completely blind, you’re reading the paper, say you weren’t that good at Braille and you couldn’t read it, I mean, [mumbles] couldn’t really help you but GNIE could just read it for you. And if you couldn’t find a point like on a paper graph and you didn’t know what numbers you’re on, or say you’re on (-2, 1) or something, and you wouldn’t even know you’re on that. Like, if you want, like if you forgot about it or something and you had GNIE it could tell you if you’re on -2 or 1 or one of those. It could tell you.

73F: yup.

R: yes. Did you have something to say [72F]?

72F: GNIE is easier because when you’re looking on a paper, and you lose your spot, you have to go back and look, and you have to come back and look for it again. And when you’re using GNIE you can mark where you’re at if you forget what you’re looking for and pick up right where you stopped so you don’t have to re-find it.

R: that’s a good point. [53M]?

53M: you know how some teachers emboss stuff? And like the embosser doesn't work…like the numbers are messed up and then, like, Braille students, they can't like, they don't know what number they're on. They have to go page to page and back to back then page to page and then, on GNIE you could just hit – set like the keys and it'll tell you what number you're on #1, #2, #3, #4, #5 and stuff like that. And, if you're going as a class you can, like if somebody's lost, they could just hear the number and so they can figure it out.

R: So are you saying that it's easier to remember where you are -

53M: - on GNIE.

R: - through a series of questions?

71F: I think it's -.

R: yeah? Go ahead

71F: I think it's about equal. Because sometimes on GNIE you could lose your place too and sometimes on Braille you can do the same thing so I think it's about equal. But GNIE is kind of easy. It's easier. Kind of.

R: So I know a few of you had a chance to use bonephones to work with other students using GNIE. I know [54M] you worked with [52M] a couple times and [55F]. How did you guys feel about that?

53M: the bonephones?

R: well, just being able to work on the computer with someone else.

54M: ooh, I know what you mean. You're talking about whenever you can hear what the other person is saying? [52M] has bonephones and I got plugged into his computer so I could hear what he's doing? I think it's cool because you can hear what they're doing. You can understand what they're having troubles with and you can help them anytime you needed to. If they didn't need help, you could hear what they're hearing so you would actually know what they're hearing and you could help them out if they needed it.

R: anyone else?

53M: um, I was thinking like, it's kinda like, easier, because if you need help with something and I need help – say, if [55F] or [54M], anybody else who needs help, and like, I can go to [55F]'s computer or [54M] and hook it in and hear – I can basically like, instead of just having one, you can hear what he's doing so, like, the guy on GNIE can tell you what you're doing. And, I can just like help him with his problem. And like, yeah.

R: and do you feel like you're able to do the same kinds of things with paper?

53M: um, yes, almost about. Wait, no, not really. Because if I'm taking a test by myself, I don't know what I can read or cannot read. I mean, not can read and cannot read, but something like can't signed up or can sign up. On GNIE I can just know what I know. Like I can hear what's being read to me so I don't have to read it.

R: [72F], you were shaking your head. Do you want to talk a little bit about -?

72F: I don't think paper gives you the same advantage because if you were looking on paper you would have to try and get that person to move over and try and find what they're looking for and it would make it harder. But when you're listening on GNIE with your – with the person you're helping, you can hear where they're at and help them find them and instead of making them move and losing their place and you trying to find their place and whatnot.

R: mm-hmm. [54M]?

54M: I kind of agree with that, but, say there's like a totally blind person and a person that could see and the paper was print, it wasn't Braille, and they were trying to find a point on the graph, well that blind person won't know what you're doing. I mean, he or she cannot tell what you're doing or anything like that. I mean they can't tell where you're going or where you're going to place the point at or anything. But on GNIE you can hear what they're doing so it's kind of a bigger advantage for visually impaired people and for people who are non – not blind.

R: so for students who use print copies, do you feel like you would be able to work with another student who uses Braille copies on GNIE?

72F: yes

R: but what if it was on paper?

55F: it would be hard for the Braille person to really see the print

72F: and if you're print you might not be able to understand Braille.

R: and for the students who use Braille, do you feel the same? Do you think that you would be able to work with a low-vision or sighted student on GNIE?

53M: yes

71F: yes

54M: I will. Well, I could still read print so…but if I couldn't, I would go with in the medium – in the middle. I'd go in the middle

73F: yeah.

54M: because I could and I couldn't somewhat

71F: I could work with them, you know, just using regular paper because, you know, the teacher might have it print out as a Braille copy because that's how we – you know. And I could – I think it's better on GNIE but either way I think – it's better on GNIE because I could understand a little bit more, but other than that, I think on paper would be fine too because that's how we do it all the time. We work together with Braille and print.

R: so is there anything we can do to make GNIE better? [53M]?

53M: you can change the voice settings because sometimes I can't understand what he's saying

55F: like how he sounds like a little robot?

53M: yeah he sounds like he's a Australian or something like that and I can barely understand him

71F: Australian

R: anything – anyone else?

71F: lessen the noise. More games

73F: yeah, more games

71F: lessen the noise

R: lessen the noise like fewer noises? Softer noises?

71F: softer noises

54M: and instead of the beeping, just like a ding or something like that

72F: change the tones for - different sounds for different points and stuff.

71F: yeah

R: so if there's more than one point on the graph, you want the points to sound different?

72F: yeah so you wouldn't think you're on the same point

54M: say if it's point P and S

55F: oh, make the numbers bigger on the number lines

53M: here's one thing I have a problem with: like when I look at it sometimes like the numbers are crossing over to each other when I look at the coordinate plane.

R: do you feel like you get more time with [T] on days that you use GNIE?

55F: well I think it's hard for her because she's moving back and forth to each one of us because we're all calling out her name, "[T]!"

71F: I would say no, but I understand where [51F] is coming from. It's kind of hard.

73F: yeah, me too. I mean because in 8th grade we go "[T]" or "somebody?". It's mainly me.

R: okay, two more questions. First, is there anything you feel that paper graphs help you with more than GNIE?

73F: no not really

71F: yes. I do. It helps me find it a little easier because I like things like, you know, hard like a paper in front of me because like on the computer, it could say I'm at "3" but I may a little off and I don't know

73F: yeah

71F: I think the paper helps

R: the paper helps you find points or find -?

71F: helps me find points on the paper.

73F: paper.

71F: because like if you're on the computer it may say like that you're on 3, but you know you may be a little off of 3. It may be a little ways from 3 like just a smidge off and you wouldn't know. And you might put the point in the wrong place.

R: okay. So taking a step back, is there anything you find confusing or hard about graphing and learning graphs in general? Just graphing concepts. No? graphs are pretty easy?

53M: well actually on GNIE, graphs, like they're just the same to me as print paper but see sometimes like print I can't listen to it because paper don't speak. But a computer like sometimes stuff just gets real blurry and I can't hear anything or see – I mean, not hear anything but see anything and I can use GNIE like the sounds so I can know where I am like it says 1, 2, and 3. And on paper my eyes get blurry and I can't help anything about that.

R: okay that's all the questions I have.

Focus Group part 2 with 52M and 74M

R = YC

R: So the first thing I'd like to talk to you about is GNIE is and how this Spring compares to the Fall. As a reminder, this Spring we had the new line-drawing element that was not there last year so what do you guys think?

74M: I like it.

52M: I like it. Kind of. Like the one thing I don't like is the – I think it's gotten a little bit better on the – how it talks, like how fast it talks

R: but it's still too fast?

52M: a little too fast.

R: did you have any difficulty with the line drawing portion?

52M and 74M: no

74M: no, it was pretty easy.

R: okay. Do you feel like you're able to work independently using GNIE?

52M: sometimes

74M: yeah

52M: in case, like, if I couldn't get the dots or something. Like the error.

R: what else do you have difficulty with?

52M: well when it reads the questions it kind of reads it too fast

R: what about you [74M], do you have any trouble with GNIE?

74M: mm-mm. not really, I like it. It's better when the voice is slowed down

R: do you feel you're able to work independently using GNIE compared to paper graphs?

74M: oh yeah

52M: yes

74M: most definitely.

R: is there anything you feel GNIE helps you with more than paper graphs?

74M: I can actually find the points better

52M: you don't really have to look for anything you just use the arrows and stuff and, like, to find a point. You just use the arrows to find it so

R: is there anything you feel paper graphs help you with more than GNIE?

74M: not really

52M: no

R: I remember there were a few times recently when you worked with other students by plugging in to their computer and helping them

74M: I had to do that one time because mine would never come up. I remember that last year.

R: how did you like that?

74M: helping somebody? Um, I liked it. It helped me and whoever I helped too.

52M: well, same thing. What he said.

R: well, I know you [52M] had to do it several times, how did you like being able to plug into somebody else's computer

52M: I just like helping people sometimes. And it feels good.

R: how about when you use paper graphs to help other students? How does it compare with GNIE?

74M: GNIE is so much quicker.

52M: yeah it's quicker and easier – the GNIE is. But the paper graphs take a little bit longer

R: why is it quicker on GNIE?

52M: because you don't have to, like, read it sometimes. It reads it to you and you can understand it sometimes. But, sometimes you can't so -. GNIE's better.

R: is there anything you like best about days when you use GNIE?

74M: it's kind of like you're playing a game on the computer.

52M: yeah, you're just answering the questions and then go to the next one. It's easier than just, like – I don't know.

74M: because on paper graphs you can lose your spot where you're going to put your point

52M: yeah. But on GNIE you just move around with the arrows and it just explains where you are.

R: so what are some things that you think we can do to make GNIE better?

52M: um -.

R: you mentioned slowing down the voices even more

52M: yeah just a little bit more. That'd be good. And then –um – the pitch I think.

R: the high and low sound? Is it too high? Too low?

52M: I think it's a little too high. Like it's hard to understand. I can understand it when it's saying numbers but not words

R: okay. Anything else?

52M: no

74M: that's it

R: do you feel like you're able to get more time with [T] when you're using GNIE?

52M: can't really tell.

R: [74M]?

74M: um, yeah? I feel like GNIE is better with [T] than at home doing it by myself because she's able to help me find the spot and where to put the point at.

R: now we're going to talk about graphing and learning graphs in general. Is there anything that you find confusing or hard about graphing?

74M: not really with GNIE but paper graphs you got to put your finger where the point – where you want to put the point at and on GNIE you can just use the arrow to get there.

52M: I think it's pretty simple.

R: so nothing that's hard or confusing about graphing?

52M: nope

R: okay so I guess that's it for these questions.

Focus group part 3 with 51F and 77M

R = YC

R: So what we are going to do right now is I'm going to ask you a few questions about GNIE ok? How do you like GNIE?

51F: I do everything on the grid, like I was doing. And number lines.

R: what about you [77M]? how do you feel about GNIE?

77M: it's good. I like it.

R: yeah?

77M: yeah

R: do you feel like you're able to work independently using GNIE?

77M: no

R: no? why not?

77M: um, maybe because it's a little harder without any help, something like that.

R: what's hard about it? What can we do to make it easier?

77M: um, like, I guess just put a little dot over there like at the middle thing and when [T] told me to find this or that, I could just look over there from that zero and see where should I be going or something like that.

R: what about you [51F], do you feel like you're able to use GNIE by yourself?

51F: mm-mm.

R: is there anything you feel GNIE helps you with more than paper graphs?

77M: yes

R: like what?

77M: it will tell you like where you're at and stuff like that. And the paper graphs won't

R: okay. So you feel like that's more helpful?

77M: yeah. It's more helpful.

R: what about you [51F]?

51F: what?

R: do you feel there's anything GNIE helps you with more than paper graphs?

51F: um, not really sure.

R: okay. Is there anything you feel paper graphs help you with more than GNIE?

77M: no, not really.

R: is there anything you like best about days when you use GNIE?

77M: yes

R: can you tell me about that?

77M: I think so. Like, what'd you say? Hold up. It's okay. I like it. Um, it really helps me a lot just trying to guide it – just like the lines and stuff helping me and everything like that. It's more better.

R: [51F] is there anything you like best about using GNIE?

51F: um…

R: is there anything you like about using the computer to do math?

51F: mm-hmm

R: like what?

51F: dividing. And multiplying. By tens.

R: is there anything we can do to make GNIE better?

77M: no, it's alright

R: besides putting a dot in the middle? Is there anything else?

77M: nope. I'm good.

R: you like it the way it is?

77M: yeah.

R: no changes?

77M: no. just the dot on the middle thing,.

R: taking a step back, what do you find hard about graphing and learning graphs in general?

77M: um, just like where you have to place it and stuff. And going up and down and sideways and stuff like that. Because it's sometimes confusing.

R: like which axes is which?

77M: yeah.

R: and finding things?

77M: yeah. Finding the quadrants and stuff like that. Because I got mixed like that. Because I though that was 4 or something like that

R: okay. That's all the questions that I have for you.

REFERENCES

[1] Georgia Department of Education, "Common Core GPS Mathematics," 2012. [Online]. Available: https://www.georgiastandards.org/Common-Core/Pages/Math.aspx.

[2] N. F. for the Blind, "Blindness and Low Vision Fact Sheet," *National Federation of the Blind*. [Online]. Available: https://nfb.org/fact-sheet-blindness-and-low-vision. [Accessed: 09-Nov-2014].

[3] S. M. Kelly, "Use of Assistive Technology by Students with Visual Impairments: Findings from a National Survey," *J. Vis. Impair. Blind.*, vol. 103, no. August, pp. 470–481, 2009.

[4] G. Kramer, B. Walker, T. Bonebrights, P. Cook, J. Flowers, N. Miner, J. G. Neuhoff, R. Bargar, S. Barrass, J. Berger, G. Evreinov, W. T. Fitch, M. Grohn, S. Handel, H. Kaper, H. Levkowitz, S. Lodha, B. Shinn-Cunningham, M. Simoni, and S. Tipei, "Sonification report: Status of the field and research agenda," in *International Community for Auditory Display (ICAD)*, 1999.

[5] M. A. Nees and B. N. Walker, "Auditory interfaces and sonification," in *The Universal Access Handbook*, C. Stephan., New York: Lawrence Erlbaum Associates, 2009, pp. 507–521.

[6] W. T. Fitch and G. Kramer, "Sonifying the body electric: Superiority of an auditory over a visual display in a complex, multivariate system," *St. FE Inst. Stud. Sci. COMPLEXITY-PROCEEDINGS*, vol. 18, p. 307, 1994.

[7] D. L. Mansur, M. M. Blattner, and K. I. Joy, "Sound graphs: A numerical data analysis method for the blind," *J. Med. Syst.*, vol. 9, no. 3, pp. 163–174, Jun. 1985.

[8] D. R. Smith and B. N. Walker, "Effects of auditory context cues and training on performance of a point estimation sonification task," *Appl. Cogn. Psychol.*, vol. 19, no. 8, pp. 1065–1087, Dec. 2005.

[9] D. R. Smith and B. N. Walker, "Tick-marks, Axes, and Labels: The Effects of Adding Context to Auditory Graphs," in *International Conference on Auditory Display*, 2002, pp. 1–6.

[10] J. M. Batterman and B. N. Walker, "Displaying error & uncertainty in auditory graphs," in *Proceedings of the 14th international ACM SIGACCESS conference on Computers and accessibility - ASSETS '12*, 2012, p. 285.

[11] L. Brown, S. Brewster, R. Ramloll, W. Yu, and B. Riedel, "Browsing Modes For Exploring Sonified Line Graphs," *Proc. Br. Human-Computer Interface Conf.*, pp. 6–9, 2002.

[12] S. Brewster, "Visualization tools for blind people using multiple modalities.," *Disabil. Rehabil.*, vol. 24, no. 11–12, pp. 613–21.

[13] NASA Information Access Lab, "NASA LTP information access lab: MDE graphing calculator demonstration (Beta 2.0)." 2004.

[14] J. A. Gardner, "The accessible graphing calculator: A self-voicing graphing scientific calculator for windows." 1999.

[15] R. Upson, "Sonifications as Mathematics Teaching Tools," in *International Conference on Auditory Display*, 2001, pp. 218–221.

[16] R. A. Bjork and A. Richardson-Klavehn, "On the puzzling relationship between environmental context and human memory.," in *Current issues in cognitive processes: The Tulane Flowerree Symposium on Cognition*, Hillsdale, NJ: England: Lawrence Erlbaum Associates, Inc, 1989, pp. 313–344.

[17] K. Rassmus-Grohn, C. Magnusson, and H. Efiring, "AHEAD - Audio-Haptic Drawing Editor And Explorer for Education," in *IEEE International Workshop on Haptic, Audio and Visual Environments and Games*, 2007, pp. 62–66.

[18] R. Upson, "Educational Sonification Exercises: Pathways for Mathematics and Musical Achievement," in *International Conference on Auditory Display*, 2002, pp. 1–6.

[19] Georgia Department of Education, "Common Core Georgia Performance Standards." [Online]. Available: http://www.gadoe.org/Curriculum-Instruction-and-Assessment/Curriculum-and-Instruction/Pages/CCGPS.aspx. [Accessed: 01-Feb-2013].

[20] Y. Eriksson, "Tactile Pictures. Pictorial representations for the blind 1784-1940," University of Gothenburg, 1998.

[21] American Foundation for the Blind, "Basic Principles for Preparing Tactile Graphics." [Online]. Available: http://www.afb.org/.

[22] American Printing House for the Blind, "Annual Report," 2014.

[23] A. D. N. Edwards, H. McCartney, and F. Fogarolo, "Lambda: a multimodal approach to making mathematics accessible to blind students," in *Proceedings of the 8th international ACM SIGACCESS conference on Computers and accessibility - Assets '06*, 2006, p. 48.

[24] D. Archambault, D. Fitzpatrick, G. Gupta, A. I. Karshmer, K. Miesenberger, and E. Pontelli, "Towards a Universal Maths Conversion Library," *Comput. Help. People with Spec. needs*, vol. 3118, pp. 664–669, 2004.

[25] I. Duxbury Systems, "Duxbury Braille Translator." .

[26] L. Ferres, A. Parush, S. Roberts, and G. Lindgaard, "Helping People with Visual Impairments Gain Access to Graphical Information Through Natural Language: The iGraph System," *Comput. Help. People with Spec. needs*, vol. 4061, pp. 1122–1130, 2006.

[27] D. Fitzpatrick, "Mathematics : How and What to Speak," in *Computers Helping People with Special needs*, 2006, pp. 1199–1206.

[28] C. of C. S. S. O. National Governors Association Center for Best Practices, "Common Core State Standards for Mathematics," National Governors Association Center for Best Practices, Council of Chief State School Officers, Washington D.C., 2010.

[29] B. K. Davison, "Understanding How Visually Impaired Students Demonstrate Graph Literacy with Accessible Auditory Graphs," Georgia Institute of Technology, 2012.

[30] A. M. Cook and J. M. Polgar, *Cook and Hussey's Assistive Technologies: Principles and Practice*. Elsevier Health Sciences, 2002, p. 523.

[31] A. R. Beigel, "Assistive Technology Assessment: More Than the Device," *Interv. Sch. Clin.*, vol. 35, no. 4, pp. 237–243, Mar. 2000.

[32] Freedom Scientific, "JAWS for Windows." .

[33] BAUM Retec Inc, "VisioBook." .

[34] Y. C. Chew, B. J. Tomlinson, and B. N. Walker, "Graph and Number line Input and Exploration (GNIE) Tool Technical Report," 2013.

[35] B. K. Davison, "Evaluating auditory graphs with blind students in a classroom," *ACM SIGACCESS Access. Comput.*, no. 102, pp. 4–7, Jan. 2012.

[36] J. Aronson, "A Pragmatic View of Thematic Analysis," *Qual. Rep.*, vol. 2, no. 1, 1994.

[37] Dedoose Version 4.5, "web application for managing, analyzing, and presenting qualitative and mixed method research data." SocioCultural Research Consultants, LLC, Los Angeles, CA, 2013.

[38] H. Brugman and A. Russel, "Annotating Multi-media / Multi-modal resources with ELAN," in *Proceedings of the fourth international conference on language resources and evaluation*, 2004, pp. 2065–2068.

[39] MacKichan Software, "Scientific Notebook." .

[40] Triumph Learning LLC, *Crosswalk Coach for the Common Core Standards, Math*. 2011.

[41] Edmentum, "Study Island." .

[42] G. H. Abner and E. A. Lahm, "Implementation of Assistive Technology with Students Who Are Visually Impaired: Teachers' Readiness," *J. Vis. Impair. Blind.*, vol. 96, no. February, pp. 98–105, 2002.

[43] "Hawthorne effect," *Wikipedia*. .

[44] Y. C. Chew and B. N. Walker, "What did you say? Visually impaired students using bonephones in math class," in *15th International ACM SIGACCESS Conference on Computers and Accessibility*, 2013, pp. 3–4.

[45] R. M. Stanley and B. N. Walker, "Intelligibility of bone-conducted speech at different locations compared to air-conducted speech," in *Annual Meeting of the Human Factors and Ergonomics Society*, 2009.

[46] B. N. Walker and J. Lindsay, "Navigation Performance in a Virtual Environment with Bonephones," in *International Conference on Auditory Display*, 2005, pp. 260–263.

[47] D. E. Lewis, "Assistive Devices for Classroom Listening," *Am. J. Audiol.*, vol. 3, no. 1, pp. 58–69, Mar. 1994.

[48] VoxLinc LLC, "Aftershokz." .

[49] S. Alper and S. Raharinirina, "Assistive Technology for Individuals with Disabilities: A Review and Synthesis of the Literature.," *J. Spec. Educ. Technol.*, vol. 21, no. 2, pp. 47–64, Nov. 2005.

[50] D. R. Duffey and C. Fox, "National Educational Technology Trends 2012: State Leadership Empowers Educators, Transforms Teaching and Learning.," 2012.

[51] M. (Alliance for E. E. Schwartzbeck, T., and Wolf, "The Digital Learning Imperative: How Technology and Teaching Meet Today's Education Challenge," 2012.

[52] T. Gray, H. Silver-pacuilla, A. Brann, C. Overton, and R. Reynolds, “Converging trends in educational and assistive technology,” in *Breakthrough Teaching and Learning*, T. Gray and H. Silver-Pacuilla, Eds. New York, NY: Springer New York, 2011, pp. 5–25.

[53] H. M. Kamel and J. A. Landay, “Sketching Images Eyes-free : A Grid-based Dynamic Drawing Tool for the Blind,” in *ACM Conference on Assistive technologies*, 2002, pp. 33–40.

[54] R. Likert, “A technique for the measurement of attitudes.,” *Arch. Psychol.*, vol. 22, no. 140, p. 55, 1932.

[55] Speech Integration Group, “FreeTTS 1.2 - A speech synthesizer written entirely in the Java(TM) programming language,” 2001. [Online]. Available: http://freetts.sourceforge.net/docs/index.php. [Accessed: 12-Sep-2014].

[56] G. Kramer, “Some Organizing Principles for Representing Data with Sound,” in *Auditory Display: Sonification, Audification, and Auditory Interfaces*, G. Kramer, Ed. Reading, MA: Addison-Wesley Publishing Company, 1994, pp. 185–222.

[57] J. G. Neuhoff, “Auditory Motion and Localization,” in *Ecological Psychoacoustics*, J. G. Neuhoff, Ed. New York, NY: Elsevier Academic Press, 2004, pp. 87–111.

[58] Y. C. Chew and B. N. Walker, “What did you say? Visually impaired students using bonephones in math class,” in *15th International ACM SIGACCESS Conference on Computers and Accessibility*, 2013, pp. 3–4.

[59] M. Curran and J. Teh, “NV Access (Version 2014.1).” 2007.

[60] Y. C. Chew, B. J. Tomlinson, and B. N. Walker, “Graph and Number line Input and Exploration (GNIE) Tool Technical Report,” 2013.

[61] M. K. Singley, *The Transfer of Cognitive Skill*. Harvard University Press, 1989, p. 300.

[62] M. W. Van Someren, Y. F. Barnard, and J. A. C. Sandberg, *The think aloud method: A practical guide to modelling cognitive processes*. London: Academic Press, 1994.

[63] A. K. Ericsson and H. A. Simon, *A Protocol Analysis: Verbal reports as data*. London: The MIT Press, 1993.

[64] M. A. Shapiro, “Think-aloud and thought-listing procedures in investigating mental processes,” in *Measuring psychological responses to media messages*, Hillsdale, NJ: Routledge, 1994, pp. 1–14.

[65] M. T. H. Chi, “Quantifying Qualitative Analyses of Verbal Data: A Practical Guide,” *J. Learn. Sci.*, vol. 6, no. 3, pp. 271–315, 1997.

[66] T. Zhao and S. Mcdonald, “Keep talking: an analysis of participant utterances gathered using two concurrent think-aloud methods,” in *NordiCHI*, 2010, pp. 581–590.

[67] E. Krahmer and N. Ummelen, “Thinking About Thinking Aloud: A Comparison of TwoVerbal Protocols for Usability Testing,” *IEEE Trans. Prof. Commun.*, vol. 47, no. 2, pp. 105–117, Jun. 2004.

[68] S. (University of T. Chandrashekar, D. (Ryerson U. Fels, T. (Queen M. U. of L. Stockman, and R. (UniversityCollege L. Benedyk, “Using Think Aloud Protocol with Blind Users: A Case for Inclusive Usability Evaluation Methods,” in *ACM SIGACCESS International Conference on Computers and Accessibility*, 2006.

[69] V. Louise Roberts and D. I. Fels, “Methods for inclusion: Employing think aloud protocols in software usability studies with individuals who are deaf,” *Int. J. Hum. Comput. Stud.*, vol. 64, no. 6, pp. 489–501, Jun. 2006.

[70] P. Strain, A. D. Shaikh, and R. Boardman, “Thinking but not seeing,” in *CHI ’07 extended abstracts on Human factors in computing systems - CHI '07*, 2007, p. 1851.

[71] S. Borsci and S. Federici, “The Partial Concurrent Thinking Aloud: A New Usability Evaluation Technique for Blind Users,” in *Assistive Technology from Adapted Equipment to Inclusive Environments*, P. L. Emiliani, L. Burzagli, A. Como, F. Gabbanini, and A. Salminen, Eds. IOS Press, 2009, pp. 421–425.

[72] M. van den Haak, M. De Jong, and P. Jan Schellens, “Retrospective vs. concurrent think-aloud protocols: Testing the usability of an online library catalogue,” *Behav. Inf. Technol.*, vol. 22, no. 5, pp. 339–351, Sep. 2003.

[73] S. C. Yang, “Reconceptualizing think-aloud methodology: refining the encoding and categorizing techniques via contextualized perspectives,” *Comput. Human Behav.*, vol. 19, no. 1, pp. 95–115, Jan. 2003.

[74] Y. S. Lincoln and E. G. Guba, *Naturalistic Inquiry*. Newbury Park, CA: SAGE Publications, 1985.