Understanding How Visually Impaired Students Demonstrate Graph Literacy with Accessible Auditory Graphs

PhD Thesis Proposal

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June 29, 2012
What is a “Graph”? 

Find the slope of the line that passes through the points.

10. 

11. 

Georgia Institute of Technology
What is a “Graph”?  

Find the slope of the line that passes through the points.

10. \((-9, 4), (-6, -2)\)

11. \((-2, 8), (10, -14)\)
Tactile Graphics for Blind Students
Auditory Graph Basics

1. Perceptual components of a sound: \( y = -2 \times x - 14 \)
   1.1 Pitch
   1.2 Volume
   1.3 Pan
   1.4 Timbre

2. Mapping: polarity

3. Trend Analysis: graph families

4. Context: tick marks

5. Point Estimation
Point Estimation is Challenging

Standards and Curriculum

- **Standard**: learning objective for a course
  - Currently state-level, guided by national structure
  - Common Core Standards: 45 states

- **Curriculum**: specific content.
  - textbooks, worksheets, web resources, labs, and tests
  - Curriculum is often inspired by standards

Focus on small curriculum covering all graphing standards.
Testing Accommodations

Provide alternatives that are fair to all students.

1. Blind students should perform equal or better
2. Sighted students should perform equally well

Goals

1. Accessible: point estimation on graph paper
2. Relevant: based on broad set of standards
3. Practical: usable in a classroom
4. Fair: suitable accommodations
Research Questions, Phase 1

$R_1$ How can auditory display facilitate interactive point estimation?

$R_2$ What common input devices can be used by blind people for interactive point estimation?
Research Questions, Phase 2

$R_3$ What education standards require graphing?

$R_4$ What are example graphing problems that meet each standard?

$R_5$ What steps are used to solve the graphing problems?

$R_6$ How can an accessible auditory graphs tool enable the steps necessary to solve the graphing problems?
Research Questions, Phase 3

R7 What issues are there in preparing classroom materials with an accessible auditory graphs tool?

R8 What issues are there in using an accessible auditory graphs tool in classroom situations?

R9 What issues are there in using an accessible auditory graphs tool in testing situations?
AudioFitts: Point estimation with auditory feedback.
Introduction
Phase 1: Point Estimation
Phase 2: Relevant Graphing Questions
Phase 3: Summative Evaluation
Summary

AudioFitts
Study 1: interaction device
Study 2: sensory modality
Study 3: approach formula
Study 4: audio format type

Program Title: Unnamed-1336407640063
Block Number: 1
Participant Number: 997760

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Auditory Graphs for Visually Impaired Students
Study 1 Questions

Dependent variable: movement time

1. Effect of target distance?
2. Effect of target width?
3. Effect of input device?
4. Effect of level of vision impairment?

Participants: 30 low vision and blind adults.
Study 1 Results

1. Effect of target distance?
   Faster* when closer

2. Effect of target width?
   Faster* when larger

3. Effect of input device?
   Faster* with mouse (8.5 seconds vs. 12.7 seconds)

4. Effect of level of vision impairment?
   For mouse, blind participants 2.4 seconds faster* than low vision participants.

* Significant results, $\alpha_{\text{family}} = 0.05$
Study 2 Questions

Dependent variable: movement time

1. Effect of target width?
2. Effect of input device?
3. Effect of display format?

Participants: Georgia Tech students
Study 2 Results

1. Effect of target width?
   Faster* when larger

2. Effect of input device?
   Faster* with mouse

3. Effect of display format?
   Faster* with visuals and visuals+audio.
   Visuals are about three times faster than audio.

* Significant results, $\alpha_{\text{family}} = 0.05$
Study 3 Questions

Dependent variables: hit accuracy and movement time. Using mouse.

1. Effect of auditory scaling?
   (Boolean, Linear Short/Long, Logarithmic)

2. Effect of peaking?

Note: shift from Fitts’s Law study to empirical design evaluations. Participants: Blind and low vision adults
Introduction
Phase 1: Point Estimation
Phase 2: Relevant Graphing Questions
Phase 3: Summative Evaluation
Summary

AudioFitts
Study 1: interaction device
Study 2: sensory modality
Study 3: approach formula
Study 4: audio format type

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Auditory Graphs for Visually Impaired Students
Program Title: AF7
Participant Number: 691798
Block Number: 2
Trial Number: 1
Block Elapsed Time: 4
Distance To Target:
Closest Target NL Value: 19
Closest Target X Distance: -72
Audio Scaling Trial: LinearShort
Target Peak Trial: Flat
Study 3 Results

1. Effect of auditory scaling? **No significant differences.**
2. Effect of peaking? **No significant differences.**

<table>
<thead>
<tr>
<th>Audio Scaling</th>
<th>Flat</th>
<th>Peak</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boolean</td>
<td>0.875 (0.156)</td>
<td>0.919 (0.144)</td>
<td>0.897 (0.150)</td>
</tr>
<tr>
<td>LinearShort</td>
<td>0.877 (0.147)</td>
<td>0.943 (0.071)</td>
<td>0.910 (0.119)</td>
</tr>
<tr>
<td>LinearLong</td>
<td>0.931 (0.091)</td>
<td>0.905 (0.150)</td>
<td>0.918 (0.123)</td>
</tr>
<tr>
<td>Logarithmic</td>
<td>0.945 (0.071)</td>
<td>0.938 (0.097)</td>
<td>0.941 (0.084)</td>
</tr>
<tr>
<td>Overall</td>
<td>0.907 (0.124)</td>
<td>0.926 (0.119)</td>
<td>0.917 (0.122)</td>
</tr>
</tbody>
</table>

Accuracy mean (SD in parentheses)
Study 3 Results

1. Effect of auditory scaling? **No significant differences.**
2. Effect of peaking? **No significant differences.**

<table>
<thead>
<tr>
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<th>Flat</th>
<th>Peak</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>LinearShort</td>
<td>11.744 (4.910)</td>
<td>12.922 (6.854)</td>
<td>12.333 (5.933)</td>
</tr>
<tr>
<td>LinearLong</td>
<td>12.813 (5.508)</td>
<td>15.308 (12.217)</td>
<td>14.061 (9.467)</td>
</tr>
<tr>
<td>Overall</td>
<td>11.923 (4.900)</td>
<td>13.750 (8.015)</td>
<td>12.837 (6.689)</td>
</tr>
</tbody>
</table>

Movement time mean (SD in parentheses)
Study 4 Questions

Dependent variables: hit accuracy and movement time.
Threshold: Below 80% accuracy.
Using mouse.

1. Effect of auditory scaling?
   (Boolean, Linear Short/Long, Logarithmic)

2. Effect of audio type?
   (Pan, Pitch, Rate, Volume)
### Study 4 Results: Accuracy

<table>
<thead>
<tr>
<th>Audio Type</th>
<th>Audio Scaling</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pan</td>
<td>Boolean</td>
<td>0.68 (0.37)</td>
</tr>
<tr>
<td></td>
<td>LinearLong</td>
<td>0.20* (0.22)</td>
</tr>
<tr>
<td></td>
<td>Logarithmic</td>
<td>0.49* (0.29)</td>
</tr>
<tr>
<td>Pitch</td>
<td>Boolean</td>
<td>0.94 (0.08)</td>
</tr>
<tr>
<td></td>
<td>LinearLong</td>
<td>0.56* (0.37)</td>
</tr>
<tr>
<td></td>
<td>Logarithmic</td>
<td>0.89 (0.21)</td>
</tr>
<tr>
<td>Rate</td>
<td>Boolean</td>
<td>0.62 (0.39)</td>
</tr>
<tr>
<td></td>
<td>LinearLong</td>
<td>0.36* (0.35)</td>
</tr>
<tr>
<td></td>
<td>Logarithmic</td>
<td>0.74 (0.34)</td>
</tr>
<tr>
<td>Volume</td>
<td>Boolean</td>
<td>0.93 (0.21)</td>
</tr>
<tr>
<td></td>
<td>LinearLong</td>
<td>0.31* (0.24)</td>
</tr>
<tr>
<td></td>
<td>Logarithmic</td>
<td>0.85 (0.24)</td>
</tr>
</tbody>
</table>

* significantly below 80%, $\alpha_{family} = 0.05$

mean hitrate, SD in parentheses
Phase 1 Conclusions

1. Sighted, low vision and blind adults can find points with audio feedback.
2. Adults can use mouse or keyboard for input, regardless of level of visual impairment.
3. Audio only feedback is about three times slower than using visuals.
4. People can find targets regardless of scaling or peaking.
5. Pitch, rate, and volume can be used for point estimation mapping.
6. Avoid linear distance mappings (except perhaps pitch).
The SQUARE Method

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.

Participants: visually impaired students and their math teachers.
Standards

Goal: identify graphing standards.
Method:
- Use Common Core Standards for Mathematics, Grade 6.
- Collect standards based on a word search for “graph”, “coordinate”, and “number line”.
- Remove irrelevant entries.
## Standards: Results

<table>
<thead>
<tr>
<th>ID</th>
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<th>Text</th>
</tr>
</thead>
<tbody>
<tr>
<td>GS.1</td>
<td>6.RP.3.a</td>
<td>Graph</td>
<td>Make tables of equivalent ratios relating quantities with whole-number measurements, find missing values in the tables, and plot the pairs of values on the coordinate plane.</td>
</tr>
<tr>
<td>GS.2</td>
<td>6.NS.6</td>
<td>NL</td>
<td>Understand a rational number as a point on the number line.</td>
</tr>
<tr>
<td>GS.3</td>
<td>6.NS.6</td>
<td>NL</td>
<td>Extend number line diagrams familiar from previous grades to represent points on the line with negative number coordinates.</td>
</tr>
<tr>
<td>GS.4</td>
<td>6.NS.6</td>
<td>Graph</td>
<td>Extend coordinate axes familiar from previous grades to represent points in the plane with negative number coordinates.</td>
</tr>
</tbody>
</table>
Questions: Goal

Identify graphing questions in line with each of the standards. Note: literacy is reading and writing.
Question Constraints

Each graphing question had:

1. a specific main idea
2. an intended standard
3. one graph or number line
4. space outside of the graph for reading or writing text
5. an answer that was multiple choice, short text, or plotted on the graph
41. CCS-6.NS.6.a.i – Standard 2, RQ 1
What letter is the opposite of B?
1. A
2. B
3. C
4. D

44. CCS-6.NS.6.a.i – Standard 2, RQ 2
What letter is the opposite of A on the number line?
1. A
2. B
3. C
4. D

32. CCS-6.NS.6.a.i – Standard 2, WQ 1
Plot the opposite of 3 on the number line

37. CCS-6.NS.6.a.i – Standard 2, WQ 2
Plot the opposite of 4 on the number line
105. 6.NS.6c.ii – Standard 5, RQ 1
What are the coordinates of point A on the graph?

106. 6.NS.6c.ii – Standard 5, RQ 2
What are the coordinates of point A on the graph?

108. 6.NS.6c.ii – Standard 5, WQ 1
Plot (2,-5) on the coordinate plane below.

109. 6.NS.6c.ii – Standard 5, WQ 2
Plot (-1,4) on the coordinate plane below.
Plot 6.3 on the number line.

Plot (-1,2) on the coordinate plane.

Plot (-3,-2) on the coordinate plane.

What letter is the opposite of: A, B, C, D.
Goal: Obtain the steps needed to solve the graphing questions.
Method: Task Analysis for Problem Solving (TAPS)

1. Ask experts to solve problem, with think aloud and discussion
2. Solve the problem with expert observation and feedback
3. Build task analysis
4. Solve again, given only the component parts*

* Verification addition to TAPS
Answers: Results

Four actions: Find, Add, Edit, Delete

9 nouns: (number indicates presence in the questions based on the 17 standards.)

1. Axis (2)
2. Estimate Values (1)
3. Filled region (1)
4. Open/Closed point (1)
5. Origin (12)
6. Point (17)
7. Point Label (2)
8. Tick Mark (17)
9. Tick Mark Label (17)
Example: Plot (2,-3) on graph.
Example: Plot (2,-3) on graph.

1. Find Origin
2. Find Tick Mark Label for $x = 2$ (horizontal)
3. Find Tick Mark associated with $x = 2$ tick mark label
4. Find Tick Mark Label for $y = -3$ (vertical)
5. Find Tick Mark associated with $y = -3$ tick mark label
6. Add Point at current location
Example: Plot (2,-3) on graph.
Reconstruct: Goal

Build a system that enables non-visual ways to complete the parts found in the Answers step.
Proposed Work
Evaluate: Goals

Goal: validate that people can use the same approach visually and with audio.
Method

Participants: Teachers experienced in
- teaching mathematics content
- teaching to visually impaired students

Procedure:
1. View a standard, a related graphing question, and the expected steps
2. View a video of someone answering the task with GNIE, using only visuals, audio, or a combination.
3. Compare with other modes in separate videos.
4. Judge whether the actor in each video is completing the graphing problem with the expected steps.
Introduction

Phase 1: Point Estimation

Phase 2: Relevant Graphing Questions

Phase 3: Summative Evaluation

Summary

Standards
Questions
Answers
Reconstruct
Evaluate

Text for the graph standard.

Steps to complete the graphing question:
1. Find origin.
2. Move right along the tick marks.
3. Find the tick mark with label '3'.
4. Move vertically...

The graphing question goes here.

For this graphing problem, does GNie enable using the same steps as paper?

☑ Yes.
☐ No.

Paper graph video

GNIE video

Notes:

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Phase 2 Conclusions

1. There are 17 graphing standards in CCS Math Grade 6.
2. Graphing questions for reading and writing can be made for the standards.
3. A task analysis of the answers to the graphing questions led to only 9 important parts of the graph, along with four actions.
4. Finding the tick mark, the tick mark label, and finding/editing a point are a part of all 17 standards.
5. Point estimation is an ever-present component to 6th grade graph literacy.
6. It is possible to create software that enables solving graphing problems based on the 6th grade standards.
Evaluate in realistic scenarios:

1. Classrooms
2. Examinations
Classroom: Goals

1. Observe impact on solving graphing problems
2. Identify supplementary tools used or not used with new tool
3. Collect opinions about the tool
4. Observe interactions between students and with the teacher
5. Identify key parts of teacher lesson preparation for class
Method

Participants:

- 25 low vision and blind 6-12 grade students at summer camp
- one math teacher with experience teaching visual impaired students

Groups of 12 meet for 90 minutes over four sessions.

<table>
<thead>
<tr>
<th>Group 1</th>
<th>Group 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 1</td>
<td>Introduction, Paper Examples, Demographics</td>
</tr>
<tr>
<td>Day 2</td>
<td>GNIE Introduction, Steps Practice, Questions</td>
</tr>
<tr>
<td>Day 3</td>
<td>Paper &amp; GNIE</td>
</tr>
<tr>
<td>Day 4</td>
<td>GNIE &amp; Paper</td>
</tr>
</tbody>
</table>

Lesson 1

Lesson 2
Pilot Study:

- Spring 2012 after school program spanning 11 weeks
- Participatory design
- Piloted classroom and examination approaches
- Training and interest: Navy game
1. Which graphed point on the number line is greatest? 

   Answer: 3
Question 106.
What are the coordinates of point A on the graph?
Answer below.
3, -2
Question 83.
Plot the reflection of point A (5,-4) across the X axis on the graph.
Study 6: Design

Goal: Evaluate changes in test scores between GNIE and tactile graphics. Participants:

- Blind people
- Would need or want tactile graphics for a mathematics test
- Literate in braille level 1 or above
- Recruited through CVI
Method

Task: (Three 50-minute sessions)

Session 1  Training on paper and GNIE
Session 2  Paper or GNIE examination
Session 3  GNIE or paper examination
Study 7: Design

Goal: Evaluate changes in test scores between GNIE and paper graphs. Participants:

- Low vision or sighted people
- Regular or magnified graphs sufficient for tests
- Recruited through the Center for the Visually Impaired

*Changed participant population from document from Georgia Tech students to CVI.
Conclusion

1. Auditory point estimation is possible.
2. There are a handful of key steps to answering questions based on Common Core Grade 6.
3. Proposed work will:
   3.1 evaluate actual solution steps with the intended steps.
   3.2 observe students in a mock classroom
   3.3 compare test scores for visual, tactile, and auditory graphs, with blind and non-blind people.
Contributions

- A greater understanding of how interaction devices and auditory display design choices affect speed and accuracy for point estimation.
- SQUARE, a method for creating education technologies based on graphing standards.
- A list of standards, questions, and steps based on requirements for sixth grade mathematics.
- GNIE, an auditory graph technology that can be used to solve reading and writing graphing questions.
- High-Low, a method for evaluating assistive educational technologies as testing accommodations.
- Observations and feedback about preparing and using auditory graphs in classroom settings.
Plan

Phase 1  August 2011 - January 2012
Phase 2  September 2011 - July 2012
Phase 3  January 2012 - July 2012
Proposal  June 2012
Defense  Fall Term 2012
Questions?
Appendix
Technologies: Accessible Graphing Calculator (AGC)

“Graph paper” or “calculator” metaphor?
Technologies: Integrated Communication 2 Draw (IC2D)

Figure 1. IC2D Model and Drawings: a) a 3x3 grid of cells, b) a square made up of lines, c) an arrow drawn inside an arrow using grid recursion, d) a car drawn by a participant in the IC2D pilot study.
Technologies: Sound Grid
Study 1 Keyboard Results

![Graph showing the relationship between target width and mean movement time for different target distance ranges.](image-url)
Study 1 Mouse Results

![Graph showing mouse movement time vs target distance range. The graph plots target width (pixels) on the x-axis and mouse mean movement time (seconds) on the y-axis. There are four lines representing different target distance ranges: 20-319, 320-619, and 620-919 pixels. Each line shows a decrease in movement time as the target width increases.](image-url)
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<tbody>
<tr>
<td>GS.5</td>
<td>6.NS.6.a</td>
<td>NL</td>
<td>Recognize opposite signs of numbers as indicating locations on opposite sides of 0 on the number line.</td>
</tr>
<tr>
<td>GS.6</td>
<td>6.NS.6.b</td>
<td>Graph</td>
<td>Understand signs of numbers in ordered pairs as indicating locations in quadrants of the coordinate plane.</td>
</tr>
<tr>
<td>GS.7</td>
<td>6.NS.6.b</td>
<td>Graph</td>
<td>recognize that when two ordered pairs differ only by signs, the locations of the points are related by reflections across one or both axes.</td>
</tr>
<tr>
<td>GS.8</td>
<td>6.NS.6.c</td>
<td>NL</td>
<td>Find and position integers and other rational numbers on a horizontal number line diagram.</td>
</tr>
</tbody>
</table>
## Standards: Results

<table>
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<tr>
<th>ID</th>
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<th>Type</th>
<th>Text</th>
</tr>
</thead>
<tbody>
<tr>
<td>GS.9</td>
<td>6.NS.6.c</td>
<td>Graph</td>
<td>Find and position pairs of integers and other rational numbers on a coordinate plane.</td>
</tr>
<tr>
<td>GS.10</td>
<td>6.NS.7.a</td>
<td>NL</td>
<td>Interpret statements of inequality as statements about the relative position of two numbers on a number line diagram.</td>
</tr>
<tr>
<td>GS.11</td>
<td>6.NS.7.c</td>
<td>NL</td>
<td>Understand the absolute value of a rational number as its distance from 0 on the number line.</td>
</tr>
<tr>
<td>GS.12</td>
<td>6.NS.8</td>
<td>Graph</td>
<td>Solve real-world and mathematical problems by graphing points in all four quadrants of the coordinate plane.</td>
</tr>
</tbody>
</table>
## Standards: Results

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<tbody>
<tr>
<td>GS.13</td>
<td>6.NS.8</td>
<td>Graph</td>
<td>Include use of coordinates and absolute value to find distances between points with the same first coordinate or the same second coordinate.</td>
</tr>
<tr>
<td>GS.14</td>
<td>6.EE.8</td>
<td>NL</td>
<td>Write an inequality of the form $x &gt; c$ or $x &lt; c$ to represent a constraint or condition in a real-world or mathematical problem. Recognize that inequalities of the form $x &gt; c$ or $x &lt; c$ have infinitely many solutions; represent solutions of such inequalities on number line diagrams.</td>
</tr>
<tr>
<td>ID</td>
<td>CCS</td>
<td>Type</td>
<td>Text</td>
</tr>
<tr>
<td>-----</td>
<td>--------</td>
<td>-------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>GS.15</td>
<td>6.EE.9</td>
<td>Graph</td>
<td>Write an equation to express one quantity, thought of as the dependent variable, in terms of the other quantity, thought of as the independent variable. Analyze the relationship between the dependent and independent variables using graphs and tables, and relate these to the equation.</td>
</tr>
<tr>
<td>GS.16</td>
<td>6.G.3</td>
<td>Graph</td>
<td>Draw polygons in the coordinate plane given coordinates for the vertices.</td>
</tr>
<tr>
<td>GS.17</td>
<td>6.G.3</td>
<td>Graph</td>
<td>Use coordinates to find the length of a side joining points with the same first coordinate or the same second coordinate.</td>
</tr>
</tbody>
</table>