Mapping Audio and Tactile Variables

A concatenated study to find inclusive correspondences for visual variables in geographic maps

by

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Abstract

The purpose of this research was to understand current geographic mapping paradigms, expose barriers faced by people who cannot rely on visual perception in the map reading experience, and propose a framework for designing maps to address these barriers. The study involved literature review, environmental scan, semi-structured interviews, surveys, and co-design with a variety of stakeholders. At each stage of the research auditory and tactile correlates for the visual variables used in geographic maps were documented and the results were synthesized into a framework referred to here as the VATmap (visual, audio, tactile) model. The framework can be used as a reference for designers and educators by suggesting strategies for communicating geographic information beyond visual display through a combination of visual, audio, and tactile map representations.

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Chapter 1: Introduction

“Geography as a study calls for the solution of problem after problem.” - Ontario Teachers’ Manuals 1932 – Geography, p. 13

1.1 Background

Making and using maps is fundamental to learning and communicating information. Maps have been an important communication tool throughout human history, dating back to the first known world map, created in 6th century BCE Babylonia (Raaflaub and Talbert, 2009). Over time, as printing technology became more sophisticated, followed by digital technology, maps became highly visual, and easier to share more widely with diverse audiences. In contemporary societies, maps are commonly used in: exploration and route planning, city planning, government, education, and emergency planning, to name a few uses.

This research investigates geographic maps specifically. A cartographic map can be defined as “a graphic representation of spatial relationships of entities within an area” (Esri Canada, n.d.). The definition itself reveals that the current mapping paradigm is heavily weighted towards graphic, or *visual* representations. Visual aesthetics is a fundamental design objective in the layout of geographic maps as they are commonly known today (Esri Canada, 2017). However, as will be demonstrated in this investigation, there is nothing about maps that suggests they need to be defined in visual-only terms.

1.2 Description of the problem area

Sighted children grow up learning about the distribution of land and bodies of water on the Earth by referring to visual maps, photos, and what they see in the physical world. However, for children who are not sighted, fewer resources exist or are within reach. As technology has advanced, maps and models have evolved to show more dimensions of information, becoming more and more visual through the form of computer modelling, thus reinforcing our reliance on vision to create, share, and access information. Currently, the majority of existing maps and map making software are not available in perceptual modes that are inclusive to blind and low-vision readers. This is because certain information is only represented visually. This is a problem because when maps are primarily displayed visually, non-visual learners are prevented from equal access to information such as the contours of landforms, the shapes topographical features, and the sizes of bodies of water, for example. Since maps are often used throughout all levels of education, as well as for personal agency and communication, barriers to map access is a problem that affects how people live and learn. This problem can be described as a barrier to the fundamental human right to equal access to information held by public bodies, referred to as Freedom of Information, outlined in the Universal Declaration of Human Rights and the Accessibility for Ontarians with Disabilities Act

(United Nations Educational, Scientific and Cultural Organization, n.d.; Accessibility for Ontarians with Disabilities Act, n.d.).

Equal access to information is a concern of our education system. There are five barriers to accessibility outlined by the Council of Ontario Universities Accessible Campus. Information or communications, and technology are two of these five barriers, and the current mapping paradigms put access to maps within these barriers to accessibility. An example of information or communications barriers is electronic documents that are not properly formatted and cannot be read by a screen reader. As this study will reveal, the information in visual maps is not completely accessible by these standards (Council of Ontario Universities, 2018).

A variety of stakeholders involved in the creation, dissemination, and consumption of maps are responsible for implementing equal access to them. Recent and ongoing implementation of global, national, and locally based guidelines place accountability on government agencies, industry, educational institutions, and non-profit organizations to make information accessible to everyone, with or without a disability (Henry & McGee, 2018; Manitoba Government, 2018; AODA, 2017; Government of Ontario, 2018).

1.3 Affected population

Advancements in technology, coinciding with our increased time spent looking at digital screens, is thought to be correlated to an increase in eye related health issues.

According to the Canadian National Institute for the Blind Foundation (CNIB), an estimated half-million Canadians are living with a form of visual impairment that impacts their everyday life, including 198,414 Ontarians (2019). An estimated 5.59 million Canadians, or 15% of all Canadians are living with an eye disease that could cause vision loss (CNIB Foundation, 2019; Statistics Canada, 2018). Moreover, on a global scale, the World Health Organization (WHO) reports that 1.3 billion people, or 17% of the global population are living with some form of visual impairment (WHO, 2018; DESA, 2017). This population, along with people who have temporary or partial blindness, are neglected when it comes to equal access to information that sighted users have access to. These statistics are especially important given that maps are routinely distributed through digital technology.

1.4 Purpose

Maps are increasingly created and accessed via web-based interfaces, and mapping products such as ArgGIS online are the status quo in education and industry. As it stands, maps are conceived of, created, displayed, and shared in the visual realm. Therefore, maps are designed primarily for sighted people who can understand data visualizations. This access problem prevents populations of people who are blind and low-vision from autonomy and agency to explore the world, to access geography and related educational practices, and from actively participating in the Geographic Information Systems (GIS) community. There is a need to create, test, document, and share potential solutions to this problem with maps.

1.5 Research questions

In order to guide this research, we must ask the following questions:

- What is afforded by visual maps for sighted audiences that is not afforded for non-sighted audiences?
- What are the key elements that comprise a cartographic map that must be translated so that the message is maintained?
- How can a map be represented through audio, tactile, or other non-visual techniques, in a meaningful way?
- How can we successfully represent relationships between geographic features non-visually?
- How do people detect patterns and gain information about the world using senses other than sight?

1.6 Objectives

There are four main objectives of this research:

- First is to conduct a literature review and environmental scan to understand the barriers that people face in accessing maps and what solutions are being developed in industry, education, and everyday life.

- Second is to conduct expert interviews and deploy surveys to gather insights and suggestions for non-visual mapping techniques, and involve the voices of a diverse audience throughout the developed of this field.
- Third is to co-design with stakeholders to design a map interface that will serve a diverse audience.
- Finally, the fourth objective is to synthesize the findings from this series of connected studies to compile best practices and present a preliminary framework to be used by practitioners to manifest the affordances of maps through multiple modes of perception.

1.7 Research scope and limitations

The review of the problem area includes an environmental scan of research and practices taking place all over the world, in locations such as in Canada, the United States, and Europe. In order to understand how to design maps for readers who are blind and low-vision, this research consults with stakeholders from industry and education who are directly connected to the population in question. This includes an in-depth, semi-structured interview with the design team a San Francisco based tactile street map design team, a survey with Ontario teachers who are interested in making accessible maps for their geography classrooms, a co-design session that took place in Toronto and involved a variety of stakeholders, and an in-depth, open-ended interview with a Toronto based globe designer and globe user who is blind. My role within this project is to provide expertise from my formal education in geography and inclusive design.

There are also some existing limitations to this study. The limitation with the greatest potential impact on the results might be the implementation of data collection. The collection of primary data is limited to the given studies that are outlined in this paper. Four individual studies were conducted with a small number of stakeholders, and the recurring input from one key stakeholder participant. Working with a key stakeholder repeatedly throughout the entire study allowed for consultations with the participant multiple times throughout the two-year study. This resulted in reassurance that the data being collected was properly recorded and understood because the participant could be asked to clarify about the meaning of their statements if needed. The limitation here is the subjective nature of the data. In the future, this study could be implemented to a wider audience and more user testing could be included to test the resulting framework.

1.8 Intended output

The intended output of this study is to develop a language to raise awareness about the problem of inequality as it pertains to access to geographic information. This entails communicating the strengths and weaknesses associated with visual, audio, and tactile modes of perception and how they can be fostered for the creation of a mapping system that benefits a wider audience. The result will be a framework for educators, cartographers, designers, industry professionals, and government to refer to in our collective journey to producing accessible maps. The following methodology section will describe the output in more detail.

Chapter 2: Methodology

2.1 Concatenated exploration

The type of discovery methodology used in this research followed the concatenated exploratory method referred to by Robert A. Stebbins (2010). Stebbins defines the concatenated method as it pertains to this study:

> Concatenation is, at once, a longitudinal research process and the resulting set of field studies that are linked together, as it were, in a chain, leading to cumulative, often formal, grounded theory. Studies near the beginning of the chain are wholly or dominantly exploratory in scope. Each study, or link, in the chain examines or at times re-examines a related group, activity, or social process or aspect of a broader category of groups or social processes. (p. 195)

The concatenated method described here is a series of cumulative studies taking place from fall 2017 to spring 2019. Each individual study within the concatenated series can be described in terms of a specific purpose, delineation, methods, findings, analysis, and conclusions, which will be individually outlined in their respective sections to follow. A review of literature and environmental scan is considered to be part of this concatenated method as part of the exploratory stages. Within each of these phases, recommendations were gathered for representing map data (geographic data and themes to be mapped) through audio and tactile components that could be used alongside the visual representations. Table 1 below is an example of the framework that this research will begin to solve for throughout the series of studies. The visual variables, and the elements that this table will be filled in with, will be described in detail in Chapter 3.

Visual Variables	Tactile Correspondences	Audio Correspondences
Position (changes in x, y, z location)		
Size (change in length, area, or representation)		
Shape (infinite number of shapes)		
Value (changes from light to dark)		
Hue (changes in colour)		
Orientation (changes in alignment)		
Texture (variation in pattern)		

Table 1: Accessible mapping framework with empty cells where tactile and audio correspondences will be filled in throughout the study.

The findings of this research will provide recommendations for designers to apply the functions of visual variables - as they pertain to geographic maps - to audio and tactile correspondences in order to represent map elements. Throughout this paper, variations of this table will be presented as a means to convey examples of how map elements can be represented through tactile and audio cues. A selection of existing maps and proposed tactile and audio techniques will be described by placing their individual map elements into specific locations in the table as a way to develop a taxonomy for maps that are not strictly described in visual terms. As the tactile and audio cues present themselves, they will be compared or contrasted to the way similar elements are presented in visual maps. For example, on a visual map, a lake could be presented as a blue area located in the centre of a landmass. In a tactile map, we cannot rely on the colour blue (or the visual variable *hue)* to indicate a body of water. This study offers examples for how elements such as the lake example can be represented non-visually. A synthesis of the respective findings will be presented as conclusions to this study.

2.2 Research design

The stages of this research design are as follows:

- Stage 1 - Literature review and environmental scan
- Stage 2 - TMAP design team interview
- Stage 3 - Survey geography educators
- Stage 4 - Co-design with stakeholders
- Stage 5 - In-depth interview with DIY globe designer

- Stage 6 - Synthesize findings from all stages

2.3 Research ethics

An important aspect of the research design was to recruit participants in the people-centred research stages (stages 2-5 above) who represent the target population of blind and low-vision map readers. Representation is a major theme of this research in order to gather insights and lived experiences that will add a meaningful element to the findings. As such, there are ethical implications to consider since the research design involves researching with human participants. These include protecting the privacy and safety of the volunteers who participated in the research, using respectful language, and understanding power sharing dynamics. Ethics approval for this study was obtained through the Research Ethics Board (REB) at OCAD U that protects the welfare of the participants.

We will begin the concatenated study in the following section by providing a brief overview of visual maps. This is meant to lay the foundation that proposed tactile and audio mappings will be in reference to throughout this paper.

Chapter 3: Map fundamentals

A map as a whole consists of a collection of map elements working together in unison to communicate an intended message from the map maker to the map reader. When a map is intended to be printed or shared, the map elements are strategically placed on a page for visual balance and clarity (Dent, 1972). This is referred to the map *layout*. Some of the key elements that are arranged in the map layout include (Esri Canada, 2017):

- An informative title for the map that describes the map content,
- A legend of map symbols that are being used to represent data,
- A scale that represents the relationship between the distances on the map and the real world,
- A north arrow to inform the direction of true north, relative to the map itself,
- Geographic data represented as (Bertin, 2011):
    - Points (no length, no area, representing a location),
    - Lines (have length, no area, independent of width, representing a boundary, route, or connection),
    - Areas (a measurable size, signification applies to entire area).

Figure 1, below, is a simple schematic showing how layers are generalized onto a 2D map. This example appears to show land cover, bodies of water, and unspecified landmarks at large scale zoomed in on a lake with land surrounding it. Symbols and hues present information visually within the geographic extent and scope of the example environment.

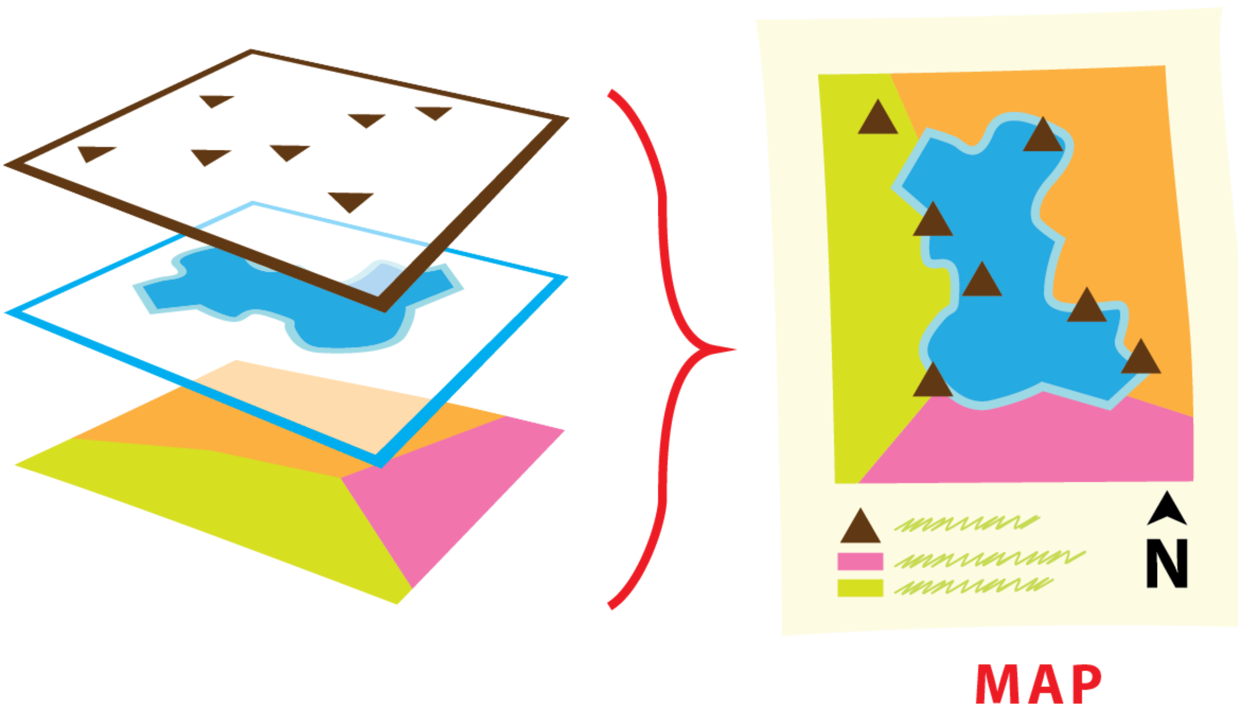

Figure 1: Simple schematic of a map showing how layers of map information are represented on a 2D plane (adapted from Esri Canada, 2018).

Maps can be described as the visual sharing, or communication of ideas and relationships of geographic and thematic data (Dent, 1972). Geographic information is the base map providing locational reference to the distribution being mapped. Thematic information is the distribution which is mapped, including all of the symbols that are used to convey the data (Dent, 1972). For example, a map can show how wealth is distributed across Canada. The map of Canada provides the geographic reference information, depicted by the base map of Canada. Wealth is the thematic data, and could be symbolized by any symbol that the designer chooses. For example, an ordered range of large to small squares, where the largest square symbolizes the highest amount of wealth, and the smallest square the lowest amount, is one way this thematic information could be represented. The designer’s goal is to represent all of these visual elements together so that the reader can understand the message as a whole (Dent, 1972). Arguably the most outstanding characteristic of visual maps is their ability to communicate several information variables simultaneously at single a glance to the reader. This is done through the graphic language of visual variables, which were introduced briefly above (ex: different sized squares representing scales of wealth), and will now be described in detail below.

3.1 Bertin’s Semiology of Graphics

In the year 1967, French cartographer Jacques Bertin proposed a set of visual variables as the standard units for symbols and rules to represent graphic representations. Bertin compiled these ideas into his book (translated to English) Semiology of Graphics - Diagrams, Networks, Maps. In this book, Bertin talks about four groups of graphic representations: diagrams, networks, maps, and symbols, within the limits of that which can be displayed on printable, white sheets of paper, be visible at a glance and at a standard reading distance, and in normal constant lighting (2011).

Bertin refers to graphics as the organization of marks on a two-dimensional plane, where the visual variables are a system that is used for portraying information by assigning variations in the marks (2011). These variations in marks include where we place the marks on the plane, how we place them (as points, lines, and areas, described above), and different visual characteristics. When the network of marks on the plane are arranged/placed on the map area with respect to what is seen on earth, the graphic is a geographic map (Bertin, 2011).

In the case of geographic maps, the two dimensions of the plane are utilized to represent the coordinates of geographic locations in a space (position). In order to describe the conventions of a visual map, this research borrows terms from the multidisciplinary field of Cognitive Semiotics, with particular emphasis on the notions of *iconic* representations and *symbolic* representations. Maps contain areas and lines representing features like countries, continents, and coastlines. In semiotic terms, these features are considered to be more-iconic representations resembling what exists in the physical world (Jeon, 2015). This is what Bertin describes as being represented in the two dimensions of the plane. The visual variables, also known as the retinal variables, are referred to as being above the plane, meaning they provide a third level of information (Bertin, 2011). In semiotic terms, symbolic representations have meaning by convention, such as language or shape symbols (Jeon, 2015). Symbols are used to give the map reader more information about certain elements on the map plane. Symbolism is based on learned analogies and conventions of shape or colour and include items such as language for labelling items on the map, or a red X (two diagonal lines crossing) symbol representing a railway crossing (for example), which are imposed on the map (Bertin, 2011).

Not all of these variables are treated the same. The visual variables are used in different ways to achieve different goals that the map designer is trying to solve, and each have a different capacity for communicating information. The variables are characterized as being *selective, associative, quantitative, and/or ordered*. Marks that are perceived as different, but still within a group, are considered *selective*. Marks that can be perceived as similar, and allow the reader to perceive groups are *associative*. When the reader can approximate a numerical size difference between marks, the variable is considered to be *quantitative*. Marks are considered *ordered* when the changes in the variable allow the reader to perceive a sequence (Bertin, 2011). Visual variables are “the differences in map elements as perceived by the human eye” (Axis Maps, 2018). For any kind of map, these are the fundamental ways in which graphic symbols can be distinguished.

The visual variables are drawn in Figure 2 below, and described by Bertin as follows:

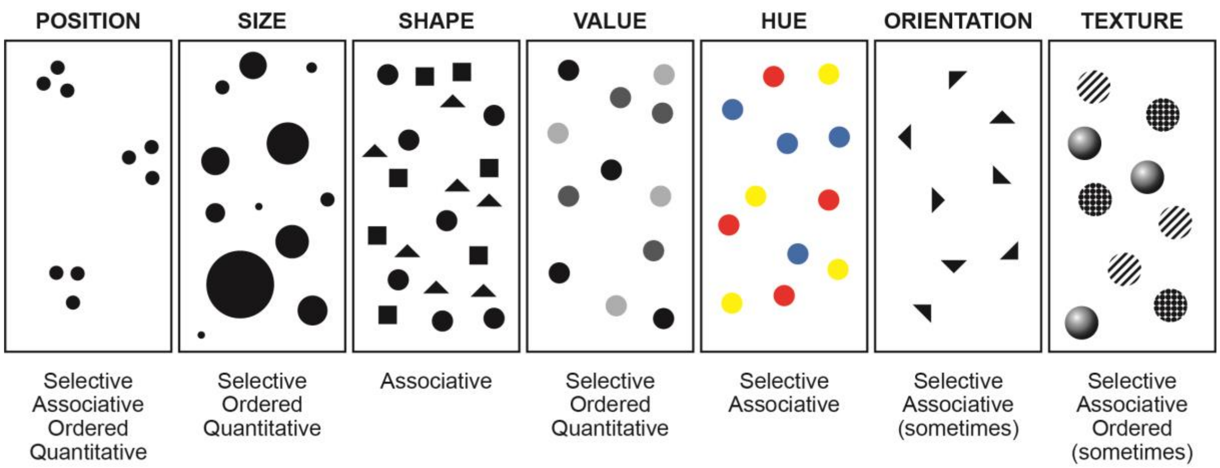

Figure 2: Bertin’s visual variables (adapted from Axis Maps, 2018).

- The *position* of marks on a 2D graphic (changes in x, y location),
- Categories of *size* of the marks depicted as the length, area, or representation that the mark occupies on the map,

- Categories of *shape* include an infinite number of shapes and are used to differentiate between marks of the same size.
- Categories of *value* are the various degrees of change from white to black of a hue,
- Categories of *hue* or colour include any number of colours that are displayed at equal value,
- Categories of *orientation* include changes in alignment of a line or line pattern from vertical to horizontal, in a distinct direction, and
- Categories of *texture* through variations in fineness, coarseness or pattern.

Researchers have since expanded on these variables. For example, with computational display, *motion* has been considered as a new variable as objects can become more dynamic on a computer screen (Carpendale, 2008).

Maps also contain symbolic written labels. According to a paper written by Richard Brath and Ebad Banissi, Bertin wrote about topographic variables in his book, however they say that this section was not translated from the original French version to the English version that many studies, including this paper, refer to (2019). Brath and Banissi say that in the last four pages of Bertin's book, he had referred to typographic attributes such as bold and italics, and their relation to the visual variables (2019). They also note that Bertin differentiates between thematic maps (those which utilize the visual variables such as size and hue to convey data), and more text-rich reference maps (2019). They reported that Bertin wrote that text *literally* encodes data, but that *literal* perception is not included as a characteristic of understanding visualizations (recall: *selective, associative, quantitative, and ordered)*. They say that because of this omission, typography has somewhat disappeared from Bertin's framework (2019).

Since Bertin proposed this set of visual variables for graphics such as maps, his standard has been adapted and extended by cartographers (Filippakopoulou, *et al.* 2004). This paper begins with a look at how Bertin's visual variables are used in the successful communication of geographic information because this is how the majority of maps are currently being designed. This research looks for clues for how to adapt the techniques used by Bertin on to other modes of perception.

In visual maps, the more-iconic properties such as the geography represented in the 2D plane, and the more-symbolic properties such as language and shape symbols work together to create a useful map tool. Consider the map of Canada below (Figure 3). This map is a very simplistic thematic map of Canada's political regions that can be described with the visual variables.

Figure 3: Map of the geography of Canada (Wikipedia, 2019).

At first glance, the map of Canada contains variations in hues, shapes, lines, and labels. With a small amount of training beginning at a young age, we learn that different shapes in a map of Canada represent the provinces and territories, dotted lines represent boundaries within the country, solid lines represent borders between countries, and text labels represent the locations of major cities or bodies of water. This describes an example of the visual variables in action. Table 2 below details how the visual variables are used in this map.

Visual Variables	Map of Canada
Position (changes in x, y location)	The points representing locations of Canada's capital cities communicate relative distances between cities. The points representing locations of positions that define the political boundary of a province communicates the relative distances between points along the boundary (or in other words, the contour of the political boundary).
Size (change in length, area, or representation)	The sizes of the point symbols for capital cities are larger than the sizes of the point symbols for non-capital cities, communicating order.
Shape (infinite number of shapes)	The shape of the symbols for capital cities is different than the shape of symbols for non-capital cities which helps to differentiate between the two categories of cities. Canada's capital city uses another symbol to set it apart as well.
Value (changes from light to dark)	The water is a lighter value of blue than the blue/hue value that is used to represent provinces.
Hue (changes in colour)	Hue is used in this map to represent different provinces and territories, bodies of water, and the non-Canadian regions on the map. Hue helps the

	reader see what areas are located in Canada.
Orientation (changes in alignment)	The orientation of the text labels is aligned to fit relatively within or around the areas they are labelling.
Texture (variation in pattern)	The lines in this map change in texture to show differences in line types. The solid black line shows international borders, whereas the dashed line shows provincial borders.
Written labels	The names of provinces and territories are in larger, bolded text, where the cities are in smaller text. Labels for bodies of water are in blue.

Table 2: Description of the visual variables in the above map of Canada.

In the map of Canada, point locations allow the reader to quickly contextualize the distribution of the mapped area. The variable size is utilized in the map of Canada to show the order of hierarchy of cities. Capital cities have a larger sized point symbol, and other local are designated smaller sized points. The different categories of location are also designated with different symbols for capitals versus other locale to further show the reader that the points have different meaning. There is also a prominent use of colour (hue) in this map. The separation between political borders (provinces and territories) in Canada is instantly communicated to the reader through the variation of hues. The variation in line types (broken lines and solid lines) is also simultaneously communicating the borders between regions to the reader.

The problem here in terms of accessibility is that the highly visualized elements are not typically described in detail and thus information that is given through colour, shape, line type, and size are not translated to non-visual representations. Instead regions are generally given an audio label without further description. For example, if a map reader were to come across the region of Toronto using a screen reader on a digital map, the reader would only hear “Toronto”, which provides far less information than visual representations. Furthermore, only the text that is properly tagged on the digital map will be made accessible by a screen reader. This is a problem for the population of people who have low levels of vision, or no vision. Beyond general map reading, a larger problem exists when it comes to education. Since maps and models are a common tool in many different areas of study, this means that a population of people are also not provided with an equal access to education compared to the level of resources there are for sighted students.

3.2 Mainstream map accessibility

Currently, there are some solutions at play for map accessibility, however they are not approaching a solution to the problem being addressed in this research. Map designers use techniques such as cross-hatching, adjusting contrast, use of patterns (texture), and gray-scale, to increase legibility for colour-blind individuals (Jenny and Kelso, 2007). The Web Content Accessibility Guidelines (WCAG) is the standard for web accessibility, placing accessibility and the quest for equal access to information into the mainstream in web design. However, when it comes to accessibility for people who visually impaired the guidelines mostly pertain to colour blind, or low-vision users (W3C Web Accessibility Initiative, n.d.). Some current web accessibility features include accessibility map viewers at the WCAG level 2, allowing the map reader to navigate the map using a screen reader to gain information through text to speech. For example, you can use tab to navigate from item to item, the enter key to activate a focused item, and alt + arrow-down keys to expand a section (Esri Canada, n.d.). A WCAG compliant Chrome extension has also been developed for making online content more accessible for colour-blindness. This is a luminosity contrast ratio analyzer that suggests colours that will provide contrast that is permitted by the WCAG (Tudosie, n.d.).

It is not customary to consider blind audiences in the planning and execution of maps today. For example, in April of 2017, the Ontario Ministry of Natural Resources and Forestry, Mapping & Information Resources Branch released a document entitled Map Design Considerations for Accessibility to help guide map designers through the process of increasing inclusive practices. However, the document only provides suggestions that will help moderately low vision map readers, and excludes anyone who is fully blind (Sikma, 2017).

Now that we have laid out the terminology for describing visual maps, let us consider a map that was designed for readers who are blind and low-vision - a raised line, braille map of the world (Figure 4, below).

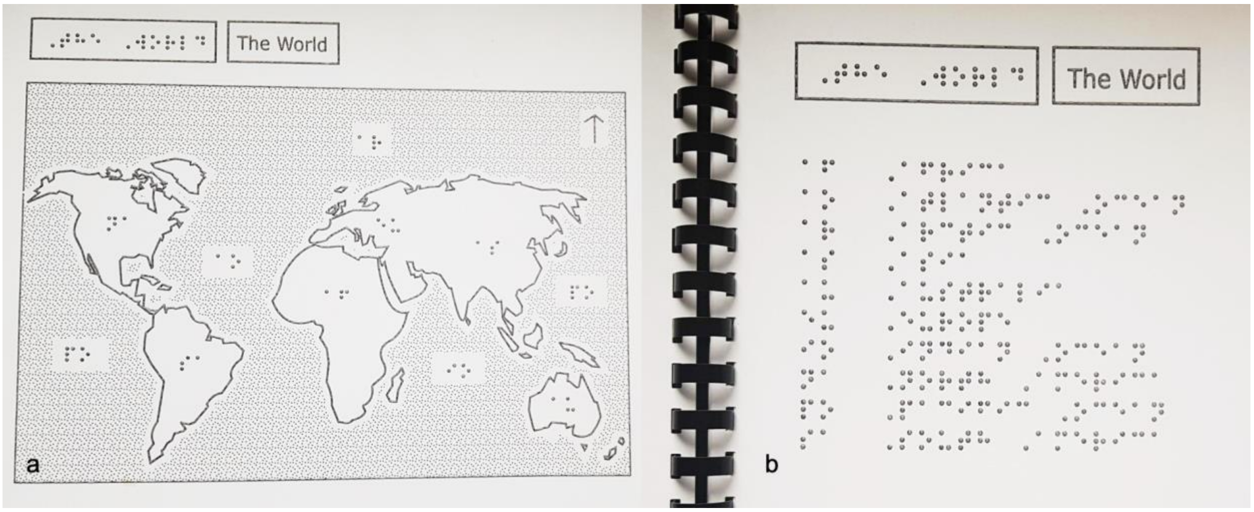

Figure 4: Photographs of braille map taken at OCAD University. a) Raised line, braille map of the world, b) legend.

This world map in Figure 4 contains many of the important map elements listed above. There is a title, north arrow, a legend, and geographic information present in this map (there is no scale bar in this map). However, this map also exemplifies a few problems with the design. For example, the map is extremely over-simplified compared to what a simple thematic visual map can achieve. One way the map is simplified is that labels are also acting as position symbols. The map is also general in that only the continents are labelled. Compared to the map of Canada, much more locational information can be given in a simple visual where the application of the visual variables allowed for the capital of Canada, capital cities, other local to be shown simultaneously with a change in dot size and shape. These conventions are not seen in this raised line braille map of the world example. Furthermore, the labels of the continents are abbreviated braille. If the entire name were to be written out in braille the map would need to be made much bigger, which is not always practical. The direction of true north is represented by a vertical line topped with a point, depicting an arrow pointing upwards. This mapping convention could become confusing with the presence of other lines on the map. That is because in thematic mapping, point locations are usually connected with lines and topped arrowheads in order to represent the sense of movement over time, or *motion* in maps (Briney, 2016; Bertin, 2011). In visual maps, multiple arrows may be used in a single map, differentiated through the use of the visual variables such as size, value, and orientation. The chosen representation for north in the raised line braille map example would be difficult to differentiate from a flowline and this is something to be considered in the development of tactile representations of complex datasets.

The presence of tactile texture in a raised line map is extremely useful. In the map of the world example, areas representing bodies of water have a bumpy texture and the land is represented with a smooth texture. The uses of texture are not seen this way in visual maps because they are given to the reader through changes in hue. The use of texture (ex: cross-hatching) is more commonly used in visual maps to represent changes in quantities, not for representing areas on the plane. A comparison between the use of visual variables in the map of Canada (Figure 3) and possible tactile correspondences in the raised line map of the world **(**Figure 4**)** is detailed in Table 3 below.

	Visual correspondences	Tactile correspondences
Visual Variables	**Map of Canada**	**Braille map of the world**
Position (changes in x, y location)	The points representing locations of Canada's capital cities communicate relative distances between cities.	Location of the braille labels represent the relative center of continents.
Size (change in length, area, or representation)	The sizes of the point symbols for capital cities are larger than the sizes of the point symbols for non-capital cities.	The braille labels are all the same size
Shape (infinite number of shapes)	The shape of the symbols for capital cities is different than the shape of symbols for non-capital cities which helps to differentiate between the two categories of cities. Canada's capital city uses another symbol to set it apart as well.	True north is represented by a vertical line topped with a point, depicting an arrow pointing upwards.
Value (changes from light to dark)	The water is a lighter value of blue than the blue/hue value that is used to represent provinces.	The value of the tactile area representing water is visually dark and the value of the area representing land is visually light.
Hue (changes in colour)	Hue is used in this map to represent different provinces and territories, bodies of water, and	Since this map is for blind and low-vision readers it does not use the hue variable to a great extent

	the non-Canadian regions on the map. Hue helps the reader see what areas are located in Canada.	other than to represent water and borderlines as black and land as white.
Orientation (changes in alignment)	The orientation of the text labels is aligned around the areas they are labelling.	The orientation of the map elements does not vary from the normal orientation.
Texture (variation in pattern)	The lines in this map change in texture to show differences in line types. The solid black line shows international borders, whereas the dashed line shows provincial borders.	Texture correlates with hue. The area representing bodies of water is a bumpy texture and the land is a smooth texture. Labels for bodies of water are on a smooth white background differentiating the braille from the raised dot texture representing water.
Written labels	Provinces and territory labels are larger, bolded text, cities are smaller text. Blue labels for bodies of water.	Standard braille abbreviations are used for labelling locations on the map, and braille is also used for the map title.

Table 3: Comparison between the visual variables represented in the map of Canada and tactile representations in the tactile map of the world.

Although this raised line map would be far more useful to someone who is blind than a standard visual map, it provides much less detail than a visual map provides to sighted map readers. Nevertheless, this appears to be the standard mapping convention that would be most readily available to a student who is blind.

Now we have seen how visual maps communicate information, and reviewed a few accessibility features that have been put in place. The following section is a literature review and environmental scan describing ways in which the auditory and tactile modalities can help bridge the gap in map accessibility that 2D raised line maps, and visual adaptations fail to champion.

Chapter 4: Literature review and environmental scan

A review of literature surrounding this research explored the current environment of non-visual modelling and mapping. This exercise is a continuation of the exploratory stage of the concatenated method employed by this study.

Questions that were used to guide the literature search are as follows:

- In terms of non-visual map display, how have different forms of mapping been explored?
- What kinds of data has been displayed through non-visual perceptual modes?
- What is the impact of providing alternatives to visual tools, such as cross-sensory tools that promote auditory and tactile learning in geography?

With these questions in mind, literature was collected and reviewed, and an assessment of the trends and outliers was performed, leading to the identification of gaps that exist currently in the field of non-visual modelling and mapping. Acknowledgement of these gaps would later advise the interview, survey, and co-design portion of this study.

A variety of publications have been used to inform research on non-visual mapping and modelling including journal articles, conference proceedings, books, websites, maps, mobile apps, and dissertations. Since maps and models are important to a magnitude of disciplines, academic research and qualitative data collection from stakeholders were both important for this environmental scan.

The works reviewed for this research could be placed into three major categories:

- Auditory modality
- Tactile modality
- Multi-sensory modalities

4.1 Auditory modality

4.1.1 Sonification

The Sonification Handbook by Thomas Hermann, Andy Hunt, John G. Neuhoff (Eds.) (2011) underscores the capabilities of human hearing, especially the act of pattern recognition. Sonification is the application of non-speech audio cues to communicate information that might typically be represented as a visual representation (ex: a graph). This is possible through the characteristics of sound such as amplitude and frequency, and adds a new way of exploring datasets that are typically only accessed through the visual mode of perception (Hermann et al. 2011). The Sonification Handbook encourages designers to try sonifications for communicating data and understand phenomena. Hermann et al say: “Another fascinating feature is the ability to learn and to improve discrimination of auditory stimuli. For example, an untrained listener may notice that “something is wrong” with their car engine” (2011). Hearing enables listeners to notice anomalies in a sequence of data. They also point out that visual, audio, and tactile perception give different, and complementary information to the individual. The incorporation of an audio channel to make sense of data can help fill gaps in the user experience (Hermann et al. 2011). Pattern recognition in visual maps, such as communicating ordered data through the visual variables, could benefit from this type of audio component.

Another example from the Sonification Handbook introduces the idea that sound can reveal information about the layout of a digital document. This is done by applying a sound to help a reader navigate the page, similarly to how the scrollbar works with vision. The scrollbar is essentially useless if there is only a visual cue letting the reader know where they are located on the page or in the document. By applying a sound cue to the scrollbar, and altering the characteristics of that sound based on where the reader is on the page or in the document, the reader can reduce their time spent locating their position on the page. For example, a higher pitch sound could represent the top of the page, and a lower pitch sound could represent the bottom of the page (Hermann et al. 2011). This type of audio cue could prove to be helpful to help orient around the coordinate system of a geographic map.

Research by Sergio Mascetti, Andrea Gerino, Cristian Bernareggi, and Lorenzo Picinali explored the use of novel sonification techniques for non-visual shape exploration in order to address issues of access to information for blind or visually impaired persons (2017). In their research, they introduced participants to a sonification and asked them to complete tasks based on what they heard. Participants were asked to recognize an invisible shape by exploring it in sound space where frequencies were mapped to locations of a shape. After that, they were asked to identify the correct shape (that they had just explored) from four possible choices either on shown their screens or through described audio. They used the sound parameter approach to make an audio shape. Their results gave credence to the learnability of sonification as a form of data communication because participants were able to correctly identify the drawn (or described) shapes in just a few minutes of training (Mascetti et al., 2017). Although the use of non-linguistic sounds in the form of musical instruments and tones have been the focus of sonification applications, it might be most useful in combination with text descriptions, as we will see in geographic mapping.

We have now briefly looked at examples depicting ways in which sonification has been applied to communicate data. The following section outlines a taxonomy for auditory mapping in order to discuss this further in terms of geographic maps.

4.1.2 Krygier's audio variables

American geographer John Krygier developed a list of abstract sound variables that could be applied in a similar manner to Bertin's visual variables in cartographic design. These variables can add to our knowledge of what a map can tell us (Krygier, 1994). Krygier suggested the following variables which could be prototyped to represent geographic data:

- The *location* of a sound in 2D or 3D space could be used to represent a point on a map.

- The *loudness* or the magnitude of a sound could represent a range of attributes that are associated with a hierarchy. Loudness is ordered (high to low) and can be used to represent ordinal datasets. Patterns and anomalies can be detected through the loudness variable. (Recall: the visual variables with ordinal characteristics are location, size, value, and texture (Bertin, 2011)).
- The variations in *pitch* from highness to lowness (frequency) could also represent ordered data.
- The order of pitches in a range of pitches, or the *register* could be applied to order different quantities in a hierarchy.
- The quality and characteristic of a sound, or the *timbre,* could be used for representing nominal/categorical/unorderable data, such as different languages, professions, or land use categories for example (similar to the use of hue in the visual variables) (Bertin, 2011).
- The *duration* of a sound (length of time a sound is or is not heard) to represent different quantities and order, such as a longer duration referring to a higher quantity.
- The *rate of change*, or relation between durations of sound and silence over time can help a listener detect patterns and identify anomalies in the data.
- The *order*, or the sequence of sounds over time might represent chronological/temporal data.
- The *attack/decay* or the time it takes for a sound to reach its maximum/minimum. This could help represent scale (for example, longer attack and longer decay represents a wider value range).

Similarly, to the way that the position of a location can be indicated with the use of a point symbol in a visual map, Krygier states that locations can be mapped to positions in a sound space through stereo or 3D audio display **(**Krygier, 1994). Krygier also states that audio variables can help communicate ordered data and gives examples of audio-visual correspondences for this type of mapping. For example, the visual variables size has perceptible order in visual maps. If you have a set of different sized circles, the eye can sense that a larger sized circle would be associated with a higher quantity (ex: temperature ranges in a climate map). According to Krygier, changes in location, loudness, pitch, register, duration, rate of change, order and attack/decay could all be used to represent ordered data (1994). For instance, in the example above, temperature ranges could be mapped through changes in pitch where low pitch (deeper sounds) would be associated with higher temperatures, and higher pitch (sharper sounds) would be associated with lower temperatures (think the whistling of a cold wind). Timbre on the other hand, as Krygier describes, is less effective for representing ordered data, but could be used for representing nominal/categorical data. One example of this would be to represent different regions with different timbres. One example of this from Krygier is to represent a rural area with the “mellow” sounds of a cello, and brassy sounds could represent urban areas (1994). This is similar to Bertin’s notion of using the visual variable *hue* for classifying different land use categories (in this example, you could represent rural areas with a green hue, and urban areas with a red hue, but these hues could not be perceived as ordered) (2011). Examples of audio variable mappings like this can also be found in Chapter 7 (Table 8) from results of the co-design study. Table

4 below outlines suggested correspondences between the Bertin's visual variables and Krygier's audio variables.

	Visual correspondences	**Audio correspondences**
Visual Variables	**Map of Canada**	**Krygier's audio variables**
Position (changes in x, y location)	Points representing locations of capital cities communicate relative distances between cities.	The *location* of a sound in 2D or 3D space could be used to represent a point's position on a map.
Size (change in length, area, or representation)	Sizes of the point symbols for capital cities are larger than the sizes of point symbols for other sizes of locale.	Changes in loudness, pitch, duration, and the attack/decay could all be used to represent size.
Shape (infinite number of shapes)	The shape of the capital city symbols is different than the shape of symbols for non-capital cities to differentiate between the two categories. Canada's capital city uses another symbol to set it apart as well.	As there is an infinite number of shapes, similarly there is an infinite number of sounds that can be used for representing map symbols.
Value (changes from light to dark)	The water is a lighter value of blue than the blue/hue value that is used to represent provinces.	Loudness, pitch, duration, and order are examples of audio variables that seem to correlate with changes in value because they can be used to represent ordinal ranges.

Hue (changes in colour)	Hue is used in this map to represent provinces, territories, bodies of water, and other regions. Hue helps show which areas are located in Canada.	Timbre could be considered as a correlate to hue for data that is characterized nominally.
Orientation (changes in alignment)	The orientation of the text labels is aligned to fit relatively within or around the areas they are labelling.	The location of sound in 3D space could be considered an audio correlate for orientation.
Texture (variation in pattern)	The lines in this map change in texture to show differences in line types. The solid black line shows international borders, whereas the dashed line shows provincial borders.	The audio correlate of texture could be described as timbre. Similar to hue, nominal data could be expressed through distinct changes in timbre.
Written labels	The names of provinces and territories are in larger, bolded text, where the cities are in smaller text. Labels for bodies of water are in blue.	The audio correlate to a written label would be spoken word, which is not part of Krygier's variables.

Table 4: Comparison between the visual variables represented in the map of Canada and Krygier's proposed audio variables.

The study of the auditory channel for communication has helped us understand how map information can be represented through audio variables. Research has shown that in tandem with sound, the tactile modality can help to deliver a clearer map reading experience. The following section is a review of the how tactile modality can be used for communicating map representations.

4.2 Tactile modality

An early example of traditional methods for wayfinding includes tangible navigational aids representing coastal topography. Gustov Holm discovered 3D wooden carvings representing islands and coastlines during his expedition to the *Ammassalik* region of Greenland during his 1881-1885 expedition (Figure 5). Holm found that 3D handheld carvings like the ones shown in Figure 5 helped an Inuk hunter navigate landmarks and routes while hunting and fishing because they depicted not only the contours of the land but also the relief of the Eastern coastline (Heyes, 2002).

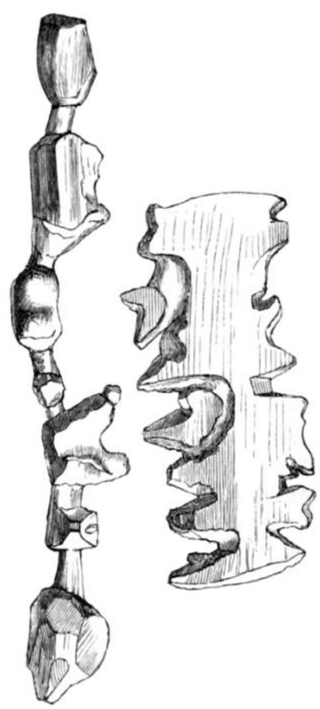

Figure 5: Image of wooden relief maps of East coast of Greenland (Holm and Garde, 1887).

There is an iconic relationship between the contours of the carvings and the coastlines that they represent. This representation of spatial relationships of the given area makes the representation consistent with the definition of a map (Bertin, 2011; Esri Canada, n.d.). Since map representations have become ubiquitous with digital technology, representations like these are not commonly found (nor were there necessarily common during the time they were used by the Inuk hunter). However, given that they are consistent with the definition of what a map is, and are multi-sensory (visual, tactile), they could offer suggestions for new ways to make map representations accessible to a more diverse audience if used alongside more powerful geographic information technology.

A number of attempts have been made over the years to provide hands-on mapping tools for sighted, blind and low vision learners in an academic setting. Support for tangible 3D removable pieces was proposed specifically for teaching blind students geography over a century ago (Eliot, 1875). Puzzle map games that are produced today could offer inspiration for non-visual mapping activities. See Figure 6 below for example.

Figure 6: Puzzle map game with removable pieces (Max Pixel, 2016).

The map game shown in Figure 6 has pieces that come out of a puzzle board. The puzzle board uses different hues to outline where the pieces fit. In this map puzzle, we see there is an iconic relationship between the contour of the puzzle pieces and the political borders that they represent in real life. The user could take out two pieces and compare the relative landmasses of each piece and actively conduct analysis and gain spatial awareness about the given area being depicted in the puzzle. This puzzle example does not have any braille labels to accompany the visual text labels, but that would also be very useful for designs of this nature.

In 1837, Stephen Preston Ruggles built the Perkins Globe, designed with the intention for teaching blind students geography at the Perkins School. This globe has tactile cues such as raised continental contours, lines of longitude and latitude, and braille labels. It is the first known American built globe of its kind. The thirteen-foot globe has undergone restorations and is on display at the Perkins Museum in Watertown (Shih, 2017). The massive size of this globe allows for distinct tactile details compared to what can be built up on a standard twelve-inch diameter globe. For those with low vision, the globe is also painted in bright colours that standard globes would display (Shih, 2017). In the 1950s, Richard Tunley of Queensland, Australia built the Tunley Braille Globe (Figure 7) for blind and low vision learners that is similar to the Perkins globe, but much smaller.

Figure 7: Wooden and metal Tunley Braille Globe (State Library of Queensland via Scott, 2017).

The tactile wooden globe shown in Figure 7 above was made accessible through the addition of raised metal surfaces and braille labels to provide a non-visual sense of Earth’s geography (Scott, 2017). Since metal feels cold to the touch (when it has not been handled or heated) is a useful material for tactile globes to quickly sense when your finger has come in contact with the labels. The Queensland Library Foundation is replicating the globe using 3D printing.

Conventional globes that we commonly see today can be smooth and show information purely through visual representations, or they may also contain visual information that is accompanied with raised areas for highlighting changes in topography, similar to the continental ridges that were displayed in the Perkins globe. This use of a visually perceived tactile variable provides the user a more detailed understanding of what the globe is showing through its visual features.

See Figure 8 below for an example of a topographic globe with slightly-raised tactile features.

Figure 8: Photograph of a globe with raised topographic features. a) Full view of the globe b) Zoomed-in globe.

Thinking back to the Perkins globe, and the globe shown in Figure 8, there has been relatively little evolution in the field of tactile learning tools with the intention for aiding blind and low vision learners to study geography (this is especially exacerbated if you consider the leaps and bounds technology has made in the development of digital mapping tools). Some existing products could provide clues for how to make more accessible educational toys. For instance, the Ravensburger 3D puzzle (Figure 9) is a globe was made into a jigsaw puzzle. Perhaps if the puzzle pieces were shaped to resemble the areas they are representing it could be educational to blind and low-vision users as well.

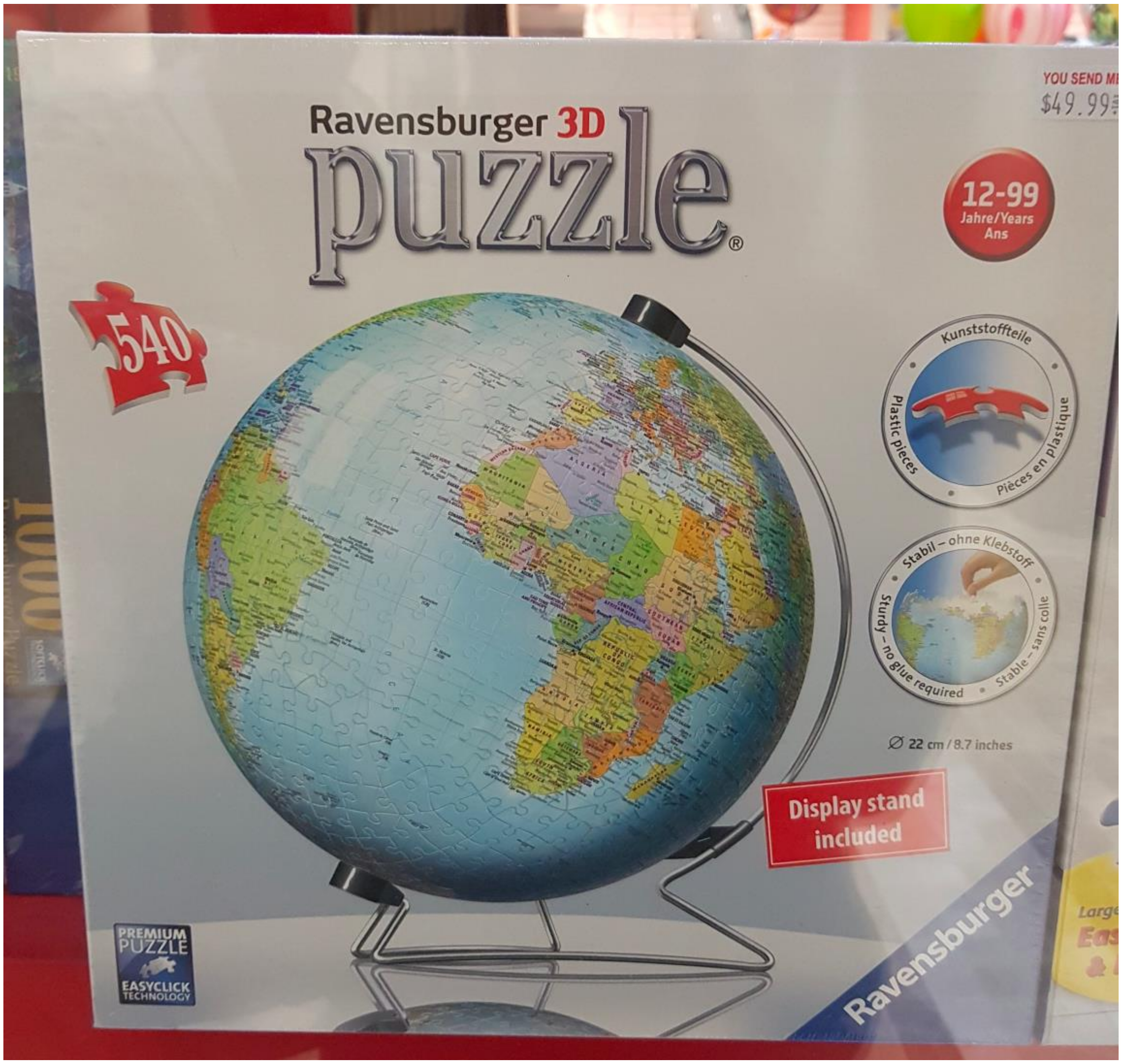

Figure 9: Photograph of Ravensburger 3D globe puzzle for sale in a Toronto store window.

Some other examples of tactile and braille maps and globes were also observed during field work for this study. For instance, a braille globe at San Francisco's LightHouse for the Blind and Visually Impaired was observed. The Features of this globe were represented with raised areas depicting landmasses, and braille labels for important location names. Figure 10 (below) shows someone using the globe.

Figure 10: Photograph of person touching the braille tactile globe at San Francisco's LightHouse for the Blind and Visually Impaired.

A model of Liberty Island in New York City and a large topographic map of San Francisco at Fisherman’s Wharf were also observed. Models like these could be used for non-visual exploration through the application of different textures and materials.

One example like this was observed at Enchanted Hills Camp and Retreat for the blind in Napa (see Figure 11 below).

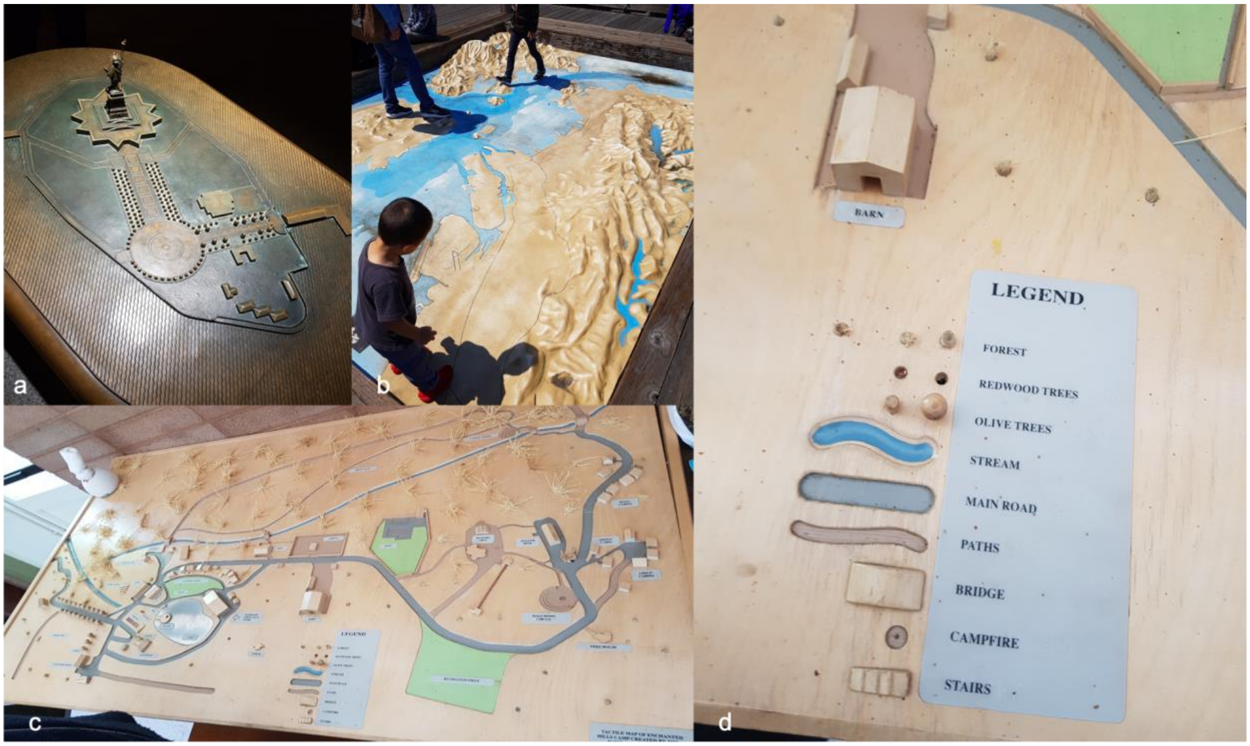

Figure 11: Photographs of tactile models and maps seen in New York, San Francisco, and Napa. A) Scale model with tactile cues of Liberty Island, b) large tactile map of the Topography of San Francisco, c) tactile map of Enchanted Hills Camp and Retreat (EHCR) in Napa, d) zoomed-in legend on EHCR map (note: some details on the legend seem to be missing).

In terms of variable correspondences for maps, we can look at how the tactile map of EHCR portrays tactile variables. For instance, in visual maps, hue is used to designate categories or classes in thematic maps (Roth, 2016). The tactile correspondence that we see in the EHCR map is depicted by different tactile textures for the different line types. The main road, path, and stream are all represented by different sized lines, but are also given different tactile textures to help the map reader differentiate between the lines. Furthermore, these lines are also engraved which adds another dimension of communication to this map. A 3D map can give more context to the map reader than a

2D raised line map for instance. Recall the raised line representation of the north arrow in the braille map of the world **(**Figure 4). Since this raised line was the same height and weight of the other line representations on the map, this could cause confusion to the map reader when differentiating between a border, or a coastline, or a north arrow. 3D elements such as the raised stairs and the engraved stream shown in the EHCR map show how much more information a reader can gather compared to raised lines alone.

Table 5 below provides an overview of visual and tactile correspondences in the examples we have looked at (visual, 2D raised line maps, and 3D tactile map).

	Visual correspondences	**Tactile correspondences**	**Tactile Correspondences**
Visual Variables	**Recall: map of Canada**	**Recall: 2D braille map of the world**	**3D tactile map of EHCR**
Position (changes in x, y location)	The points representing locations of Canada’s capital cities communicate relative distances between cities.	Location of the braille labels represent the relative center of continents	Location of the tactile symbols on the tactile map represent the locations of the features on the map in relation to their real-world positions.
Size (change in length, area, or representation)	The sizes of the point symbols for capital cities are larger than the sizes of the point symbols for non-capital cities.	The braille labels are all the same size.	The variations in line sizes represent differences between the main road, paths, and the stream.

Shape (infinite number of shapes)	The shape of the symbols for capital cities is different than the shape of symbols for non-capital cities which helps to differentiate between the two categories of cities. Canada's capital city uses another symbol to set it apart as well.	The North is represented by a vertical line topped with a point, depicting an arrow pointing upwards.	The shape of the symbol for stairs uses tactile elevations to differentiate from the shape of the symbol for bridge.
Value (changes from light to dark)	The water is a lighter value of blue than the blue/hue value that is used to represent provinces.	The colour value of the tactile area representing water is dark and the value of the area representing land is white.	A variable mapping for value could be comparable to the size and texture through value ranges in those tactile cues (ex: value changes from very rough to very smooth).
Hue (changes in colour)	Hue is used in this map to represent different provinces and territories, bodies of water, and the non-Canadian regions on the map. Hue helps the reader see what areas are located in Canada.	Since this map is for blind and low-vision readers it does not use the hue variable to a great extent other than to represent water and borderlines as black and land as white.	Visual variable for hue is depicted on this map through representations of blue symbolizing water, grey symbolizing roads, and beige symbolizing paths. These classes of data are also

			represented through different tactile textures.
Orientation (changes in alignment)	The orientation of the text labels is aligned to fit relatively within or around the areas they are labelling.	The orientation of the map elements does not vary from the normal orientation.	Tactile map elements do not vary from the normal orientation.
Texture (variation in pattern)	The lines in this map change in texture to show differences in line types. The solid black line shows international borders, whereas the dashed line shows provincial borders.	The tactile correspondence for value in this case is texture. The area representing bodies of water is a bumpy texture and the land is a smooth texture. It is also observed that the labels for bodies of water are given a smooth white background in order to differentiate the labels from the raised dot texture representing water.	Each symbol uses a different tactile texture. Texture can be used to differentiate between line symbols, for example, the main road, path, and river are all forms of lines, but each are built from a different material to show variations through touch (ex: the main road is metal and the path is wood).
Written labels	The names of provinces and territories are in larger, bolded text, where the cities are in smaller	Braille abbreviations are used for labelling locations on the map, and braille is also used	Braille labels and text in English are both used for labelling features of the map.

	text. Labels for bodies of water are in blue.	for the map title.	

Table 5: Comparison between the visual variables represented in the map of Canada, 2D tactile representations present in the tactile map of the world, and 3D tactile representations present in the EHCR tactile map.

Many researchers have proposed that audio and tactile elements can be used to represent geographic map features. We have looked at the audio and tactile modalities separately, but there has also been research in how these modalities work together to form cross-sensory representations with the goal of providing a more inclusive and accessible map reading experience.

4.3 Multi-sensory modality

Research has shown improved usability of geographic maps through interactive audio and tactile cues as well as the involvement of end users in the design process for producing more effective designs of audio-tactile interfaces. In 2013, Jonathan Lazar, Suranjan Chakraborty, Dustin Carroll, Robert Weir, Bryan Sizemore, and Haley Henderson created a successful audio-tactile prototype using keyboard commands and a touchscreen with a tactile overlay for non-visual access to weather data. In 2015, Anke Brock and Christophe Jouffrais developed an interactive navigational map by combining a raised-line map overlay placed over a multitouch screen with speakers for the audio output. In 2018, Jeremy Albouys-Perrois, Jeremy Laviole, Carine Briant, and Anke Brock also developed a multi-sensory map for blind and low-vision learners using a participatory design approach, combining projected imagery, finger and object tracking, tactile cues, and text-to-speech synthesis. Each of these examples employs a 2D rectangular overlay for tactile cues. The majority of work in the field of computer-human interaction employs techniques for creating maps for blind and low-vision learners where the tactile overlay was intended to be used over an interactive touch screen with an audio component. The idea of applying a tactile overlay over a 3D sphere with corresponding audio labels in the audio-tactile design, rather than 2D raised-line graphics will be explored later in this paper.

4.4 Gaps in the research

The practice of inclusive design in geography is somewhere in between lacking and advancing. The research (outlined in the literature review) shows that a combination of tactile and audio representations should be useful. However, a major gap in the research exists in the realm of attainable applications of non-visual mapping tools into common practice. As well, there is a need for the development of a data representation system that can be a widely used as Bertin’s visual variables are for representing geographic information.

Bertin seemed to utilize the visual variables predominantly for expressing changes in map symbols that are outside of the coordinate plane. The idea here is that the visual representations of points, lines, and areas depicting topography is taken for granted. In Bertin’s views, only data that cannot be expressed in the 2D plane needs to be expressed using the visual variables to bring the information out to the viewer's visual perception. But what we have found is that even representing the surface of the Earth is a complicated task when mapping using audio and tactile correspondences for non-visual map reading.

This research takes findings from the individual studies and seeks out suggestions not only for using variables to map changes in thematic data, but also to elevate topographic data. Looking back to Figure 3 Map of Canada, the following methodology is an investigation of how we can represent these features through sound and touch, making a map representation that is more inclusively designed.

The background and literature review of this study shows that despite existing research demonstrating the need for alternative forms of map information, there is a lack of products on the market today that are made accessible for blind and low-vision map readers. Key stakeholders were approached in order to investigate what is currently being done to address the problem, to find out what map elements might be included in the design of a useful tool, and how those elements should be represented in the tactile and audio modality. Stakeholders included people who design and/or use maps on a daily basis. The stakeholders come from various sectors such as industry, education, government, and the local community. The importance of creating connections between different stakeholders in this study is to facilitate communication between all the important parties in the life cycle as it pertains to designing more accessible maps.

Results from these studies add to the collection of findings that show how the visual variables manifest themselves through sound and touch.

The following chapters will provide an in-depth overview and analysis of the four individual studies that were conducted as part of the concatenated study:

- Study 1: TMAP Design Team Interview,
- Study 2: Surveying Geography Educators,
- Study 3: Non-Visual Mapping and Modelling Co-Design Session,
- Study 4: Interview with a globe designer and user who is blind.

Chapter 5: TMAP design team interview

TMAP is a project housed at San Francisco's LightHouse for the Blind and Visually Impaired, in collaboration with the Smith-Kettlewell Eye Research Institute. A small team of designers have automated the production of tactile street maps, and they are in the beginning stages of launching this system to the public. The product uses publicly available street map data to design accompanying tactile maps for blind and low-vision individuals. The individual sends a request to LightHouse with a central location they would like to navigate around, and then LightHouse ships the user a tactile map representing the surrounding area. An example of a TMAP that depicts the location of the Cooper Hewitt Museum in New York City is shown in Figure 12 below. This map depicts the museum as the epicentre of the map. The centre point is represented by a raised circular point symbol. The streets surrounding the museum are represented by raised lines.

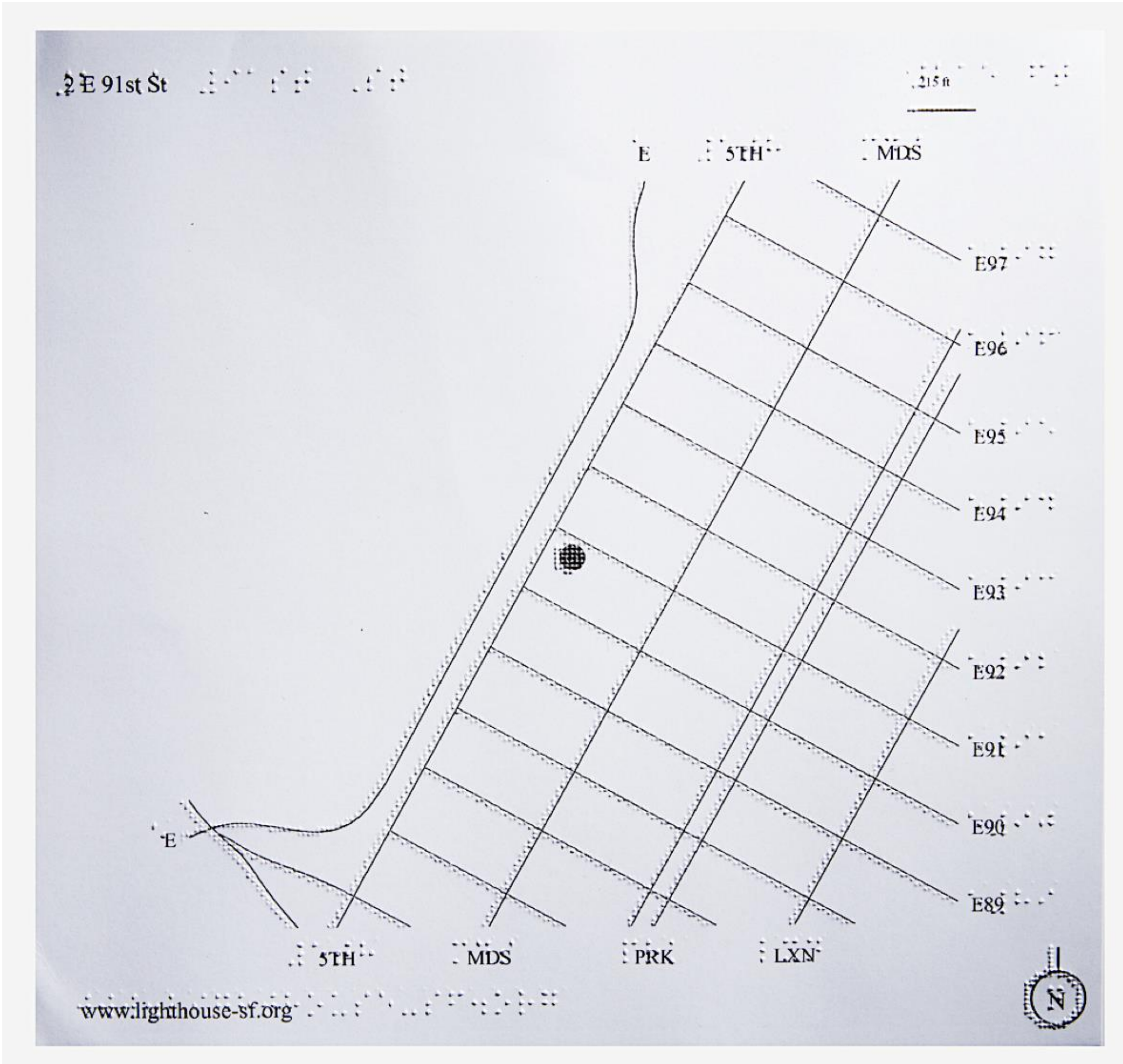

Figure 12: Image of an example of a TMAP street map with raised lines, a raised centre point, and braille labels depicting the location of the Cooper Hewitt Museum in New York City (Cooper Hewitt, 2017).

To learn more about the work being done in this field, the director of the Media and Accessible Design Laboratory at LightHouse was personally contacted via email requesting an interview with the TMAP design team. An open-ended interview method was used to discover approaches or problems not addressed by the literature and then incorporate the findings into the future of this research, including the design of a cross-sensory map that has tactile map elements.

The interview took place in August 2018 and participants included five members of the OCAD research team and three members of the TMAP design team and lasted just over an hour. TMAP was selected for the interview because they are located at the intersection of map design and accessibility, with a specific focus on tactile maps. It was important to interview members of the production side of maps to complement the research aspect of this study. They have a unique role in this research because they are directly facing the demands to the mapping problem.

The purpose of this meeting was to conduct an open-ended exploratory interview to gather information directly from accessible map makers about their process. Audio and visual recordings were taken at the interview and later transcribed. Kehret also presented some artifacts from the TMAP lab including some raised line drawings and tactile map prototypes. The result is qualitative data in the form of direct quotes that were transcribed verbatim, providing an expert account of best practices for providing tactile maps to blind and low-vision map readers.

The interview was open-ended in nature, and led by the participants. Some key questions that came up during the interview were as follows:

- How can we reduce the number of map key (legend) elements?
- Does TMAP use metaphorical representations on the map (non-linguistic indicators) for particular areas on the map?

- Have you conducted studies to find the most effective representations for your maps?
- Who requests TMAPs?
- Have you heard back from TMAP users to receive feedback on these maps?
- Do people use other types of map information in conjunction with TMAP, like audio or other?
- What do people generally use TMAP for?
- Are there certain rules that you follow of what to include in the map?
- Do you have a go-to person who tests out the maps?
- Once you receive feedback have you ever made changes to these maps?
- How do people request TMAPs?
- Do you have a goal in mind of where this might be going? What is the use case of TMAP?

This line of questioning is helpful for giving clues about many different aspects of accessible map design, from the elements to be included, to understanding the nature in which customers will request and obtain the maps.

The following is a summary and analysis of the interview including direct quotes from the TMAP design team. This includes answers to the questions listed above as well as other anecdotes deemed particularly insightful. The extensive transcription can be found in Appendix A of this paper.

5.1 Interview data and analysis

On the automation process

> *"It usually boils down to roads, paths, the most accessible path of travel, usually the main building entrance, not all the building entrances, sometimes bus stops." - Interviewee 1*

> *”We can crank out those TMAPS in just about 3 or 4 minutes and the idea that, me, who is not a braille transcriber who is not a designer, can hand you a well formatted, braille labelled, embossed tactile map is pretty astounding.” - Interviewee 1*

Automation is part of the TMAP acronym and the speed in which a TMAP can be generated is a great sign that these maps could be disseminated broadly. TMAP’s laboratory director began this interview by first distinguishing the difference between all tactile maps and TMAPs. For instance, TMAPs are strictly street maps because it is challenging to automate maps that have more detail.

The map must be simplified. The designer is seeking a balance between having enough information, and not having too much clutter. TMAPs solution is raised lines and braille maps that strictly represent street maps in a designated locale. Since this process is simplified to the distinct purpose of representing street maps, the process could then be automated, which was a goal for TMAPs. That means that the TMAPs design team can quickly produce maps quickly and for more people.

How can we reduce the number of map legend elements?

> *"We try to minimize the number of line types and area types, but some of our maps are pretty complicated so we do have a lot of things in the key and a lot of people struggle with that" - Interviewee 2*

When it comes to tactile maps reducing the number of map legend items is important because people can only hold so much in their memory (tactile memory, in this case) at one time. The solution that TMAP offers is to reduce the number of line and area types.

Does TMAP use metaphorical representations on the map (non-linguistic indicators) for particular areas on the map?

> *"We used a wavy texture for water for a very long time but someone asked why is this wavy, water is flat? So were using these visual standards that do have representational metaphor viewpoints, but it doesn't necessarily make sense. We have to be careful as sighted visual designers about what our expectations for people's understandings of things that we think are really common place, but we have been bombarded with visual imagery our whole lives. It's also a controversial thing though if we're talking about braille use. We're relying heavily on braille use to understand the keys and the names of the streets, and as you guys know, braille literacy is not all that high but it is a useful way to convey information." - Interviewee 3*

This quote highlights two important findings. Firstly, visual metaphors do not always translate for non-visual, and this is a bias that all visual designers carry. The quote shows the importance of including blind audiences in the design process to get a point of view that the designer does not have. This point also foreshadows what will follow in the chapter about the co-design session where we bring in stakeholders who are not trained designers into the design process.

Secondly, we are reminded that braille literacy is relatively low. This is a problem that is beyond the scope of this project but important to point out. In response, TMAP includes braille, but also plenty of non-linguistic representations too. This suggests that a future non-visual map should use non-linguistic tactile cues to represent features on the map area, and that braille text (or perhaps audio cues) can be used to give further accompanying information.

Have you conducted studies to find the most effective representations for your maps?

TMAP operates outside of academia, and no *formal* studies have been done to test the effectiveness of TMAP.

> *"Other than in house anecdotally with people that we work with and people that we show stuff to but no, no formal studies." - Interviewee 1*

In order to make more people aware of this resource, a study on the effectiveness of TMAPs would be useful. This highlights the need for co-designing between industry, academia, and end users in the design of accessible maps.

Who asks for TMAPs?

> *"We typically hear from universities who would like to create wayfinding maps for students to get around the campuses. Museums is another one. We have seen a lot more of an uptick in museums wanting to make their museums more accessible so they want floorplans of the interiors. What's driving it? I don't always know. We have seen an uptick in interest in providing people with tactile braille maps in recent years. Maybe part of that is the more that we have done and as our portfolio grows and experience, through word of mouth people start hearing about us. In the time we have been doing it I think there has been more of an awareness growing around inclusive design, it seems that there are more designers who are speaking that language, and more people who contact us who are speaking that language." - Interviewee 1*

The demand for tactile maps is growing and TMAP is receiving requests from institutions and campuses who would like to provide a better wayfinding experience for their community. Since TMAP began in 2018 they have already noticed more people who are wanting to use these maps and learn about them.

Have you heard back from TMAP users?

> *"We don't always hear back. Typically in most schools they don't have many blind students, maybe 1 or 2 in any given school year, although schools do keep coming back to us to order more maps or re-up and get more copies, or map more areas of the school, so that would suggest that the maps are useful to someone." - Interviewee 1*

When it comes to knowing the effectiveness of maps they have not conducted formal studies, as previously mentioned. However, since TMAP receives repeat requests from particular institutions, it is believed that TMAPs are helping people navigate along their routes.

Clutter is the enemy of tactile maps

> *"Usually people are expecting way too much from it. They're used to the world of visual maps where there's many many layers that the eye can quickly sort through based on colour or appearance so we have to guide the conversation to something that is more practical. We learned it quickly early on the guiding principle is that clutter is the enemy of tactile maps. That is one of the beauties of TMAP is there is very little to clutter it up. Other than the zoom resolution if it's a dense urban area so if there are too many streets to represent cleanly, but it's an interesting conundrum. Everyone sees the potential in it, and is thrilled they can get a map so quickly that they want more information, they want their bus stops,*

> *they want their transit routes, but if you lump all that stuff into the map it would then be less useful." - Interviewee 1*

The similarity between visual maps and tactile maps (and audio maps), is that clutter is the enemy of any map. The difference is that a tactile map cannot be designed with the exact same expectations that a visual map is conceived from so clutter has a different meaning in tactile maps. This is an important element for non-visual map design. This quote highlights a conventional difference between visual and tactile map design and underscores the difference between what a map reader can understand visually versus tactually. Designing for that difference is key. In general, the customers are becoming more aware of this as they work with TMAP to produce maps for their communities. As Interviewee 1 points out, since TMAP is strictly for representing street maps, there are fewer map key elements included, and thus these maps are less cluttered than other tactile graphics might be. What this suggests is that they need layers of information in physically separate components to avoid clutter but to get more contextual information for the given area. In a later chapter we will discuss how removable pieces could help add more elements of information to tactile maps that would not be possible in a 2D, single layer map sheet.

Do people use other types of map information in conjunction with TMAP?

> *"TMAP is not the be all end all. Anyone who is going to really benefit from it already has to have pretty confident mobility skills, orientation skills in which case*

they're already going to have the tools they need to deal with things effectively like street crossings and sense of direction and all that." - Interviewee 1

The key takeaway from this quote is TMAP is a tool in a toolkit. TMAPs are useful, but people still need more information. Interviewee 2 stated that aids that complement the use of a TMAP generally include wayfinding apps and GPS audio information in conjunction with a TMAP. This finding suggests benefits of using maps that give information in multiple modalities.

What do people generally use TMAP for?

"It gives one the big picture, so rather than just simply learning a route which is either narrated to you or you're following turn by turn directions you get the lay of the land, you can see how that actually fits into the grand scheme. I guess you could call it location literacy. You get the big picture the sense of where you are and fit in with all of that." - interviewee 1

"I have had people comment things like 'oh I didn't know that road curved!' or 'I didn't realize this was so close to that'". - Interviewee 2

The goal for TMAP is to provide what Interviewee 1 refers to as "location literacy". This means that the reader is able to comprehend a greater context and where they fit in a space, rather than taking turn by turn directions that fail to provide a sense of context. Characteristics such as the position of the centre point and raised lines are extremely important for providing this locational literacy. These cues are providing information through tactile feedback that allows the user to continuously be *referencing* the relative *distances* from one street to the next *in relation to* the centre point and the surrounding streets. The ability to touch two places on the map at once and feel the distances provides a new level of spatial awareness that is different from step by step spoken directions.

Are there certain rules that you follow of what to include in the map?

> *"We talked about this with map makers and they said, "these are all the things that we grapple with when we're creating visual maps, simplifying and deciding do we need to include this in there". We go back and forth to see what is useful and what is clutter." - Interviewee 1*

There are some specific rules that TMAP automation follows and are comparable to the rules for designing visual maps. Important TMAP map elements include title, point for central location, scale, and north arrow. Raised lines for are used to represent streets and areas, and raised dots are used for representing locations. Similar to visual map layouts, even the location of where items are placed on the TMAP is deemed important information. For example, all TMAPs are oriented with North being the top of the page and the title (which is the actual address of the requested map epicentre) is placed on the upper left-hand side. It comes down to the professional making design decisions through and trial and error.

Do you have a go to person who tests out the maps?

> *"Yes, we do, and he's so good at it that he's practically useless because he understands, he's read this stuff so much and he's familiar with our stuff. He's also aware of his limitation in that regard. We will often times just take it around the shop to other people who are not part of our day to day operation to weigh in on this. Literacy is huge thing. A person who is literate in these kinds of maps will get more out of them and understand them better because they will know what to look for first, second, and third whereas someone who is not used to them will be all over the place." - Interviewee 1*

There is a learning curve when it comes to reading TMAPs. Similarly, there is a learning curve when it comes to reading visual maps. The key difference is the volume of information that sighted children are exposed to starting from a young age, compared to learning to read a TMAP later in life. To help with creating legible maps there are some rules for layout. The layout and formatting of a TMAP follows similar rules to graphically designed information visualizations (for instance, in both types of maps it is important to avoid clutter and label collision). For instance, with TMAPs if there is a collision problem with braille labels, that is to say, two labels are too close together, then the decision is made to not label every street. Avoiding clutter and making decisions about which labels are most important helps with the legibility of a TMAP.

Responding to user feedback

> *"Every single project presents its own new design challenge. We continually get*

feedback, everything is kind of in an iterative state, some things have become more standardized. The TMAP on the table has the north arrow at the bottom. Some people gave feedback saying the north arrow should be in the north, so we moved it. We understand that north arrows don't always need to be in the quadrant of the map that it's pointing to and referring to, but it just made more sense to a lot of people and it provides that information at the top meaning it's important and it's the first thing you want to look at so we did change that." - Interviewee 1

The TMAP design team are constantly iterating on their designs and listening to customer feedback. An example of user feedback was with regards to the location of the north arrow. The user requested to always have the north arrow in the upper area of the map because that is how they understood where north is. TMAP agreed and made the change. To have the north arrow in the top area of the map also symbolizes the importance of direction. Important information such as title and north arrow are at the top of the page meaning they are important elements.

How do people request TMAPs?

"Right now they are available at Adaptations, the LightHouse store. They're developing their own webstore and will sell it through that. I like the idea of having a web portal. People are interested in printing their own map. We haven't had the bandwidth or resources to design a TMAP that is going to compatible across the range of embossers that are out there, or the best files for 3D printing,

and we certainly don't have the ability to do the tech support around all of that when people call us and say it's not working." - Interviewee 1

"It's not like sending it to like an HP versus a Brother printer, it's a whole different set of symbols." - Interviewee 2

"We don't want to be creating bad tactile maps and putting people off of tactile maps. We're just making sure that what we are putting out is good and usable." - Interviewee 3

When it comes to getting TMAPs into user's hands, this is still an area the design team is working on. At the time of this interview they were currently in a soft launch state, figuring out ways to make these maps widely available through different channels and for many different printers. This is a unique challenge for tactile maps as opposed to visual maps because it really depends on the material being used, where as a web based map that can be accessed on all kinds of technology devices, and printed out on various printers. Their current focus is to develop a great product before pushing it out widely. Since tactile street maps is relatively new they do not want to provide poor user experience.

Do you have a goal in mind of where this might be going? What is the use case of TMAP?

"Yes, the goal is to get more of these maps in people's hands, and we also see it as an opportunity to increase awareness of tactile literacy, maybe even help

people become more tactually literate, because they're so quick and easy for us to produce it makes it easy for people to get tactile graphics in their hands, and maps in particular, because one of the big barriers to getting tactile graphics is the amount of time and expense it takes, like the hoops you have to jump through. This changes that, because it only takes my shop 5 or 10 minutes to fill an order. All of a sudden we can just reach individuals, we don't have to only deal only with institutions." - Interviewee 1

"It helps explain that a picture is worth a thousand words because you can show why it makes more sense to cross at one intersection rather than another. We want to make these useful for campuses, because that's probably one of the biggest audiences out there is students, and if we can auto generate useful maps that don't take dozens of hours to design and create we would like to do that." - Interviewee 1

The overarching goal for the TMAP design team is to get these maps to the people who need them, and spread awareness about tactile literacy.

5.2 Recommendations for audio and tactile variables

Position is represented through raised tactile features, with the centre point of the map represented by a raised dot in the middle of the map sheet. The variable *position* is important as it defines the locale the map and allows the reader to differentiate between one street and the next as they relate to the centre point.

Another key tactile variable manifested in TMAP is *size*. Size refers to changes in thickness, height, or representation such variations in line types. Thickening the size of a line in order to signify that it is a major route is one way that size can be used.

Texture is another variable. Similar to the way that *hue* is used to classify different categories on visual maps, texture can be used in TMAPs, or other tactile representations, to classify categories of land use/land cover. For example, different textures could be used to define the presence or absence of a body of water on a map.

Since the focus of these maps was to show a neighbourhood street network, there was hardly any use of different shape symbols that we saw. There was a raised circle for the position as we have discussed, and lines to represent streets, but we did not observe shapes that are used in the complex ways that the visual variables will employ them. It is likely that too many shape representations would add to cluttering the map, and that is what they are trying to avoid for their purposes.

In order to provide tactile feedback where a map would typically use visual text (title, legend, scale, and labels), TMAP applies braille to these features. Although TMAP does not contain audio labels, they recommended to audio through a mobile device's GPS wayfinding application to enhance the TMAP user experience. For instance, the user could use the TMAP at home to get a lay of the land, and then a GPS receiver can read directions and locations out from your mobile device while on the journey as well.

These tactile correspondences are described in Table 6 below. Previous examples of 2D and 3D tactile map correspondences are also present in order to show the different ways that these variables manifest themselves depending on their purpose or the designer's intent for the map. For example, the 2D braille map of the world is in a similar category in terms of how much detail is being represented compared to the TMAP example, whereas the map of EHCR has more detail. This suggests that 3D representations are capable of showing more information than 2D representations.

	Tactile Correspondences	**Tactile Correspondences**	**Tactile Correspondences**
Visual Variables	**Recall: 2D braille map of the world**	**Recall: 3D tactile map of EHCR**	**TMAP**
Position (changes in x, y location)	Location of the braille labels represent the relative center of continents	Location of the tactile symbols on the tactile map represent the locations of the features on the map in relation to their real-world positions.	The variable position is represented through the central raised dot and signifies the epicentre that the streets radiate out from.
Size (change in length, area, or representation)	The braille labels are all the same size.	The variations in line sizes represent differences between the	The size variable is employed through changes in line types. A

		main road, paths, and the stream.	thicker line can be used to signify a major street. Braille labels are all the same size.
Shape (infinite number of shapes)	The North is represented by a vertical line topped with a point, depicting an arrow pointing upwards.	The shape of the symbol for stairs uses tactile elevations to differentiate from the shape of the symbol for bridge.	The symbol for the centre location is always depicted by a raised circle. Streets are depicted by lines.
Value (changes from light to dark)	The colour value of the tactile area representing water is dark and the value of the area representing land is white.	A variable mapping for value could be comparable to the size and texture through value ranges in those tactile cues (ex: value changes from very rough to very smooth).	Raised tactile features such as the centre point, and lines representing roads are black, over a white background. The braille labels are also white.
Hue (changes in colour)	Since this map is for blind and low-vision readers it does not use the hue variable to a great extent other than to represent water and borderlines as black and land as white.	Visual variable for hue is depicted on this map through representations of blue symbolizing water, grey symbolizing roads, and beige symbolizing paths. These classes of data	The tactile correlate for hue appears to be texture. Different texture of raised or flat surfaces represent categories like differences in land cover.

		are also represented through different tactile textures.	
Orientation (changes in alignment)	The orientation of the map elements does not vary from the normal orientation.	Tactile map elements do not vary from the normal orientation.	Tactile map elements do not tend to vary from the normal orientation.
Texture (variation in pattern)	The tactile correspondence for value in this case is texture. The area representing bodies of water is a bumpy texture and the land is a smooth texture. It is also observed that the labels for bodies of water are given a smooth white background in order to differentiate the labels from the raised dot texture representing water.	Each symbol uses a different tactile texture. Texture can be used to differentiate between line symbols, for example, the main road, path, and river are all forms of lines, but each are built from a different material to show variations through touch (ex: the main road is metal and the path is wood).	Texture is sometimes used to show the presence or absence of a body of water on a map and is helpful for representing changes in land type.
Written labels	Braille abbreviations are used for labelling	Braille labels and text in English are both used	Braille is used to label title, legend, scale, and

	locations on the map, and braille is also used for the map title.	for labelling features of the map.	labels for geographic features. The use of a mobile device's GPS wayfinding application was recommended in conjunction with TMAP.

Table 6: Comparison between variable correspondences for 2D tactile representations present in the tactile map of the world, 3D tactile representations present in the EHCR tactile map, and 2D tactile representations recommended by TMAP.

This interview provided an in depth look into what is currently being done in industry, complementing the highly research-focused side of this project. This interview helped to inform how to incorporate 2D tactile representations into geographic maps as summarized in Table 6 above. As expected from a design that is focused on tactile representations, few audio recommendations were made. However, the recommendation of using linguistic audio through screen reader technology does suggest that a multimodal map using audio and tactile elements is recommended.

Now that the recommendations from industry professionals have been taken into account, this research looks how educators have approached map accessibility for blind and low vision students in the classroom.

Chapter 6: Surveying geography educators

Educators were surveyed to explore the level of interest and experience making accessible maps for delivering geography curriculum. Geography is a highly visual study, with maps, mainly visual maps, as a central tool for teaching and learning. The purpose of this survey was to connect with educators who experience first-hand what works in the classroom, investigate what educators need in order to provide materials to their blind and low-vision students, and provide an opportunity to share ideas for making maps accessible to more students. The educators were asked questions with regards to teaching geography to students who have visual impairments. Visual impairment is defined as having vision loss to a degree that cannot be aided by corrective lenses, and includes a range of individuals from low-vision to blind (CDC, 2017). Since geography is core curriculum for kindergarten to grade twelve in Canada, educators are constantly using maps in lessons, and observing students using them. This exposes teachers to observing what works well, and what could be done to make maps better for students. Perhaps a teacher has had to come up with their own solution for making curriculum accessible for a blind or low-vision student in their classroom. Surveying teachers was a way to explore this area of the research.

The survey took place online through the ArcGIS survey system Survey123. This method was chosen because the educators selected for this survey are familiar with responding to using surveys on this platform. The survey was sent to the email lists generated by Esri Canada’s K-12 and Higher Education departments. Permission to access to these email lists was obtained during an internship at Esri Canada. An email was sent to these lists inviting educators to participate in the survey. The email invitation can be found in Appendix B. The higher education list contains 507 recipients and the K-12 list contains 850 recipients from across Canada. The survey received a total of 22 responses from these educators via the Survey123 online submission portal. The survey was open for responses from early September to the end of October 2018.

6.1 Survey questions

The survey consisted of eight set questions. The style of questions included pin your location on a map, single choice, and short answer. The survey questions were as follows:

1. Where is your school located?
2. How long have you been teaching?
3. Have you ever taught geography to a student in your class who was visually impaired (including students who are low-vision to students who are fully blind)?
4. Please list common teaching materials/tools you use in the classroom related to geography.
5. How could you imagine adapting teaching materials you listed above to be more accessible to a student with visual impairment in your classroom?
6. How could you imagine using a cross-sensory globe or map to help teach students geography? Would you use it if you had access to one?
7. Have you ever come up with your own strategy for altering a lesson to make it more accessible? Please describe briefly.

8. How comfortable are you using new technology and related emerging learning techniques?

Below is a summary of the data collected in the survey.

6.2 Survey data and Analysis

Q1: Where is your school located?

Of the 22 respondents, 19 indicated their location from the following regions:

Saskatchewan (2 responses):

- Prince Albert
- Regina

Manitoba (1 response):

- Winnipeg

Ontario (15 responses):

- Downtown Toronto
- Guelph
- Kitchener
- Kingston
- Markham
- Mississauga

- Oshawa
- Ottawa
- St. Catharines

Nova Scotia (1 response)

- Louisdale

Q2: How long have you been teaching?

Of the 22 responses, 21 educators indicated they have been teaching for 10 years or over, and one educator indicated they had been teaching between 6-10 years.

Q3: Have you ever taught geography to a student in your class who was visually impaired (including students who are low-vision to students who are fully blind)?

Of the 22 responses, 11 educators indicated they had taught geography to a student in their class who was visually impaired, 10 educators indicated they had not taught geography to a student who was visually impaired, and one educator indicated they were not sure if they had or had not taught a student with visual impairment.

Q4: Please list common teaching materials/tools you use in the classroom related to geography.

The word cloud below (Figure 13) was auto-generated from the Survey123 survey tool. A word cloud is an image of words clustered together relating to a particular subject or theme. The words that appeared more frequently in the results of Question 4 are represented in a larger font size depicting order of importance. The words are deemed important because of their frequency in the responses. As Figure 13 shows, maps are the most commonly used tool used to teach geography.

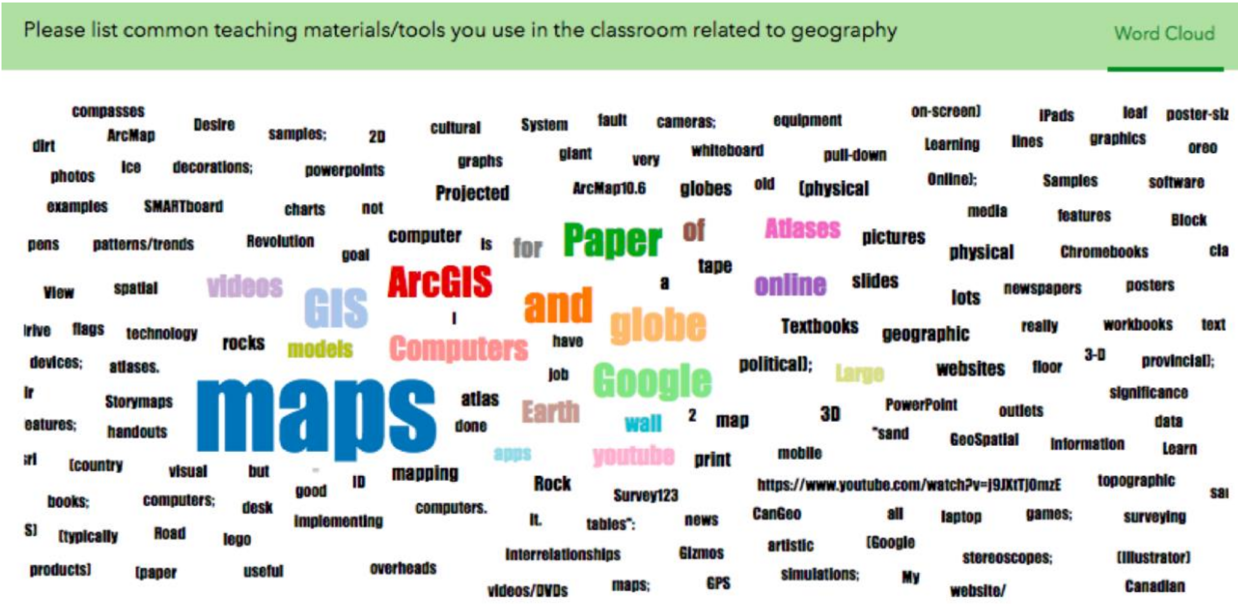

Figure 13: Word cloud (image consisting of a cluster of words) generated from Survey123 resulting from Q4 showing common tools used to teach geography (maps, GIS, globe etc.).

The 22 responses were coded and three main categories were observed. These categories are visual print materials, visual digital materials, and tactile interactive/3D materials. Note that the digital materials used may also contain a digital audio component, but this was not explicitly stated in the responses so the term audio was left out of that category. The educators tend to use a variety of tools from these three main categories and in total 18 educators teach with visual print materials, 21 educators teach with visual digital materials, and eight educators teach with tactile, interactive/3D materials. Print materials tend to include paper maps, digital materials tend to include digital maps, and interactive materials tend to include rock samples. 19 out of the 22 educators teach using GIS technology. This number is probably high because the survey was sent to a list compiled of educators who subscribe to a GIS software company's mailing list. The coded table of responses for Question 4 showing the variety of teaching tools used by geography educators in this study is found in Appendix C.

Q5: How could you imagine adapting teaching materials you listed above to be more accessible to a student with visual impairment in your classroom?

18 out of the 22 respondents replied with ideas for adapting their teaching materials. These responses were then coded and three main categories emerged. The categories are visual tools, 3D/tactile tools, and audio tools.

Nine of the educators gave ideas for visual adaptations and of those, seven educators suggested magnification tools and three educators suggested using colours that are optimized for colour blindness. One of these nine educators suggested that taking video recordings of their laboratory demonstrations would be helpful so students could refer back to them, as opposed to only using handout sheets.

11 educators suggested adapting teaching materials to have a tactile or 3D component, and six of those educators suggested 3D tactile maps. Three educators suggested incorporating braille into their teaching tools. One educator suggested tactile descriptive video.

Finally, seven educators suggested incorporating an audio component to adapt their teaching tools for accessibility. Listening to notes in some way, whether through recordings, or screen readers was a suggestion that appeared five times. One educator suggested that technology should include described audio to provide details that might be missed in a screen reader. Lastly, one educator suggested incorporating interactive maps that use sound to delineate map items such as boundary lines.

Four of the educators did not provide any ideas for how to make their course materials more accessible for blind and low vision students and their responses are categorized as “not sure/ambiguous”. Educator 11 said, *“That is a great question. I am sorry, I don't know”* and

Educator 4 said:

> *“This is something I've kind of wondered about myself. Our course outlines are supposed to be AODA compliant, and mine are. My slides are not yet compliant, although I guess they should be! In our curriculum we do cover red-green colour deficiency, from a design standpoint, but that's about it”.*

The coded table of responses for Question 5 describing how educators imagine adapting teaching materials to be more accessible to a student with visual impairment in their classroom is found in Appendix D.

Q6: How could you imagine using a cross-sensory globe or map to help teach students geography? Would you use it if you had access to one?

20 out of the 22 survey participants responded to question 5. Of the 20 responses, 15 educators indicated they would like to use a cross-sensory globe or map to help teach students geography. Below are selected direct quotations showing educators see a benefit to using cross-sensory teaching/learning tools.

> *"I would definitely use it. I think it could benefit all students." - Educator 2*

> *"I have not seen or heard of this before. This would be an excellent tool to help deliver an equitable program." - Educator 11*

> *"I think this would help ALL students." - Educator 12*

Of the 20 responses, six educators detailed specific uses they would have for a cross-sensory globe or map to help teach students geography. Below are selected direct quotations from educators who were enthusiastic about the idea of a cross-sensory teaching/learning tool and gave suggestions of how they would imagine using it.

> *"I saw a map in Dawson City, Yukon, made with vials of materials that convey the smell found at different locations around their town. Very innovative, and certainly would be useful for someone with visual impairment. Sighted students would also*

benefit from a cross-sensory globe, so I would be interested in trying something like this." - Educator 7

"Calculating distance, physical geography, economic exchange of goods and services between regions. Climate." - Educator 3

"Allow students to access all senses when viewing the world, helps to create a picture/image in the mind's-eye, brings global geography into the classroom by providing a tangible object to imagine/discuss very large places/locations." - Educator 9

"It would be great for things like topography. Teaching landform patterns." - Educator 13

Q7: Have you ever come up with your own strategy for altering a lesson to make it more accessible? Please describe briefly.

17 out of the 22 survey participants replied to question 7. Of those 17, 13 educators mentioned they had come up with strategies for altering lessons to make them more accessible at one point or another. Four educators said they had not ever come up with their own strategies.

One educator suggested breaking tasks up into manageable steps. Two educators emphasised the importance of communicating with students and their parents to find out what works best for them. Two educators mentioned utilizing the Individualized Education Program (IEP) to make adaptations to their lessons. Five educators said they have incorporated a tactile element to their lessons. Educator 7 suggested that tactile mapping helped a visually impaired student study topography, saying:

> *"We used a 3D-relief map once with a visiting student who was visually impaired, and it helped them understand the extent of mountain ranges on continents." - Educator 7*

One educator indicated they incorporate guest speakers, and field trips, and another educator said they have incorporated a food element.

Educator 5 said they had adapted data from visual to oral and tactile:

> "*An alternate technique was used to present the data (verbal descriptions and physical models were used) and the work evaluated orally". - Educator 5*

Another strategy submitted by a respondent was to convert activities into braille and change the way questions are asked:

> *"Many questions were altered from using a map to decode the answer to using relative position. E.g. Instead of giving a map and asking what is at this location*

the question would be which Great Lake is between Lake Ontario and Lake Huron?" - Educator 8

Q8: How comfortable are you using new technology and related emerging learning techniques?

20 of the 22 survey participants responded to the question asking how comfortable they would be using new and emerging technology in the classroom. The educators in this survey ranged from very comfortable with new technology, to not very comfortable. There were several responses that fall somewhere in the middle.

Of those 20 respondents 10 educators indicated they were “very” comfortable with using new technology.

> *“Very comfortable. I create resources for teachers to teach with technology and have led workshops for teachers.” - Educator 13*

> *“Very comfortable. Our school uses one-to-one laptop computers, and all gr. 9 students do their major projects using ArcGIS Online”. - Educator 7*

Three educators indicated they were “comfortable” with using new technology and six educators indicated they were “moderately”, “fairly”, or “pretty” comfortable with using new technology.

> *"I am open and comfortable, it is often an issue of not having the necessary time to master the use of the technology." - Educator 3*

Lastly, one educator indicated they were not comfortable with integrating new technology into their lessons.

> *"Not very. Takes me a long time to learn it myself and then figure out how to use it in lessons." - Educator 22*

6.3 Recommendations for audio and tactile variables

The survey responses show that educators are excited at what cross-sensory teaching tools can provide for all students, and see a benefit to students who are sighted and visually impaired. With the increase of blind students entering mainstream schools, there is a need for cross-sensory learning tools. Integrating cross-sensory learning tools would allow students with visual impairments to receive a richer level of education in a visually dominant field of study such as geography. This would also provide a richer experience to sighted students and educators as well because cross-sensory tools have the power to reveal new levels of understanding for all learners. When it comes to tactile cues the educators' responses revealed that raised 2D and 3D point locations can be used to represent a geographic position for a given location. For example the location of a piece of Lego could be placed strategically to represent a specified point in a given map area. This suggests that position is a key variable in the tactile modality.

It was suggested that variations in the height of raised lines or points would be useful to show ordered or hierarchical differences. For example, the thickness of a political boundary between neighbouring countries could be represented by a thin line, and a coastline boundary (representing a major change in topography) could be represented by a thicker line. This type of specification suggests that *size* is an important variable. Changes in line *type*, such as a raised *solid* line to represent the equator compared to a raised *broken* line to represent a political border is another tactic for representing different map line features. This change in line type is referred to as a change in representation and is also captured in the size variable. This could also be considered under the texture variable. Here, there is a concern that these are assumptions that visual/sighted educators might make about what might be effective tactilely. For instance, difference in raised lines might *look* accessible to someone with vision, but it is possible that these differences in line size might be too subtle to be effective tactile variables. This foreshadows the importance of the need for 3D tactile representations to make map representations even more clearly discernible in the tactile modality.

Texture is another variable that was extracted from this dataset. Changes in textures of an area can be useful for representing differences in land areas. For instance, the use of sand could be used to represent a desert region, and tin foil, which can be cold to touch, could be used to represent a body of water. Another use of texture is to show changes in line types. For example, Wikki Sticks, which are thin strings of material coated in a waxy texture could be used to discern a specific boundary line type such as a major highway.

Shape is a key tactile variable. Areas such as countries and lakes would be best represented through 2D or 3D models that are shaped as they appear on Earth. These differences in shape can be used to compare one area to another.

Finally, language in the form of braille labels was suggested many times to be useful in addition to these other tactile cues for labelling all types of geographic features. Given that text is deemed necessary so often, language is a key variable for discerning one place from another.

In terms of audio cues language can also be considered an audio variable in the form of spoken word. Most of the surveyed educators are using GIS software in their lessons. It is not clear how much information a student would obtain with a screen reader using GIS technology. So, the use of described audio was suggested, so that the details that are typically highly visualised could be accompanied by very detailed descriptions. These could be pre-recorded audio, or written descriptions provided by the teacher that the student could listen to with a screen reader. Along with that, tactile models could be used as a reference, so the student would hear the description, and then touch a 3D model that represents what the GIS is showing. Strategies for this type of lesson plan need to be developed and tested. Features such as countries and lakes would be best represented through 2D or 3D models that are iconically representing the features they represent on Earth. These differences in shape can be used to compare one area to another. A similar tactic could be used to represent map symbols that show phenomenon such as population size or other statistical information where changes in tactile size correlate to information such as the quantity of something. As Krygier suggested, an infinite number of sounds could be used to represent shapes, and changes in other audio variables could be used to order this data.

Another audio variable that appeared from this dataset is non-linguistic sounds associated geographic features. One suggestion was to have a general sound cue when moving over a boundary line, or when a reader locates a point. Where these sounds are located on the map provides information. Therefore, position of audio label is a suggested variable here where on a map, this could act as a virtual position of a map feature listened to through headphones. This suggestion is reminiscent of the sonification technique referred to by Hermann et al. 2011. Recall their study that proposed sonification could act similar to a scroll bar to help a user orient around the pages of a document.

As it pertains to students who have partial vision, some educators also made some suggestions for altering the visual variables for low-vision users such as magnifying screens and text, or choosing optimized colours for low vision.

These audio and tactile correspondences gathered from the surveys are summarized and provided in Table 7 below.

	Audio correspondences	Tactile correspondences	Audio correspondences
Visual Variables	**Recall: Krygier's audio variables**	**Survey results - tactile**	**Survey results - audio**
Position (changes in x, y location)	The *location* of a sound in 2D or 3D space could be used to represent a point's position on a map.	2D and 3D point locations can be used to represent a geographic position for a given location (ex: Lego placed in a map area for point location).	In combination with tactile cues, audio feedback could be used to represent locations of symbols on the map. One suggestion was to have a general sound cue when moving over a boundary line.
Size (change in length, area, or representation)	Changes in loudness, pitch, duration, and the attack/decay could all be used to represent size.	Variations in the height of 2D or 3D tactile cues such as the thickness of boundary lines. Changes in line type to denote different categories of lines.	See Krygier's recommendations.
Shape (infinite number of shapes)	As there is an infinite number of shapes, similarly there is an infinite number of sounds	Areas such as countries and lakes would be best represented through 2D or 3D models that are	See Krygier's recommendations.

	that can be used for representing map symbols.	iconically representing the features they represent on Earth.	
Value (changes from light to dark)	Loudness, pitch, duration, and order are examples of audio variables that seem to correlate with changes in value because they can be used to represent ordinal ranges.	Needs development.	See Krygier's recommendations.
Hue (changes in colour)	Timbre could be considered as a correlate to hue for data that is characterized nominally.	Needs development.	See Krygier's recommendations.
Orientation (changes in alignment)	The location of sound in 3D space could be considered an audio correlate for orientation.	Needs development.	See Krygier's recommendations.
Texture (variation in pattern)	The audio correlate of texture could be described as timbre. Similar to hue, nominal data could be expressed through distinct changes in timbre.	Changes in textured areas can represent differences in land areas (ex: sand could be used to represent a desert region).	See Krygier's recommendations.

		Another use of texture is to show changes in line types. For example, Wikki Sticks, which are thin strings of material coated in a waxy texture could be used to discern a specific boundary line type such as a major highway.	
Written labels	The audio correlate to a written label would be spoken word, which is not part of Krygier's variables.	Braille labelling all types of geographic features such as place names.	Described audio and screen readers in combination with tactile representations to provide clarity about attribute information.

Table 7: Examples of tactile and audio map correspondences from educator survey.

This survey provided an in depth look into what is currently being done in the classroom and what teachers might like to see or try in order to make geography a more accessible subject to teach and learn. Classrooms are an exciting place to try new tactics and the use of 3D hands on tools to amplify what GIS technology can do appears to be a fruitful place to start.

What matters is what is afforded by these variables. For example, what is afforded by visual variables would be information about physical structures of the Earth, such as continent shapes, land elevations, and political boundaries (for example). Also, information about categories that culture has assigned to those structures would be available in a visual map (for example). These include labels that denote cities, countries, and continents. This needs to be taken into account when talking about the mapping between visual and aural variables. For example, there might not be a clear mapping between a visual variable such as the position of a mark on a printed surface and an audio variable. However, there could be an explicit mapping between a specific concrete structure of the Earth, such as an elevation (or location of an item) and an audio variable. In other words, to attempt a bridge between visual and audio variables, one could use *knowledge* of the structure that the map designer is trying to represent, such as a concrete structure of the earth or a category assigned to it when designing an audio or tactile variable to represent it.

In the following section this study attempted to apply and test some of the notions described in the preceding sections and try prototyping a usable map interface through the practice of co-design with stakeholders.

Chapter 7: Non-visual mapping co-design session

In the concatenated study, we have moved from the exploratory phase of the research and built up some ideas through methods such as environmental scan, interviews and surveys. The following chapters deal with co-designing an interface that might reflect some of the research findings above.

7.1 Introduction to the co-design

Co-Design, or Participatory Design, is a technique that has been used for over three decades that invites non-designers (potential users) to participate in design activities during the design process for a given project. This technique brings a unique element to the design process as it brings together a team of people with multiple backgrounds and experiences to help shape the outcome of the design (Sanders, 2010). Stakeholders were identified and invited to participate in the design process. Pre-co-design interviews were arranged to help identify the main problem to focus on in the co-design activities, and to familiarize participants with map interfaces. The co-design session consisted of a series of activities led by the research team. The participants looked at graphic, tactile, and audio maps to inspire them in the activities. The practice of fast-paced, low-fidelity prototyping communicated design ideas quickly. The goal of this co-design session was to gain insights from stakeholders on what the biggest problems they may face in current mapping paradigms which are predominantly visual, and how they envision a solution incorporating sound and touch to create greater access to the information stored in a map or model. Following the co-design, findings were analyzed to incorporate the results into future prototypes for creating accessible maps.

7.2 Participants

In preparation for the co-design session, four adult individuals were invited to participate. The co-design session included four researchers from OCAD U and four stakeholder participants. These participants and researchers are living with different levels of vision abilities and vision loss. This group of participants helped develop requirements for a tool that will positively impact the lives of the potential end users who are living similar experiences. Invited participants were recruited from stakeholder organizations through personal and professional networks, and included two members of the CNIB, a developer at Esri Canada, and a Spatial Analyst from the Manitoba government. These participants were extremely helpful in providing a well-rounded perspective from the creation, dissemination, and use of maps and map technology.

7.3 Pre-session meetings

Since non-visual mapping is a relatively novel research area, most people might not be familiar with the topic. The research team decided all participants and researchers would benefit from educating our participants on auditory map interfaces so they could come into the co-design session with some background knowledge. Thus, prior to the co-creation session we conducted individual semi-structured meetings with our four participants to allow them to explain their current successes and difficulties of how they access maps, and educate them on current forms of audio maps. After they addressed a particular problem they were having, they were then asked to imagine how the presence of sound could be used to help solve the problem. After that, the participants were presented with a few examples of how audio maps are being used in the Audio Games community to get their ideas flowing on what an audio map is comprised of. The Meeting Guide for these interviews is located in Appendix E.

This process allowed for the research team to smoothly transition from an ice breaker activity into the design activities during the co-design session with little need to spend time on background information - this was key since the co-creation session takes place on a tight timeline.

7.4 Designing the co-design activities

We chose to use the famous Napoleon's March infographic by Charles Joseph Minard as the basis for the co-design activity, which involved designing auditory variables for the existing data variables. The infographic is a famous example of a data visualization that displays a map including multiple variables, and their relationships, and is considered to be a highly useful visual tool (see Figure 14). The research team selected this infographic due to its success at portraying the many variables that contributed to the losses suffered by Napoleon's army in the war of 1812. The participants were presented with the datasets associated with the infographic and they attempted to prototype an audio interface to represent this data. The work of Peter Coppin and

Richard C. Windeyer on the sonification of Napoleon’s March was a source of inspiration for focusing the translation activity on this infographic, and resulted in a co-created version of the sonification (Coppin and Windeyer, 2018). The dataset can be viewed in Appendix F.

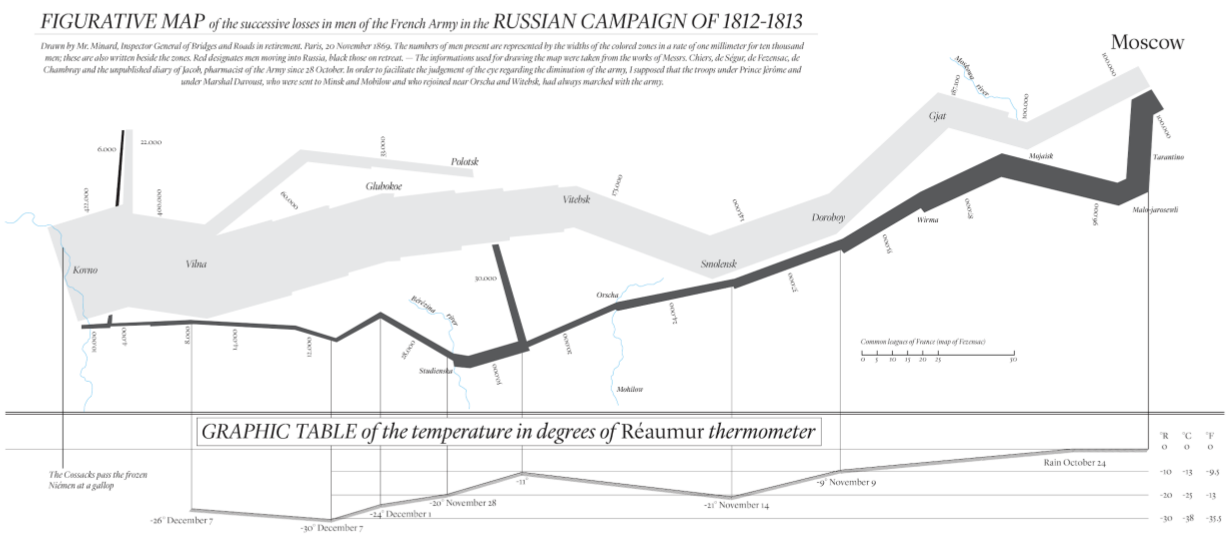

Figure 14: Napoleon’s March Infographic by Charles Joseph Minard retrieved from https://www.edwardtufte.com/tufte/posters.

The research team commissioned raised line drawings containing raised lines and braille to make the data visualization accessible as a control to test the sonification by Windeyer and Coppin. Given that our co-design participants had varying levels of vision, these raised line maps were used as a reference to convey the infographic non-visually in a direct translation. An example of a raised line braille map is shown below (Figure 15). This meant we could provide visual and tactile representations to help guide the design of an audio representation.

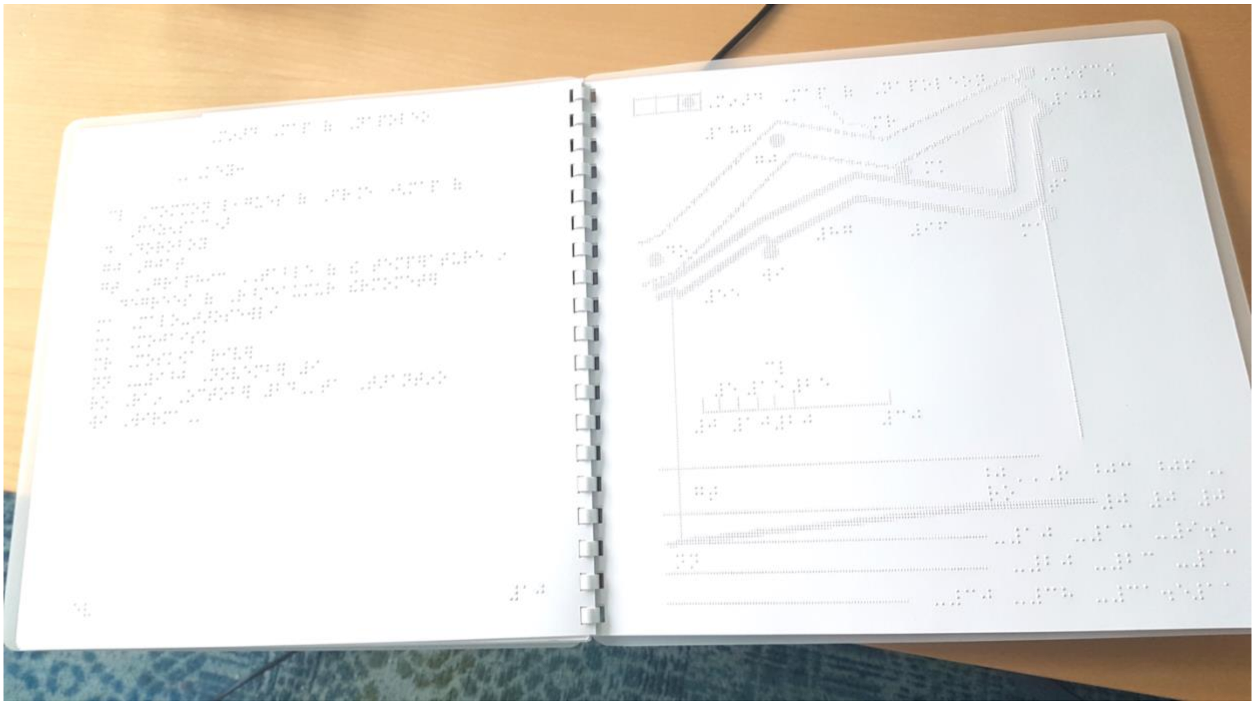

Figure 15: Photograph of raised line braille map depicting the Napoleon's March infographic.

7.5 Co-design activities

The main design activity was to live-prototype an auditory representation of the data. As the participants did this, the research team members were guiding, illustrating, and taking notes. One participant was randomly selected to be the map creator. This participant directed the sound objects (acted out by the other three participants) in relation to their position in the 'map' (the classroom). With the dataset in hand, the map creator directed the sound objects to represent the data. The sound object participants helped the map creator select sounds to represent the data variables and produced sounds with their voices or bodies (by stomping or clapping for example).

Figure 16 below is a photograph from the co-design session showing the participants moving around the physical space, interactively prototyping their design.

Figure 16: Photograph of participants in action co-designing a cross-sensory mapping of the Napoleon’s March infographic depicted in Figures 14 and 15.

Participants moved around in physical space and imagined how the Napoleon’s March map would sound by acting themselves as the map variables. This activity, and the entire co-design framework are explained in the Facilitation Guide found in Appendix G.

7.6 Recommendations for audio and tactile variables

The co-design was originally focused on creating audio variable mappings. This resulted in recommendations for audio variables only. Nevertheless, conclusions of the co-design led to the suggestions that the development of 3D tactile representations should be used in conjunction with audio labels for a well-rounded learning experience. Since braille maps were presented at the co-design for reference, it was suggested that the application of different *hues* could still be used so that those who have some level of vision could potentially learn from them. Suggested mappings for the audio modality were further developed in this study.

The first variable that resulted from this study is non-linguistic sound. Map attributes can be allocated different sound labels to portray their characteristics. The recommendation here is if the labels are non-linguistic audio cues, they should bare ecological resemblance to the object being represented. One example from the co-design was the sound of boots marching to represent army troops.

Another sound variable resulting from this co-design is pitch. Changes in pitch can be used to represent changes in a quantity or value of an attribute. The example from the co-design was the changing of pitch to represent changes in temperature at a given location. Speed is another variable was suggested to show changes in a data type such as the quickness or slowness of a particular sound to articulate changes in quantity or value. The example from the co-design was the speed of the sound of army boots marching, where slower meant lower value, and faster meant higher value.

Position of audio label is another key variable as differences in sound locations can be associated with different locations on a map. Further to that, the variable orientation is also recommended since the position of the sound icons can be mapped in 3D stereo sound to orient the reader within the map. For example, when the troops retreat back from west to east, the orientation of the sound in 3D audio would change and the listener could hear sounds located in a corresponding orientation that is offset from the centre point.

These audio correspondences are described in Table 8 below.

	Tactile correspondences	**Audio correspondences**	**Audio correspondences**
Visual Variables	**Recall: Braille map of the world**	**Recall: Krygier's audio variables**	**Co-design variables**
Position (changes in x, y location)	Location of the braille labels represent the relative center of continents	The *location* of a sound in 2D or 3D space could be used to represent a point's position on a map.	Positions can be mapped in 2D or 3D sound space to represent key locations on the map such as battle locations.
Size (change in length, area, or representation)	The braille labels are all the same size.	Changes in loudness, pitch, duration, and the attack/decay could all be used to represent size.	Changes in pitch can be used to represent changes in a quantity or value in a data type (ex: high pitch for cold

			temperature and low pitch for warm temperature). Quickness or slowness of a particular sound could be used to articulate changes in quantity or value (ex: slower marching sounds mean lower value; faster marching sounds mean higher value). Krygier calls this 'rate of change'.
Shape (infinite number of shapes)	The north is represented by a vertical line topped with a point, depicting an arrow pointing upwards.	As there is an infinite number of shapes, similarly there is an infinite number of sounds that can be used for representing map symbols.	See Krygier's description (ex: sound of boots marching represents army troops).
Value (changes from light to dark)	The colour value of the tactile area representing water is dark and the value of the area representing land is white.	Loudness, pitch, duration, and order are examples of audio variables that seem to correlate with changes in value because they can	Pitch and rate of change (quickness or slowness of a sound) could correlate with quantity or value (ex: fast marching means larger troop size).

		be used to represent ordinal ranges.	
Hue (changes in colour)	Since this map is for blind and low-vision readers it does not use the hue variable to a great extent other than to represent water and borderlines as black and land as white.	Timbre could be considered as a correlate to hue for data that is characterized nominally.	See Krygier's recommendations.
Orientation (changes in alignment)	The orientation of the map elements does not vary from the normal orientation.	The location of sound in 3D space could be considered an audio correlate for orientation.	Orientation is also recommended since the position of the sound icons can be mapped in 3D stereo sound to orient the reader within the map.
Texture (variation in pattern)	The tactile correlate for value in this case is texture. The area representing bodies of water is a bumpy texture and the land is a smooth texture.	The audio correlate of texture could be described as timbre. Similar to hue, nominal data could be expressed through distinct changes in timbre.	See Krygier's recommendations.
Written labels	Standard braille abbreviations are used for labelling locations on	The audio correlate to a written label would be spoken word, which is	See Krygier's recommendations.

	the map, and braille is also used for the map title.	not part of Krygier's variables.	

Table 8: Comparison between variable correspondences for 2D tactile representations present in the tactile map of the world, Krygier's audio variables, and audio correspondences developed in the co-design session.

This co-design session allowed potential end users or potential creators of non-visual maps to talk about the problem together and consider how a useful tool might be represented. Through interactivity, the co-design participants proposed audio variables to represent attributes in the infographic.

This activity was successful in that it moved a group of stakeholders through from problem discovery, to ideation, and then to a potential solution in a short amount of time. In fact, one of the co-designers was not aware of what an infographic was until they came to the co-design session, and by the end of the session they had helped to design a low-fidelity prototype of an accessible version of one. Not only could this activity help to create a solution, but it could perhaps be used as a learning activity in the classroom to create awareness about the problem of map access.

It was observed that tactile maps presented as 2D raised line representations may not be engaging enough or descriptive enough. This lead us to believe that developing 3D tactile representations that are amplified with audio labels would be worth exploring. This next chapter will investigate 3D map representations that incorporate audio labels in the form of an audio-tactile globe.

Chapter 8: Interview with a globe designer and user who is blind

During the non-visual mapping co-design session outlined in the previous section, one of the participants mentioned that they had a personal interest in this problem, and had designed an accessible globe for themselves. This participant, who we will refer to here as Taylor, is an individual from Toronto who has always lived with complete blindness, thus has always had an entirely non-visual experience reading maps and using globes. For blind and low-vision learners like Taylor, the process of learning geography (through querying, exploring, and problem solving, for example) is impeded because of the unequal access to the traditional visually-oriented tools and technologies that are used to represent and understand the Earth.

An interview and demonstration of Taylor's globe at their residence took place in March 2018 and lasted for three hours. The interview was part-led by the researchers (principal advisor and advisee) and part-led by the participant, allowing for an open-ended discourse.

During our interview and the aforementioned co-design session, Taylor described difficulties they encountered due to limitations of standard tactile maps (such as with the braille map of the world seen in Figure 4). Recall limitations of the raised line braille map of the world included lacking detail in terms of number of variables being represented in the map, as well as limitations regarding the ability to compare the relative size of one area with another due to low resolution.

Taylor revealed how, in response to these limitations, they had creatively designed a solution in 2015—referred to here as Taylor’s globe—by retrofitting two independently manufactured products to afford a type of interaction that he did not have access to otherwise (see Figure 17):

1. **Intelliglobe:** The interactive audio-visual Intelliglobe globe consists of a standard visual globe, a wireless Intellipen, and pre-recorded audio labels. The pre-recorded audio labels convey country names and geography facts. These are indexed to particular locations on the visually oriented globe. The Intellipen enables the user to activate the labels by touching the Intellipen to different locations on the globe (Replogle Globes, n.d.) .

2. **APH tactile overlay:** A raised-line tactile overlay, developed, manufactured, and distributed by the American Printing House for the Blind (APH), employs two kinds of tactile cues: raised lines to represent lines of latitude and longitude; and changes in textures to distinguish land, mountains, and bodies of water (APH, n.d.).

Figure 17: Taylor's audio-tactile globe—a combination of the Intelliglobe/Intellipen with APH tactile overlay (a), and a close-up view of the tactile overlay (b).

Interactions with Taylor revealed insights through observations as they interacted with their globe as well as through his responses during the interview. The interview began with Taylor presenting their library of tactile maps, which they had acquired while studying international development for their undergraduate degree. Taylor demonstrated reading the raised-line maps, where they pointed out many of the challenges that are associated with them.

For example, raised-line graphics with braille labels are routinely employed to produce tactile maps that are specifically designed to be accessible for blind and low-vision learners. However, these are costly and scarce. When access is possible, these tactile maps can present challenges because they require a great deal of training to be useful (Golledge, 1993; Loomis and Lederman, 1986). Furthermore, there are low dimensions of information available in tactile graphics, partly because of the difficulty in deciphering subtle differences in raised-line heights. Another is the use of abbreviated place names. One example Taylor mentioned, for instance, was the braille label ‘PAK’ for Pakistan. Due to the standardized size of braille characters, which is relatively large, words are often abbreviated on braille maps. This was also pointed out by the TMAP team. This approach can only be effective if the reader has prior knowledge of the association between PAK with Pakistan. Furthermore, these maps lack interactivity for the user, mostly offering the user with a passive map reading experience. This, compared to the interactive exploring that digital maps offer to readers who are sighted, helps exemplify existing inequality in the map reading experience.

Taylor then demonstrated using their DIY audio-tactile globe. After demonstrating the functions of the globe, we progressed into an open-ended interview that evolved into a creative conversation about a future globe design. What emerged from the interview and conversation was a compelling example of user-driven innovation as it pertains to designing a solution for non-visual maps and globes (Näkki & Antikainen 2008). The interview suggested fundamental affordances of globes for representing geographic information about the Earth, and possible cross-sensory representations of globe elements that should be effective for blind and low-vision learners.

The following is a summary and analysis of the interview including direct quotes.

8.1 Interview data and analysis

The interview was transcribed verbatim, and direct quotations from the participant were categorized into strengths, challenges, and opportunities for improvements regarding Taylor’s globe. Other meaningful quotations referred to as ‘miscellaneous highlights’ are also included in the data. The coded data can be found in Appendix H.

8.1.1 Summary of strengths

Audio labels

It was observed that incorporating audio labels through the use of the wireless Intellipen is a major strength of Taylors globe. The audio labels paired with the tactile overlay provides confirmation to the user that they have arrived at a particular location on the globe.

> *“It comes with this pen thing (audio sounds: the Intelliglobe - discover the world with a touch of the pen). I can touch anywhere on here” - Taylor*

Although Taylor mentions they would like more detailed information with regards to the different sizes of mountain ranges, they also indicated that the ability to locate these areas with the touch of a pen does have its benefits.

> *"This globe can tell you continent or geographic features so you can wander around with the pen and find mountains and rivers and that's fun too" - Taylor*

New ways of learning

The combination of audio and tactile representations for geographic information in one tool has opened up new pathways of learning for Taylor. Although it took Taylor an extended period of time to locate a region, Taylor said, *"but its information I never had before".*

Social aspect to learning

Taylor explained that the use of their globe has become a new way of connecting with friends. The globe provides Taylor the ability to get a sense of where friends from abroad are located around the world. This social aspect of the globe has become another pathway to learning.

> *"I play around with it now and then, when I am talking to a person on the internet from a certain country and I want to find it I find it, and I now have the sense oh! that is Central America, so I am getting an idea of how our continents look, the Americas." - Taylor*

Topography

A key strength of the tactile overlay is the ability to differentiate between changes in topography. The tactile overlay represents differing topographic regions with differing textures. Taylor indicated that a strength of the overlay is their ability to notice where a mountain range begins and ends.

> *"I like on this globe how they've done something different for mountains" - Taylor*

Visual metaphors

Since the location of the equator is considered to be a well-known feature, Taylor found it useful to include this as a raised line on the tactile overlay. However, Taylor indicated they found other lines of latitude and longitude confusing.

> *"The equator is of course useful" - Taylor*

8.1.2 Summary of challenges

Spatial distributions

With regards to Taylor's raised line maps, they found difficulties in understanding spatial distributions from one region to the next.

> *"I've had these maps for a long time, and I like them, but they are really limited in terms of what I can get. This is SE Asia and its huge so I can't really get how far things are relative to each other" - Taylor*

This is because on tactile maps, the size must be large for the map to include enough elements to make sense. The result is the map only contains a localized region, and thus, the reader is unable to quickly reference the shape and size of one region in comparison to another unless they had many map sheets to refer to.

The issue surrounding the size of the tool was also observed with regards to limitations that the globe is faced with.

> *"If I want more detail it is nice to not only get where the countries are but also the shapes of them, there would be no way to make a globe with India this big on it, it would be huge" – Taylor*

In order to get a better sense of the shape of a region, the large size of the raised line braille map does have its benefits. In the current iteration of Taylor's globe, there is no way that this large format could be displayed on a standard sized globe.

It was also observed that Taylor struggled with understanding spatial distributions due to challenges with the audio Intellipen.

> *"What the (Intellipen) doesn't give is the shape. I wouldn't use it if I didn't have the tactile overlay. Just knowing something is an ocean isn't enough information for me, I need the shape and the size relative to other things" - Taylor*
>
> *"It's not always easy to decide where one continent finishes and one starts. I's a problem I have conceptually." – Taylor*

Since the function of the pen is to read labels, it does not give Taylor a sense of the size of a landform. This is one of Taylor's main motivations to procure the tactile overlay for the Intelliglobe.

Braille labels

Taylor also found challenges associated with the use of abbreviations on the raised line braille maps.

> *"This TH is Thailand, but that's all they have space for in Thailand is TH" – Taylor*

This issue was also pointed out by the TMAP team. The use of abbreviations appears to be necessary in order to fit labels on tactile maps, however it does require the use of a key if the reader is not able to recall what that particular abbreviation stands for, such as TH for Thailand.

With regards to Taylor's globe. A major shortcoming of the tactile overlay on the globe is there are no braille labels on that particular model. This means there is no way for

Taylor to confidently identify a location on the globe without the use of the audio labels featured on the Intelliglobe.

Scale

Although the audio labels help Taylor to locate mountain ranges on the globe, these mountain ranges are not given any type of scale to refer to. This means that Taylor cannot gather any information farther than the presence or absence of mountains, by reading out the name of the mountain range being pressed with the Intellipen.

> *"There's no scale it's just mountain or not mountain" - Taylor*

Visual metaphors

The tactile overlay on Taylor's globe appears to follow some of the conventions that visual maps take on. In particular, the tactile overlay has raised lines to represent lines of latitude and longitude. However, these lines are artificial boundaries and without an awareness of what these lines represent, they lose all meaning.

> *"I am not familiar enough with the globe to have in my mind that the Greenwich mean time would be a good way to find England" - Taylor*

Time

Taylor spent a relatively large amount of time foraging on the globe with the Intellipen, along with tactile exploration with their hands on the globe. During one task, it took Taylor 43 seconds to locate Canada, which Taylor referred to as taking “a long time”. They stated that lack of life-long exposure to globes has probably led to this increased time to orient and complete tasks on the globe.

> *“I guess children would have been looking at globes but for me it’s quite a new thing.” - Taylor*

8.1.3 Summary of opportunities

Audio-tactile

Although the integration of audio and tactile was the goal for Taylor’s globe, they do see opportunities for improvements. If a tool was specifically designed for non-visual map reading as it core intention, it would result in a more precise integration of modalities.

> *“That’s kind of a dream of mine to have audio and tactile combined, and I tried to do it with this globe but the pen is not ideal because it’s not designed to go through this overlay” – Taylor*

Taylor proposed improvements for 2D raised line maps such as integrating tactile maps with touch screen devices such as a tablet.

> *"You could make something like this (braille) map that was on say an iPad then if I could touch things and have it read out what it is that would be faster than having braille labels, and also I wouldn't even try to do the world, but more on this (regional) scale, these ones are more useful, if it were coupled with a touch screen under it that I could push and it would tell me which country I am on." – Taylor*

Moreover, Taylor also suggested using different kinds of textures to represent changes in topography, as well as more pronounced tactile features on tactile maps in conjunction with audio. Taylor made a good point that if a map utilized different textures to represent different variables, they must be distinctively different. Taylor said: *"I love how flat and rough is easy and you could do other textures but it's hard to get them to be distinctive texturally."*

> *"(Touching braille map) this map doesn't indicate mountains, so if somehow they could do that texture that would be good too. With speech it could be really precise. it could tell me which city I am touching or have a stylus for that level." – Taylor*

> *"After looking at these for a while, I know this is ocean and this is land, but if the land were higher you wouldn't have to think about it, it would be intuitive." - Taylor*

Removable 3D tactile representations

Probably the most exciting opportunity that transpired from the interview was how the use of 3D removable pieces that retract from a globe model could help non-visual learners. On a global level, Taylor said: *“I think if the continents could come out that would be pretty cool”.* This innovation is thought to be a solution for the challenges associated with understanding the spatial distribution of landforms.

> *“You could make puzzle pieces that are each plate that can pull out of the globe and go back in.”* – Taylor

Further to that, Taylor suggested that these 3D removable pieces should contain orientation markers to aid the user in replacing the piece back to the globe model.

> *“If you pull this out of the map, it would be confusing if it didn’t have say a scratch indicating that it’s the north arrow, glossy on one side, or wood on the other side, otherwise it would be confusing to put back together, otherwise I think it would be very good.” - Taylor*

The idea for the removable pieces may have been influenced by a previous experience that Taylor had using a puzzle with removable pieces. Taylor said: *“I did once have a puzzle, designed for kids that was the US, and all the states could be pulled out, I had some trouble labelling them but the idea is nice because when you hold it in your hand* *you get the shape."* This puzzle is reminiscent of the puzzle map described in Chapter 4 (Figure 6**)**.

On a localized level, there are other opportunities for 3D tactile representations. Localized tactile maps could contain a different level of detail compared to the global scale. Taylor even suggested creating maps that stack inside one another, similar to the idea of stacking dolls:

> *"There's a mall near here, the only thing I care about is where the door is; so if I know the location of the door off a street that's good enough information, but the mall is a different beast, it has many doors; if there was a model of this area with the mall and I could feel the shape of it and pull its roof off and say inside it, this is the path you'd have to take to find something, like a mini map was inside the bigger map that would be useful… if you had a map you could trace on the streets the routes you take to get to the mall and then once you get there the mall is depicted and you could see the outside of it what streets go around it where you would have to go to get into the different entrances, and you could remove the roof and see this store is here this store is here.. that would be really useful."*
> *– Taylor*

Taylor was asked what the most useful map for him would contain, to which they said:

“I think my surrounding area. I rarely walk anywhere partly because I have come to realize there aren’t that many places to walk to around here but also, I just don’t understand. I have a fairly good grasp of the grid pattern of streets in Toronto but when I go North I am not sure what is East-West and what is North-South anymore. It could include streets, businesses…” – Taylor

This finding is reminiscent of the work that TMAP is doing now. At the time of this interview, TMAP was just starting out, but there are similar ideas at play here. What Taylor is suggesting would benefit from the use of a tactile street map like what TMAP offers.

8.2 Recommendations for audio and tactile variables

The final study in this research provided recommendations for tactile and audio variables for representing geographic features of a map. When it comes to tactile variables, language is one variable that was somewhat useful for labelling points, lines, and areas where ever there is room. In order to recognize variations between areas, another variable that is recommended here is texture. Textures such as smooth feeling areas to represent land, or rough textures to represent water is one use of the texture variable.

Another way to show different land cover representations is through changes in the variable size through elevation. For instance changes in the height of a raised surface can be used to represent changes in elevation and topography such as a mountain range. The size variable is also used to show differences in line representations such as borders and rivers. Different line styles such as a solid line to represent the equator was recommended, so in order to differentiate that line from other line types such as geographic borders or coastlines, dotted, or dashed lines would be used to represent those differences. The size of a 3D removable piece would allow for discerning relative comparisons between land masses.

Taylor repeatedly mentioned that they long to gain a better understanding of the relative differences in landmass. For that reason, the variable shape is important. The recommendation is different shaped 3D pieces resembling the land areas they represent on Earth will help with shape and landmass comparison between regions. In terms of the audio variables, language is once again an important variable, through the use of designated audio labels. Pre-recorded spoken word is recommended to label location names (points), to label the presence of important borders (lines), and to provide a label to substantial areas such as bodies of water, to name a few examples. Each place that is depicted with an audio label thus uses the variable position to represent a place and differing positions of these audio labels will result in a general understanding of where things are on the map.

Finally, the audio and tactile correspondences gathered from the interview with Taylor are summarized and provided in Table 9 below. Krygier’s audio variables and examples of tactile correspondences observed in the EHCR tactile map are also presented in Table 9 to refer back to.

	Audio correspondences	**Tactile Correspondences**	**Audio correspondences**	**Tactile correspondences**
Visual Variables	**Recall: Krygier's audio variables**	**Recall: 3D tactile map of EHCR**	**Interview variables**	**Interview variables**
Position (changes in x, y location)	The *location* of a sound in 2D or 3D space could be used to represent a point's position on a map.	Location of the tactile symbols on the tactile map represent the locations of the features on the map in relation to their real-world positions.	Positioning of audio labels will result in a general understanding of locations on the map.	3D continent pieces to correspond with audio labels.
Size (change in length, area, or representation)	Changes in loudness, pitch, duration, and the attack/decay could all be used to represent size.	The variations in line sizes represent differences between the main road, paths, and the stream.	See Krygier.	Changes in the height of a raised surface can be used to represent changes in topography such as the presence of a mountain range. The size of a 3D removable piece

				would allow relative comparison between land masses. Differences in line representations such as borders and rivers (broken vs. solid lines).These could also be described as changes in texture.
Shape (infinite number of shapes)	As there is an infinite number of shapes, similarly there is an infinite number of sounds that can be used for representing map symbols.	The shape of the symbol for stairs uses tactile elevations to differentiate from the shape of the symbol for bridge.	See Krygier.	The recommendation is different shaped 3D pieces resembling the land areas they represent will help with comparing the shape and landmass between regions.
Value (changes from light to dark)	Loudness, pitch, duration, and order are examples of	A variable mapping for value could be comparable to the	See Krygier.	See EHCR.

	audio variables that seem to correlate with changes in value because they can be used to represent ordinal ranges.	size and texture through value ranges in those tactile cues (ex: value changes from very rough to very smooth).		
Hue (changes in colour)	Timbre could be considered as a correlate to hue for data that is characterized nominally.	Visual variable for hue is depicted on this map through representations of blue symbolizing water, grey symbolizing roads, and beige symbolizing paths. These classes of data are also represented through different tactile textures.	See Krygier.	The use of classic hue visual variables along with audio and tactile correspondences to hue. See EHCR.
Orientation (changes in alignment)	The location of sound in 3D space could be considered an audio correlate for orientation.	Tactile map elements do not vary from the normal orientation.	See Krygier.	Tactile elements that are removable should contain a tactile indicator for north so when the user is holding the

				piece they can sense the true north orientation.
Texture (variation in pattern)	The audio correlate of texture could be described as timbre. Similar to hue, nominal data could be expressed through distinct changes in timbre.	Each symbol uses a different tactile texture. Texture can be used to differentiate between line symbols, for example, the main road, path, and river are all forms of lines, but each are built from a different material to show variations through touch (ex: the main road is metal and the path is wood).	See Krygier.	Textures such as smooth areas to represent land, and rough textures to represent water is exemplified and recommended.
Written labels	The audio correlate to a written label would be spoken word, which is not part of Krygier's variables.	Braille labels and text in English are both used for labelling features of the map.	Pre-recorded spoken word audio labels are recommended to label locations on the map, the presence of	Braille labels that accompany audio and tactile variables (such as a label to name a textured body of water) add to the

			important borders, and bodies of water.	understanding of the features on the map.

Table 9: Comparison between variable correspondences in Krygier's audio variables, 3D tactile representations observed in EHCR map, and the audio and tactile correspondences developed from the interview with Taylor.

With that, we have moved through each stage of the concatenated research phases.

What follows is a synthesis of findings from each study.

Chapter 9: Synthesis of studies

9.1 TMAP Interview conclusions

In order to automate the design process map elements must be highly simplified. This includes limiting the number of line types used in a single map. Clutter is the enemy of tactile maps, and TMAPs avoids clutter by focusing mainly on street maps. Tactile maps cannot follow the exact conventions of visual maps because they would become cluttered very quickly.

Visual metaphors do not always translate for non-visual, and this is a bias that all visual designers carry. One example of this was the use of wavy raised lines to represent water on a tactile map. This convention did not always translate to mean water for a non-visual map reader. Being aware of visual biases is an important recommendation for designers creating maps for non-visual readers.

Important features that must be included on a TMAP include title, point for central location, scale, and north arrow. The design team is working on standardising rules for where these should be placed on the map.

Since braille literacy is relatively low, and we want to avoid clutter, the goal is to have as little text as possible. Pairing a TMAP with audio GPS wayfinding is a good solution.

TMAP does not currently have the capacity to perform formalized studies on usability and effectiveness. That being said, the design team has noticed an increase in the demand for TMAPs over the course of one year in operation. They are also receiving repeat orders, which leads them to believe that these maps are helping people. With the in-house user testing they have performed, the design team has found there is a learning curve to reading TMAPs, and they incorporate feedback they have received into account when they are designing future maps.

TMAP allows the map reader to see themselves in a greater geographic context compared to step by step spoken directions. The work they are doing is an exciting example of the potential for tactile mapping. Wherever there is open street data, there can be a TMAP made for that area, making them a universal resource.

9.2 Educator survey conclusions

22 educators, located in the southern regions of Canada showed interested in creating a more inclusive space around geography education. More than half of the respondents reported they had taught a student with visual impairment in their career, meaning educators must be using alternative teaching methods to provide geography curriculum to those students who cannot learn from conventional visual maps. An increasing number of children with visual impairments are entering mainstream schools, and the results of this survey suggest that more teachers will find non-visual geography teaching and learning tools increasingly helpful, and at growing rates (Davis, 2013).

A majority of educators surveyed are teaching with GIS technology. As geography becomes more synonymous with technology, educators have been faced with the challenge bringing out those concepts into the physical environment of the classroom. One survey respondent gave unique examples of interactive learning tools they are using in the classroom including Wikki Stix, Oreo cookies, graham crackers, clay, Lego, straw connectors, water, sand, dirt, rocks, tinfoil, wood, and ice. Although there were no details given about exactly how they use these materials (probably due to the structure of the questions being asked) it seems reasonable that these materials could be used as correspondences to the visual variables such as texture, shape, and size. A combination of hands-on tools with the power of GIS technology could support a more well-rounded learning experience for all students.

The survey also showed that educators have some awareness around accessibility and geography. When one educator suggested incorporating interactive maps that use sound to delineate map items such as boundary lines or change in theme it shows that some educators are thinking deeply about how to make maps accessible. Another educator mentioned they are required to be in compliance with the Accessibility for Ontarians with Disabilities Act (AODA) in their institution.

Most educators who participated in this study self-report being fairly comfortable integrating new teaching tools and technologies in the classroom. The main issue that educators see is the time associated with learning and integrating new technology into lessons.

Findings from educator surveys and an interview with TMAP designers both found that incorporating hands-on or tactile element in conjunction with a technology that provides audio feedback in the form of spoken word and non-linguistic sounds to help orient through map coordinates is the recommended map interface for blind and low-vision learners.

9.3 Co-design session conclusions

During the co-design session, the participants proposed ideas for auditory representations to for the data variables given in the provided dataset, and plotted them in a corresponding audio interface. The interface they designed had the map reader wandering within the map along the advance and retreat trajectories given in the dataset. By the end of the co-design a few variable mappings were solidified for the audio map prototype: direction, troop size, battle locations, and temperature. The sound of feet marching quickly represented the advance of a fully army, and the sounds of feet marching slowly and quieter represented the retreat with a significant loss of troops following several battles along the way. When the map user would enter a battle location, the sound of gunshots would be heard. Low pitched whistling was chosen to represent warmer temperatures and high-pitched whistling represents colder temperatures. Direction was deciphered by the location of the sound source being placed in particular locations in the room to correspond with the map coordinates.

It was observed that co-designing multi-modal maps adds a new level of interactivity because the map makers are physically interacting with the data. This kind of interactive learning could help all types of learners become more engaged in maps for educational purposes.

It was also concluded that in order to communicate audio variables most intuitively, the use of life-like or ecological sounds made sense. One example of this was the use of the sound of footsteps to represent troops marching. An interesting observation was that these participants came up with the same audio variable to represent troops marching as was selected for Coppin and Windeyer's 2018 sonification. It is possible that the participants were inadvertently presented with this variable mapping and this could have caused the similarity.

Beyond the audio component, observations surrounding tactile maps were also made. The 2D raised line drawings that we provided were deemed unappealing by all participants and difficult to understand by the participant who is a braille reader. The sighted participants were not inspired to engage with the braille maps that were monochrome, however, a two-tone braille map did provide information to a sighted map reader. Although they are meant to be read by non-visual map readers, this presented an opportunity to make a tactile map that is engaging to a wider audience. This aligns with the education survey results that repeatedly mention that multimodal maps could be beneficial to all learners. The participants and researchers also made observations regarding preferences for which materials are more attractive to touch when it comes to tactile maps. In the co-design session, when our participants touched the different braille maps, we concluded that some materials feel better than others, and are easier to understand. For instance, the paper texture was easier to read than another braille map that was plastic.

9.4 Taylor interview conclusions

The interview with Taylor suggests a cross-sensory geography tool that would be useful for blind and low-vision learners should convey information through tactile and audio cues. Whereas in the TMAPs interview we found that the maps had to be highly simplistic to avoid clutter, representations with audio and tactile cues allow for more information to be present without clutter. Where map elements typically iconically represent features seen on earth (resembling what they look like on earth) through visual cues such as shape and hue, these should be represented through 3D tactile models (like a continent piece with elevations representing a mountain range, for example). Features typically represented visually through text labels should be represented through pre-recorded audio labels.

Challenges that Taylor faced with regards to understanding spatial distribution of land masses can be addressed through the creation of 3D tactile pieces representing areas that are removable from a full set model. 3D pieces that can be held in one’s hand could solve problems with comparing the differences in the sizes of landmasses. The increased level of information that 3D pieces would provide on the surface of a full globe model could also help to convey the relative distances between land masses because changes in topography would be made more apparent.

Tactile cues could also have different textures to represent differences in landforms such as land, water, and mountain ranges.

The use of audio labels in conjunction with a tactile model could solve issues surrounding limitations of braille labels. This research also suggests that audio labels that are easy to access will decrease the time it takes to locate particular areas on a map or globe.

Taylor also made statements in support of using maps like the tactile maps made by TMAPs for non-visual street navigation and sense of place.

Globe navigation and understanding spatial relationships among the Earth’s landmasses was a top priority for Taylor. However, with his globe, this task is time-consuming due to the lack of detail provided by the tactile overlay. Taylor suggested that removable and retractable 3D tactile continent or country pieces could provide a better experience compared to 2D raised-line representations. What was observed was a form of user-centric design that fueled creativity, problem solving, and interaction for educational purposes.

9.5 Cross-sensory mapping framework

The following model (Figure 18) synthesizes what this research found to be important elements in a more inclusively designed map:

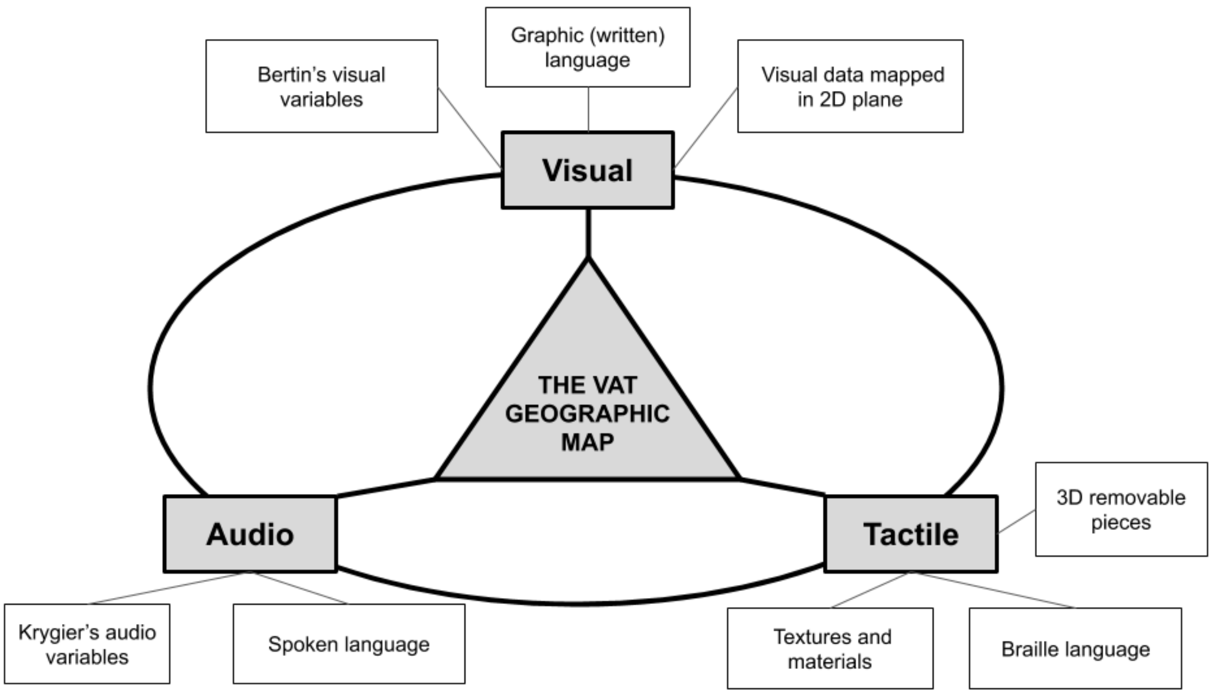

Figure 18: The VATmap Model showing what should be contained in a geographic map that does not rely on vision.

The model in Figure 18 above shows how we have reimagined what a geographic map should contain. The map has visual, audio, and tactile (VAT) representations. The recommendation is to employ each modality together, but they can also be used in any combination that the designer chooses.

The visual representations on a map are graphic/written language, visual variables, and visual data in the 2D geographic coordinate plane. The written language can be used for map elements such as the title, legend labels, location labels, and any other elements that must be written. Earth's geography can be represented as points, lines, and polygons on the 2D plane, and the visual variables are best used for adding a 3D dimension of thematic data above the 2D plane (Bertin, 2011).

Audio representations on the map should include spoken language and audio variables. Spoken language correlates with the visual written language and can be used for labelling place names, giving directions, and providing greater contextual information to a given map. The audio variables correlate with the visual variables when they are used to represent ordinal or categorical thematic data (Krygier, 1994). Similarly, the audio variables are used to represent earth's features when sounds are assigned to them.

Finally, tactile representations on the map should include braille labels, textures and materials, and most importantly 3D pieces that can be held and explored outside of the complete base/board/model that it sits in. Braille labels should be present, and audio labels, as previously mentioned, should also be present in order to provide multiple channels of information. The use of textures and materials can provide categorical information such as land cover, or any category it is assigned to. Since we found that 2D raised lines and dots were too simplistic and low resolution, 3D objects should be used to provide a more immersive map experience. The 3D pieces could iconically represent the landforms they resemble on earth. 3D pieces could also be something simple like different sized Lego blocks to show hierarchy or quantities, for example.

The visual, audio, and tactile elements are connected in this diagram because they can be used all together to create a map.

Chapter 10: Conclusion and future research

Through the literature review, environmental scan, and four individual studies this research collected suggestions for representing geographic features through audio and tactile variables. Each of the stage of this research provided many recommendations for tactile and audio variables for representing the distribution of earth's features, and geo-referenced thematic data revealing variable correspondences from each study.

The need for language through audio or tactile labels for verifying location names and attribute information was prominent. Some studies gave more explicit variable recommendations than others. For instance, the interview with Taylor provided examples for explicit ideas (ex: 3D pieces that can be removed, that have a north indicator to help with orientation) because of the nature of the open-ended style interview, whereas the educator survey mainly suggested broad categories (ex: use Lego, sand, and ice) without suggestions for explicit uses (though explicit uses were extrapolated from these broad suggestions). The map variables presented here are relatively invoking the classic set of visual variables. A prominent conclusion from these studies is the recommended use of audio and tactile cues in tandem for the clearest understanding of map information.

It is important to remember that the visual variables are rooted in a visual perspective. This means researchers and map designers must propose adaptations and new variables for other modalities that make sense of *those* perceptual modes, not necessarily a direct translation from a visual metaphor. Conventions that make sense in visual map representations will not always translate perfectly into audio or tactile modalities. Tactile and audio map variables are associated with a different set of strategies and challenges for communicating information to the reader compared to visual maps and there is a need for further research and development in this area. For instance, there needs to be a formal testing of some of the ideas that have been developed in this research so that products can be brought to the mainstream and into classrooms.

Interviewing tactile map designers at TMAPs provided an extensive investigation of how one organization is getting effective tactile maps into the hands of blind and low vision map readers. A survey of geography educators from K-12 and higher education provided a glimpse into what challenges and solutions are taking place in the classroom when it comes to having blind and low-vision students participating in highly visually-oriented activities. A co-design session with stakeholders allowed for interactive exploration of how an accessible map interface could be presented. And finally, a follow-up interview with one of the co-design participants led to deeper insights on the experiences of blind globe designer and user. The result was a series of insights from expert stakeholders who use maps in various ways and have recommended that the incorporation of audio and tactile elements can enrich the map reading experience for all map readers.

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Appendices

Appendix A: TMAP interview transcript

Time stamp	Question (Researcher)	Quotation (TMAP expert)
4m 56s	Tell us a bit about TMAP	There is a distinction between TMAPs and all other tactile maps. We do a lot of bespoke custom map designs, not pulling data from OpenStreetMap but working with artwork like a PDF of a campus and designing a map and making design decisions. What is to be included is usually attenuated because you cannot include everything. Whatever is on the public facing visual map, there’s usually hundreds of items in the key and that needs to be scaled back and it usually boils down to roads, paths, the most accessible path of travel, usually the main building entrance, not all the building entrances, sometimes bus stops. Part of that is because that creates a map that is reasonably uncluttered, that can still be useful. So it’s raised line equals streets and all streets that reach the margins, the perimeter of the page, are labelled with braille. We can crank out those TMAPS in just about 3 or 4 minutes and the idea that, me, who is not a braille transcriber who is not a designer, can hand you a well formatted, braille labelled, embossed tactile map is pretty astounding.
9m 48s	How can we reduce the number of map key (legend) elements?	We try to spell things out in full if there is space, we try to minimize the number of line types and area types, but some of our maps are pretty complicated so we do have a lot of things in the key and a lot of people struggle with that, for a set of maps, sometimes have a main key for recurring symbols, and then shorter keys per each specific map. It’s about recognition versus recall.

12m 54s	Does TMAP use metaphorical representations on the map (non-linguistic indicators) for particular areas on the map?	We used a wavy texture for water for a very long time but someone asked why is this wavy, water is flat? So were using these visual standards that do have representational metaphor viewpoints, but it doesn't necessarily make sense. We have to be careful as sighted visual designers about what our expectations for people's understandings of things that we think are really common place, but we have been bombarded with visual imagery our whole lives. It's also a controversial thing though if we're talking about braille use. We're relying heavily on braille use to understand the keys and the names of the streets, and as you guys know, braille literacy is not all that high but it is a useful way to convey information.
15m 06s	We are looking for ways to represent topological features while limiting number of map key items - have you done any studies to find the most effective representations on your maps, like the water example?	No we have not, other than in house anecdotally with people that we work with and people that we show stuff to. But no, no formal studies.

40m	Who asks for TMAPs?	We typically hear from universities who would like to create wayfinding maps for students to get around the campuses. Museums is another one. We have seen a lot more of an uptick in museums wanting to make their museums more accessible so they want floorplans of the interiors. What's driving it? I don’t always know. We have seen an uptick in interest in providing people with tactile braille maps in recent years. Maybe part of that is the more that we have done and as our portfolio grows and experience, through word of mouth people start hearing about us. In the time we have been doing it I think there has been more of an awareness growing around inclusive design, it seems that there are more designers who are speaking that language, and more people who contact us who are speaking that language.
47m 17s	I don’t have a lot of experience with tactile graphics, and many people don’t - have you looked at, after you give maps to universities, how effective is it to help students get from place to place?	We don’t always hear back. Typically in most schools they don’t have many blind students, maybe 1 or 2 in any given school year, although schools do keep coming back to us to order more maps or re-up and get more copies, or map more areas of the school, so that would suggest that the maps are useful to someone.

		We can take different approaches with universities. It's simply roads and paths of travel. A line is a line and if you can follow it, it's a lot easier than textured areas (such as environments). Usually as far as what do people want, usually people are expecting way too much from it. They're used to the world of visual maps where there's many many layers that the eye can quickly sort through based on colour or appearance so we have to guide the conversation to something that is more practical. We learned it quickly early on the guiding principle is that clutter is the enemy of tactile maps. That is one of the beauties of TMAP is there is very little to clutter it up. Other than the zoom resolution if it's a dense urban area so if there are too many streets to represent cleanly, but it's an interesting conundrum. Everyone sees the potential in it, and is thrilled they can get a map so quickly that they want more information, they want their bus stops, they want their transit routes, but if you lump all that stuff into the map it would then be less useful.
50m 40s	Do people use other types of map information in conjunction with TMAP, like audio or other?	Generally yes, TMAP is not the be all end all. Anyone who is going to really benefit from it already has to have pretty confident mobility skills, orientation skills in which case they're already going to have the tools they need to deal with things effectively like street crossings and sense of direction and all that.
		Which generally includes apps and GPS wayfinding.
	What do people generally use TMAP for?	Well, it gives one the big picture, so rather than just simply learning a route which is either narrated to you or you're following turn by turn directions you get the lay of the land, you can see how that actually fits into the grand scheme. I guess you could call it location literacy. You get the big picture the sense of where you are and fit in with all of that.

		I have had people comment things like "oh I didn't know that road curved!" or "I didn't realize this was so close to that".
	Are there certain rules that you follow of what to include in the map?	There are rules we follow for our maps. The upper left is the title, which is the actual address, which is the epicentre. We also have a scale and there is a little line under that which shows what that unit distance would be.
		Similarly with visual maps, if scale is important for understanding the map you include it, if it's not you don't. similarly with tactile maps, we're including scale because it does change and it gives you a sense of how big a block is.
		Currently all of our TMAPs are oriented with north being the top of the page. But we have been including a compass arrow nonetheless.
		We talked about this with map makers and they said, "these are all the things that we grapple with when we're creating visual maps, simplifying and deciding do we need to include this in there". We go back and forth to see what is useful and what is clutter.
56m 47s	You said you have someone test out the maps, so do you have a go to person who tests out the maps?	Yes, we do, and he's so good at it that he's practically useless because he understands, he's read this stuff so much and he's familiar with our stuff. He's also aware of his limitation in that regard. We will often times just take it around the shop to other people who are not part of our day to day operation to weigh in on this.
		Literacy is huge thing. A person who is literate in these kinds of maps will get more out of them and understand them better because they will know

		what to look for first, second, and third whereas someone who is not used to them will be all over the place.
		Lots of people dive right in and start feeling around. With TMAPs, we have really done our best to standardize that approach, we are only labelling streets at the margins, where they reach the edge of the page. There are a few rules to avoid braille collision, so if two streets are too close together a label will get dropped.
		We understand that you can't always show everything perfectly on the map itself and that additional information is helpful to make sure that its clear.
59m 50s	Once you receive feedback have you ever made changes to these maps?	We have been trying to standardize our maps forever but every single project presents its own new design challenge. We continually get feedback, everything is kind of in an iterative state, some things have become more standardized. The TMAP on the table has the north arrow at the bottom. Some people gave feedback saying the north arrow should be in the north, so we moved it. We understand that north arrows don't always need to be in the quadrant of the map that it's pointing to and referring to, but it just made more sense to a lot of people and it provides that information at the top meaning it's important and it's the first thing you want to look at so we did change that.
1hr 02m 54s	How do people request TMAPs?	Still in soft launch and need to figure some things out before we make it much easier for people to get their hands on. Right now they are available at Adaptations, the LightHouse store. They're developing their own webstore and will sell it through that. I like the idea of having a web portal. People are interested in printing their own map. We haven't had the bandwidth or resources to design a TMAP that is going to compatible across the range of embossers that are out there, or the best files for 3d

		printing, and we certainly don’t have the ability to do the tech support around all of that when people call us and say it’s not working.
		It’s not like sending it to like an HP versus a Brother printer, it’s a whole different set of symbols.
		We don’t want to be creating bad tactile maps and putting people off of tactile maps. We’re just making sure that what we are putting out is good and usable.
1hr 06m	Do you have a goal in mind of where this might be going? What is the use case of TMAP?	Yes, the goal is to get more of these maps in people's hands, and we also see it as an opportunity to increase awareness of tactile literacy, maybe even help people become more tactually literate, because they’re so quick and easy for us to produce it makes it easy for people to get tactile graphics in their hands, and maps in particular, because one of the big barriers to getting tactile graphics is the amount of time and expense it takes, like the hoops you have to jump through. This changes that, because it only takes my shop 5 or 10 minutes to fill an order. All of a sudden, we can just reach individuals, we don’t have to only deal only with institutions. That said, to get the word out we still think it makes sense right now to work with institutions and other blindness agencies to help get these maps out there. Guide dog schools seem like an obvious one because people are usually involved for an extended stay with an instructor and at some point, the lessons are going to entail heading off into town and leaving campus. And these teachers have their routes and lessons planned so TMAPs for these people can be really useful because they might want a bunch of copies of the same thing for the class of 80 people. It helps explain that a picture is worth a thousand words because

		you can show why it makes more sense to cross at one intersection rather than another. We want to make these useful for campuses, because that's probably one of the biggest audiences out there is students, and if we can auto generate useful maps that don't take dozens of hours to design and create we would like to do that.

Appendix B: Email invitation to participate in Geography educator survey

Hello! My name is Lena Yusim and I recently completed my graduate internship at Esri Canada in the Education and Research department. Currently, I am working towards completion of my master's degree at OCAD U in Toronto, studying Inclusive Design.

Geography is a highly visual discipline. Consider the power of communicating information in a data visualization, such as a map. My MRP (major research project) is aimed to understand how to create a richer map reading experience for those living with visual impairments (low-vision, to fully blind).

This survey is a way to connect with educators who experience first-hand what works in the classroom, as well as provide an opportunity to share ideas for making maps accessible to more students.

For those interested in discussing map accessibility further, there is an opportunity to participate in a semi-structured interview to discuss ideas together. Please email me at 3164470@student.ocadu.ca if you are interested or would like more information.

Please note that this information is being collected towards my graduate research and no personal identifying information will link you to the responses should they be published in the results of this study.

Thank you for your time and valuable input!

Appendix C: Coded educator survey responses for Question 4

Please list common teaching materials/tools you use in the classroom related to geography

Submission	Print materials (visual)	Digital materials (visual)	Interactive/3D materials (tactile)
1	Maps (paper and on screen), air photos, globes	GIS, graphics software	3D models
2		GIS, computers, drones, Google	Cardboard
3	Very large print maps	GIS, computer technology	
4	Projected slides	GIS, computers	
5	Paper maps, aerial photography and imagery	GIS, manly online sources of mapping data and products, Google Earth	Physical models
6	Paper maps, globe	GIS, computer maps	
7	Wall maps, posters, textbooks, pictures, flags, stereoscopes, globes	GIS, computers, cameras, GPS devices, online simulations, games	Rock samples, surveying equipment

8	Atlases, road maps	GIS, Google, Desire 2 Learn, e-Learning, websites	Rock samples, block examples of fault lines
9	Atlas, paper map, handouts, print newspapers, giant floor maps, news media, globe	GIS, online outlets, GeoSpatial Revolution (videos), YouTube videos	Really old 3D maps
10		GIS, Google Earth	
11	Atlases, paper maps, globe	GIS, computers, Google maps	
12	Paper maps atlases	GIS, PowerPoint, videos	
13	Atlas, globe	GIS	Rocks, models
14	Paper maps, poster-sized maps, atlases, textbooks, Canadian encyclopedia	GIS, Google Earth, Google maps	
15		GIS, computers	
16	Maps, whiteboard, globe		
17	Paper maps, large wall maps, desk maps, graphs, charts, pictures, globe	GIS, computers	
18		GIS, websites, videos, articles	
19	Paper maps, atlases, SMARTboard, textbooks, mapping workbooks, globe	GIS, computers, videos, Gizmos	
20	Maps, overhead projection,	PowerPoint	

	globe		
21	2D maps, photos, SMARTboard	Apps, Google street view, Google maps, location services, videos	Textured maps, 3D maps, topographic maps, Wikki Stix, Oreo cookies, graham crackers, clay, markers, pens, tape, manipulatives, Lego, tape measure, rulers, straw connectors, water, sand, dirt, rocks, pattern tool for sewing, tinfoil, wood, paper, ice
22	Wall map, textbook maps	GIS, computers, digital maps	

Appendix D: Coded educator survey responses for Question 5

How could you imagine adapting teaching materials you listed above to be more accessible to a student with visual impairment in your classroom?

Submission	Visual tools	3D or tactile tools	Audio tools	Not sure/ambiguous
1	Colour blindness options for choosing colours			
2		3D printed maps		
3		Braille	Computer technology with described audio	
4	Red-green colour blindness options			
5		Physical models, 3D printed landscapes	Audio clips	
6		Braille		
7	Enlarge text and maps	3D relief maps and globes	Screen readers	
8		Braille maps	Listen to notes	

9	Changing screen colour, enlarging print and graphics, black and white images, thick outlines	3D maps		
10				Not sure
11				That is a great question. I am sorry, I don't know.
12	Larger screens, lab instructions available in video recordings	Tactile screens	Lab instructions available in audio recordings	
13	increased font size and magnification			
14		Full-relief (bumpy) maps	Interactive maps that incorporate sound for boundaries and change in theme	
15				yes
16				Proper technology
17		3D map, interactive		

18	Software to enlarge view on the screen, portable SMARTboard			
19			Voice activated technology	
20	Magnifying glass, personal projection viewer			
21		Tactile descriptive video		
22	Enlarge maps, colour maps			

Appendix E: Meeting Guide for Non-Visual Mapping Co-Design

PLEASE NOTE THAT THIS MEETING WILL BE SEMI-STRUCTURED AND THEREFORE ADDITIONAL QUESTIONS MAY BE ASKED.

Preamble script:

We are conducting research on building cross-sensory maps that can be touched, seen, and heard. Our current focus is building maps that can be heard. These maps are created using a mixture of sound and speech.

We would like to get your thoughts on what inconveniences you may experience in your daily life where a map, amplified by the addition of sound, could help solve this problem, and what you think this map could potentially look like.

- What has been your experience with maps?
- When have you wished for a map that would be more useful to you?
- What is your biggest problem that can be solved by a map?
- How would you make a map like this using only sounds and speech in an interface?
- What has been your experience with audio games?

(Action) Show 2 examples of audio map interfaces

- What kinds of maps could be represented by these two types of interfaces?
- How has seeing these interfaces affected the design map you conceived of earlier?

Some examples of audio map interfaces in audio games:

- List Based: http://audiogames.net/db.php?id=Crafting+Kingdom
- MUD Style: http://audiogames.net/db.php?id=Materiamagica
- Grid Based: http://audiogames.net/db.php?id=Tactical+Battle
- Arcade Style: http://forum.audiogames.net/viewtopic.php?id=22557
- Side Scroller: http://audiogames.net/db.php?id=Adventure+at+C
- First Person 3D: http://audiogames.net/db.php?id=Swamp

Appendix F: Napoleon’s March Dataset

sequence	longitude	latitude	# of survivors	direction	battle group	battle	city/location	Country	date	temperature	days
1	21.3	55.3	340000	Advance	1		Neiman River mouth	Lithuania	6/24/1812		
1	24	54.9	340000	Advance	1	crossing river	Kowno	Lithuania			
2	24	55.1	60000	Advance	2		Kowno	Lithuania			
3	24	55.2	22000	Advance	3						
4	24.5	55	340000	Advance	1						
5	24.5	55.2	60000	Advance	2						
6	24.5	55.3	22000	Advance	3						
7	24.6	55.8	6000	Advance	3						
8	25.3	54.7	340000	Advance	1	skirmish at Wilna	Wilna (or Vilnius)	Lithuania	6/28/1812		2

9	25.5	54.5	340000	Advanc e	1						
10	25.5	54.7	60000	Advanc e	2						
11	26	54.7	320000	Advanc e	1						
13	26.6	55.7	40000	Advanc e	2						
14	27	54.8	300000	Advanc e	1		Nieman River source	Belarus			
15	27.4	55.6	33000	Advanc e	2		Nieman River source	Belarus			
	27.7	55.2	300000	Advanc e	1		Gloubo koe	Belarus			
16	28	54.9	280000	Advanc e	1						
17	28.5	55	240000	Advanc e	1						
18	28.7	55.5	33000	Advanc e	2		Polotzk	Belarus			
19	29	55.1	210000	Advanc e	1						

20	30	55.2	180000	Advance	1						
21	30.3	55.3	175000	Advance	1		Witebsk (Vitebsk)	Belarus			
22	32	54.8	145000	Advance	1	battle at Smolensk	Smolensk	Russia	8/16/1812		
22	32	54.8	145000	Advance	1	battle at Smolensk	Smolensk	Russia	8/17/1812		
22	32	54.8	145000	Advance	1	battle at Smolensk	Smolensk	Russia	8/18/1812		
23	33.2	54.9	140000	Advance	1		Dorogobouge	Russia			
24	34.4	55.5	127100	Advance	1		Chjat	Russia			
25	35.5	55.4	100000	Advance	1						
26	35.8	55.5	100000	Advance	1	battle at	Borodino	Russia	9/6/1812		

						Borodino					
27	36	55.5	100000	Advance	1						
28	37.6	55.8	100000	Advance	1		Moscou (Moscow)	Russia	10/18/1812	0 deg	6
29	37.7	55.7	100000	Retreat	1						
30	37.5	55.7	98000	Retreat	1						
31	37	55	97000	Retreat	1						
32	36.8	55	96000	Retreat	1		Tarutino	Russia			
33	36.5	55	96000	Retreat	1	battle at Malo-Jarosewii (Malovaroslavets)	Malo-Jarosewii (Malovaroslavets)	Russia	10/24/1812	0	6
	36	55.5		Retreat	1		Mojaisk	Russia			
34	35.4	55.3	87000	Retreat	1		Moskovskaya oblast'	Russia		0 deg	

35	34.3	55.2	55000	Retreat	1		Wixma (Wirma)	Russia			
36	33.3	54.8	37000	Retreat	1		Smolen skaya oblast'	Russia	11/9/18 12	-9 deg	16
37	32	54.6	24000	Retreat	1		Smolen skaya oblast'	Russia	11/14/1 812	-21 deg	5
38	30.4	54.4	20000	Retreat	1		Orscha	Belarus			
39	29.2	54.3	20000	Retreat	1		Bobr (Botr)	Belarus	11/24/1 812	-11 deg	10
40	29.2	54.2	30000	Retreat	2						
41	28.7	55.5	33000	Retreat	2						
42	28.5	54.2	20000	Retreat	1	battle at Berezin a (River)	Berezin a (River)	Belarus	11/26/1 812	-20 deg	4
42	28.5	54.2	20000	Retreat	1	battle at Berezin a (River)	Berezin a (River)	Belarus	11/27/1 812	-20 deg	4

42	28.5	54.2	20000	Retreat	1	battle at Berezina (River)	Berezina (River)	Belarus	11/28/1812	-20 deg	4
43	28.5	54.1	30000	Retreat	2						
44	28.4	54.3	20000	Retreat	1	battle at Berezina (River)	Berezina (River)	Belarus	11/29/1812		
45	28.3	54.3	20000	Retreat	1						
46	28.3	54.2	28000	Retreat	2						
47	27.5	54.5	20000	Retreat	1		Belarus	Belarus	12/1/1812	-24 deg	3
48	26.8	54.3	12000	Retreat	1		Moiodexno (Molodeczno)	Belarus	12/6/1812	-30 deg	5
49	26.4	54.4	14000	Retreat	1		Smorgoni	Belarus			
50	25	54.4	8000	Retreat	1		Lithuania		12/7/1812	-26 deg	1
51	24.6	55.8	6000	Retreat	3						
52	24.4	54.4	4000	Retreat	1		Lithuania		12/10/1812	-26 deg	

53	24.2	54.4	6000	Retreat	3						
54	24.2	54.4	4000	Retreat	1						
55	24.1	54.4	6000	Retreat	3						
56	24.1	54.4	4000	Retreat	1						

Appendix G: Co-design facilitation guide

FACILITATION GUIDE

Monday, Mar. 5th, 2018

6:30-9:30 pm

NON-VISUAL MAPPING AND MODELLING RESEARCH CO-CREATION WORKSHOP

Team members: Brandon Biggs, Uttara Ghodke, Lena Yusim

MDes Inclusive Design, OCAD U, Toronto

DETAILED AGENDA

6:40-7:00	**Activity 1: Introductions and Ice Breaker**
7:00-7:25	**Activity 2: Problem Discovery**
7:25-7:55	**Activity 3: Review of current maps**
7:55-8:15	Break
8:15-8:40	**Activity 4: Wizard of Oz Prototyping Activity**
8:40-9:05	**Activity 5: Prototype Presentation Template**
9:05-9:25	**Activity 6: Group Prototype**

	Presentations
9:25-9:30	**Closing Comments and Thank You**

GROUPINGS

Facilitation Team:

Brandon Biggs (Facilitator)

Lena Yusim (Facilitator)

Uttara Ghodke (Illustrator)

Guest Participants:

P1

P2

P3

P4

ROLES

Facilitator 1 (Brandon Biggs, MDes Inclusive Design)

- Introduce Activities
- Prompt participants to contribute and share

Facilitator 2 (Lena Yusim, MDes Inclusive Design)

- Collect participant sticky notes and capture notes on stickies

- Facilitate participants while taking notes
- Cluster themes among the sticky notes

Illustrator (Uttara Ghodke, MDes Inclusive Design)

- Collect participant sticky notes and capture notes on stickies
- Manage video recording
- Illustrate ideas

Participant: User of maps

Interested in adopting new technology and very up to date with technological advances. Active on social media sites, and visual learner who is interested in advancements in the mapping world.

Participant: User of maps

Interested in adopting new technology. Has desire to know what's around him, but existing technology does not tell him that there is a shop next door that sells what it takes him an hour of bus travel to get normally.

Participant: Developer

Early adopter of most technologies. Interested in developing new mapping techniques.

Participant: Geospatial Analyst

Early adopter of most technologies. Interested in developing new mapping technologies to comply with accessibility guidelines.

MATERIAL LIST

Templates

- Interview guides x 4
- Prototype buildout template x 1
- Map dataset x 4

Supplies

- Blank paper (large and small format)
- Post-it notes
- Sharpies
- Markers
- Tape
- Scissors
- Glue

Devices

- Video Recorder
- Tablets
- Laptops

Maps

- Tactile maps
- Visual maps

ACTIVITY 1: Introductions and Ice Breaker

Brandon: We would like to take this opportunity to formally introduce ourselves and have you introduce yourselves, and play an ice breaker game.

Throwing the sound ball game:

Participant says their name and makes a unique sound. They say the name of another participant - who will 'catch' the sound ball, and then that person will repeat the first sound to imply they have caught the sound ball, say the name of the next person who they will throw a new sound to, make a new sound, and so on.

Activity:

1. Participant 1: Say name
2. Sound 1: Make unique sound
3. Name: Say someone else's name (participant 2)
4. Participant 2 - Sound 1: repeat sound made by participant 1
5. Name: Say someone else's name (participant 3)
6. Participant 2 - Sound 2: make unique sound
7. Participant 3: repeat sound 2,
8. And so on…

ACTIVITY 2: Problem Discovery

This activity is meant for Identifying the problem which we will solve.

For this activity, the participants will take turns interviewing each other in order to imagine what would be considered a useful map for someone who has a different experience than their own.

Facilitators: We would like to reflect on the interviews we did with you to give you the change to ask about experiences.

Instructions: Take turns interviewing each other to gain some idea of how someone who is not you experiences maps.

Participants: interview each other to discover what works or does not work about a particular experience when it comes to using maps.

Interview teams:

1. P1 + P3 (Lena to take notes)
2. P2 + P4 (Uttara to take notes)

Interview Questions:

1. What is your experience using maps?

2. How do you identify the relationship between two variables on a map or graph?
3. What do you think is the power of maps?

ACTIVITY 3: Review of Current Maps - Napoleon's March

Facilitators: You've already seen the audio interfaces with the audio games, now here is a tactile map.

Review of current maps - Napoleon's March maps:

- Present tactile maps
- Present visual maps
- Present data set

Questions to consider from these representations:

1. What do you find most useful in the tactile representations?
2. Which of the two tactile maps are you drawn to most?
3. What works and what does not work with the tactile representations?

Recall: Think about how the audio game interfaces you were shown in the pre-interview could be incorporated into creating an auditory representation of these maps.

Address questions

Facilitator: We would like to take this time to address any questions you may have regarding the maps you have just seen.

BREAK

ACTIVITY 4: Wizard of Oz Prototyping

Problem: Sonifying Napoleon's March

This activity involves examining existing tactile and visual representations of a famous infographic - Mapping Napoleon's March, and then prototyping an auditory representation.

Brief description of the map

"Probably the best statistical graphic ever drawn, this map by Charles Joseph Minard portrays the losses suffered by Napoleon's army in the Russian campaign of 1812. Beginning at the Polish-Russian border, the thick band shows the size of the army at each position. The path of Napoleon's retreat from Moscow in the bitterly cold winter is depicted by the dark lower band, which is tied to temperature and time scales." (Source: https://www.edwardtufte.com/tufte/posters).

Wizard of Oz

Brandon: We are using the Wizard of Oz technique for prototyping. Now that you have seen the visual and tactile versions of Napoleon's March data, we will have you live prototype an auditory representation of the data. As we do this, Uttara will be illustrating and taking notes.

The wizard is the person who is creating the map. The wizard will direct the sound objects in relation to their position in the 'map' (the classroom). With the dataset in hand, you will direct the sound objects to represent the data using sounds.

Roles

P1: Wizard

P2: Sound objects

P3: Sound objects

P4: Sound objects

Uttara: Illustrator

Lena: Facilitator

Brandon: Facilitator

ACTIVITY 5: Prototype Presentation Template

This is your opportunity to compile your ideas for an auditory map of Napoleon's march based on the Wizard of Oz activity. Uttara has sketched out your ideas to help prepare a short presentation to the group.

ACTIVITY 6: Prototype Presentations

Entire group reassembles in Rm. 420 for presentations.

!!!!!!!THANK YOU FOR YOUR PARTICIPATION!!!!!!!!

Appendix H: Study 4 Coded interview data - Interview with Taylor

Time stamp	Challenges	Strengths	Opportunities	Miscellaneous insights
7s	I've had these maps for a long time, and I like them, but they are really limited in terms of what I can get. This is SE Asia and its huge so I can't really get how far things are relative to each other			
40s		it comes with this pen thing (audio sounds: the Intelliglobe. discover the world with a touch of the pen). I can touch anywhere on here		

2m 47s	*(trying to find Canada takes 43 seconds) So it takes me a long time*	*But its information I never had before*		
3m 10s	I guess children would have been looking at globes but for me it's quite a new thing.			
3m 26s		I play around with it now and then, when I am talking to a person on the internet from a certain country and I want to find it I find it, and I now have the sense oh! that is Central America, so I am getting an idea of how our continents look, the Americas.		

4m 30s	The American Printing House for the blind makes a globe that is just a tactile globe so it would have this overlay on a plain globe but the problem with that is that there are no labels on this overlay so I don't know what anything actually is.			
5m 34s	This is TH is Thailand, but that’s all they have space for in Thailand is TH			

7m 54s			You could make something like this (braille) map that was on say an iPad then if I could touch things and have it read out what it is that would be faster than having braille labels, and also, I wouldn't even try to do the world, but more on this (regional) scale, these ones are more useful, if it were coupled with a touch screen under it that I could push and it would tell me which country I am on.	
10m 40s		I like on this globe how they've done something different for mountains		

11m 00s			(touching braille map) this map does not indicate mountains, so if somehow they could do that texture that would be good too. With speech it could be really precise. it could tell me which city I am touching or have a stylus for that level.	
11m 55s			That's kind of a dream of mine to have audio and tactile combined, and I tried to do it with this globe but the pen is not ideal because it's not designed to go through this overlay	

14m 25s		This globe can tell you continent or geographic features so you can wander around with the pen and find mountains and rivers and that's fun too		
15m 14s	If I want more detail it is nice to not only get where the countries are but also the shapes of them, there would be no way to make a globe with India this big on it, it would be huge			
17m 46s	There's no scale it’s just mountain or not mountain...			

18m 06s			After looking at these for a while, I know this is ocean and this is land, but if the land were higher you wouldn't have to think about it, it would be intuitive	
18m 47s				I did once have a puzzle, designed for kids that was the US, and all the states could be pulled out, I had some trouble labelling them but the idea is nice because when you hold it in your hand you get the shape.

20m 03s			I would say it would be good to mark the north of the piece. If you pull this out of the map, it would be confusing if it didn't have say a scratch indicating that it’s the north arrow, glossy on one side, or wood on the other side, otherwise it would be confusing to put back together, otherwise I think it would be very good.	

23m 02s				*What I have seen sometimes is it's not as easy to distinguish tactically as it is visually and we may have talked about that in the tactile infographics you had. I have seen things where a person will print out say a picture of a heart and it has what you would think of as 16 gray scale with all different dot heights that are very slight, and visually it looks great. but when you run your finger over it the difference of the dot heights of 2 mm is not*

				significant enough. I love how flat and rough is easy and you could do other textures but it's hard to get them to be distinctive texturally.

28m 36s	What about the globe, because I noticed there is a lot of foraging going on because you would be on Africa but thinking you're in another hemisphere, is there anyways of easing that process that you've thought of?			
28m 56s			I think if the continents could come out that would be pretty cool	
	It's not always easy to decide where one continent finishes and one starts...it's a problem I have conceptually, Europe, Asia			

	I am not familiar enough with the globe to have in my mind that the Greenwich mean time would be a good way to find England	But the equator is of course useful		
1h 08m 06s	What the (Intellipen) does not give is the shape. I wouldn't use it if I didn't have the tactile overlay. just knowing something is an ocean isn't enough information for me, I need the shape and the size relative to other things			

				I think my surrounding area. I rarely walk anywhere partly because I have come to realize there aren't that many places to walk to around here but also… I just don't understand… I have a fairly good grasp of the grid pattern of streets in Toronto but when I go north I am not sure what is east west and what is north south anymore. could include streets, businesses...

			There's a mall near here, the only thing I care about is where the door is; so if I know the location of the door off a street that's good enough information, but the mall is a different beast, it has many doors; if there was a model of this area with the mall and I could feel the shape of it and pull its roof off and say inside it, this is the path you'd have to take to find something, like a mini map was inside the bigger map that would be useful	

1h 35m 30s			If you had a map you could trace on the streets the routes you take to get to the mall and then once you get there the mall is depicted and you could see the outside of it what streets go around it where you would have to go to get into the different entrances, and you could remove the roof and see this store is here this store is here. that would be really useful	
			You could make puzzle pieces that are each plate that can pull out of the globe and go back in	