ITG - Tangible Geometry for the Visually Impaired

Exploring the potential of extending tablet functionality with appcessories
Abstract

This thesis explores how an Android application that is used in combination with tangible appcessories is capable of facilitating a learning experience for visually impaired students within the specific domain of geometry. This study’s approach illustrates how using an application in combination with a physical appcessory can provide information concerning geometry to the visually impaired. An application, called Invisible Tangible Geometry (ITG), was programmed using Android in conjunction with a 3D printed model. This thesis describes the application, the physical appcessory, as well as early stage user studies. The application enables visually impaired users to explore simple geometric forms displayed on a tablet through sound and vibrotactile feedback. A physical appcessory, that can be manipulated to adopt several forms and is dynamic, is used in addition. Its shape is sensed by the tablet adds an additional tactile layer to the application and experience.

Within the thesis a methodological framework, as well as a user-centered design approach was applied. An expert interview and three user engagements with visually impaired individuals serve as early validations of the project and ideas and provide feedback that directs design and development of future work. Current avenues for the future work will include additional interaction modes in the application. For example, the ability to digitize real world forms, and improving the robustness of the tangible appcessory.

The plan, for future development, is to establish an autonomous functioning application that enables the visually impaired to be able to explore, participate and interact with geometry smoothly and without the need of aid from others. The correlation of application and appcessory will allow for anything between a quick glance, through feeling the model, and gaining detailed information, by using the application. The application enhances provided information through the use of a model and enriched digital feedback.

Keywords: Visually Impaired, Geometry, Application, Tangible User Interface, Appcessory, Stand-alone Solution
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It was a great journey and I am excited to see what happens next.

Thank you all!
## Abbreviations

<table>
<thead>
<tr>
<th>Abbreviations</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>DPI</td>
<td>Dots Per Inch</td>
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<tr>
<td>ERIC</td>
<td>Education Resources Information Center</td>
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<td>FR</td>
<td>Functional Requirements</td>
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<td>GUI</td>
<td>Graphical User Interface</td>
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<td>HCI</td>
<td>Human-Computer Interaction</td>
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<td>iOs</td>
<td>Operating System by Apple</td>
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<td>ITG</td>
<td>Invisible Tangible Geometry</td>
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<td>NFR</td>
<td>Non-Functional Requirements</td>
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<td>OS</td>
<td>Operating System</td>
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<td>RQ</td>
<td>Research Question</td>
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<tr>
<td>SDK</td>
<td>Software Development Kit</td>
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<td>TTT</td>
<td>Talking Tactile Tablet</td>
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<tr>
<td>TUI</td>
<td>Tangible User Interfaces</td>
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<tr>
<td>UCD</td>
<td>User-Centered Design</td>
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<td>UML</td>
<td>Use Case Modeling</td>
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<td>US SYD</td>
<td>Unga Synskadade Syd</td>
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<td>VI</td>
<td>Visually Impaired</td>
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<tr>
<td>WiFi</td>
<td>Wireless Fidelity</td>
</tr>
</tbody>
</table>
## Contents

1 Introduction .......................................................... 1
  1.1 Motivation ........................................ 1
  1.2 Problems, needs and research questions .......... 2
  1.3 Problem-Solving Approach ........................ 3
  1.4 Structure of Thesis .................................. 4

2 Background ......................................................... 6
  2.1 Current Ways of Teaching the VI ................ 6
    2.1.1 Teaching aids ................................. 7
  2.2 Digital Technology .................................. 10
    2.2.1 Usage in Testing Environments ............... 10
    2.2.2 Tangible Element aka. Appcessory .......... 12
    2.2.3 Mobile Digital Technology ................... 14
  2.3 Resulting Problem-Solving Approach ............. 16

3 Methodology ....................................................... 17
  3.1 Speed Dating Method ................................. 18

4 Prototypes & Evaluations ........................................ 21
  4.1 Concept & Implementation ........................ 21
    4.1.1 Interview with an Expert .................... 21
    4.1.2 Concept ........................................ 22
    4.1.3 Application ................................... 23
    4.1.4 Appcessory .................................... 24
    4.1.5 Correlation of both items .................... 30
    4.1.6 Ideal flow application and appcessory .... 31
  4.2 Software Specifications ............................ 32
    4.2.1 UML ............................................ 32
    4.2.2 Use Cases ..................................... 33
    4.2.3 Requirements .................................. 44
    4.2.4 Programming language ........................ 48
  4.3 The application ITG .................................. 49
    4.3.1 Usability and Accessibility .................. 49
    4.3.2 Implementation ................................ 50
    4.3.3 First High-Fidelity Prototype ............... 53
  4.4 User Studies & Analysis ............................ 55
    4.4.1 First Meeting .................................. 56
    4.4.2 First User Study ............................. 57
List of Figures

2.1 Protractor .............................................. 7
2.2 Geoboard ................................................. 8
2.3 Mylar Board ............................................. 9
2.4 TTT with VI student using it ......................... 11
2.5 TTT sheet with interaction and text .............. 11
4.1 First rough draft of screen with a square, connection lines and
the distribution of the sounds according to the lines ........ 23
4.2 Implemented application with appropriate sound representation 24
4.3 Triangle 1 ............................................... 25
4.4 Triangle 2, overview .................................. 26
4.5 Triangle 2, Zoom 1 ................................... 26
4.6 Triangle 2, Zoom 2 ................................... 27
4.7 Corner Node, sketch
(without the copper tape) .................................. 28
4.8 One Node, Sketch ...................................... 28
4.9 Corner node
(without outer rings) ...................................... 29
4.10 Assembled appcessory (dark) on wooden surface .......... 29
4.11 Assembled appcessory (dark) on tablet with application .... 30
4.12 Use case diagram for basic interactions
(included extensions in blue; future extensions, marked in a
gray outline within the diagram) ......................... 32
4.13 Rough draft - established before the actual implementation
(based on original idea) ................................... 38
4.14 Legend for the functional requirements ................ 44
4.15 Main Screen Sketch showing different modi-buttons, 2 sketches 51
4.16 Main Screen Sketch showing different modi-buttons, Implement-
ation) ........................................................... 52
4.17 Code Example of including and making Mode 4 accessible
through the main screen .................................... 52
4.18 High-Fidelity Prototype 1 ............................... 54
4.19 Application, for shapes, before first user study .......... 63
4.20 Changed Application, for shapes, after first user study, white . 64
4.21 Changed Application, for shapes, after first user study, black . 64
4.22 Changed Application, showing the menu, after first user study,
black ............................................................ 65
List of Tables

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Methodological Framework with integrated HCD approach according to Scaife, 1997, p.345 &amp; IDEO.org 2015</td>
</tr>
<tr>
<td>2</td>
<td>Created Personas</td>
</tr>
<tr>
<td>3</td>
<td>User Scenario 1</td>
</tr>
<tr>
<td>4</td>
<td>User Scenario 2</td>
</tr>
<tr>
<td>5</td>
<td>User Scenario 3</td>
</tr>
<tr>
<td>6</td>
<td>User Scenario 4</td>
</tr>
<tr>
<td>7</td>
<td>User Scenario 5</td>
</tr>
<tr>
<td>8</td>
<td>Functional Requirements</td>
</tr>
<tr>
<td>9</td>
<td>Non-Functional requirements</td>
</tr>
<tr>
<td>10</td>
<td>Comparison of Amazon.com prices for 3 models the 3 models have 32GB and are WiFi only.</td>
</tr>
<tr>
<td>11</td>
<td>Contact with target audience relating to 'encounter', age, gender, vision capabilities and referencing name</td>
</tr>
<tr>
<td>12</td>
<td>Summary of the feedback with status of implementation</td>
</tr>
<tr>
<td>13</td>
<td>Feedback from 2nd user study with priority level for future implementation</td>
</tr>
</tbody>
</table>
1 Introduction

“[A]ny student can reach his or her cognitive potential when instruction is tailored to individual needs”
(Pritchard & Lamb (2012), p.26)

1.1 Motivation

Visual impairment is omnipresent and something everyone has come into contact with at least once in their lives. According to World Health Organization (2014): The term visually impaired (VI)\(^1\) can be applied to people who have low or no vision. 285 million people worldwide, are visually impaired and from these 285 million 19 million are under the age of 15. From the 19 million VI 1.4 million are blind and will be for the rest of their lives, they will depend on “visual rehabilitation interventions for ... full psychological and personal development” (World Health Organization (2014)).

In modern society attending school is part of everyone’s daily cycle of growing up. Integrated school settings are becoming more common and the VI are facing the chance and the challenges of being a part of mainstream schools. The challenges and chances VI students are faced with include, keeping up with classes, not always having assistance, as well as not being able to show their full potential (Pritchard & Lamb (2012)). “[A]ny student can reach his or her cognitive potential when instruction is tailored to individual needs” (Pritchard & Lamb (2012), p.26). As long as the needs for the VI are met they are capable of achieving just as much, if not more, than any other student. Young delegates\(^2\) at a hearing in Brussels in 2011 “highlighted that inclusive education is the first step in being full members of society ” (European Agency for Special Needs and Inclusive Education (2012), p.11). In Sweden, where this thesis project was conducted, “[t]he ... educational system is based on the philosophy that all pupils have the same right to personal development and learning experiences. ... inclusion of all pupils within this principle is crucial and the rights of pupils in need of special support are not stated separately ” (European Agency for Special Needs and Inclusive Education (n.d.)).

During the time VI students spend in school various subjects are encountered. They take classes such as language, science and math. Math, especially geometry, is a very visual subject in which a lot of information is passed and explained according to diagrams, graphs and sketches (Pritchard

\(^1\)Also referred to as the VI

\(^2\)From a variety of countries, age 14-19 and with, and without special needs were invited to the hearing
Passing knowledge in this way can be missed or lost if the recipient cannot see. Currently teachers or teaching assistants try to manually recreate this information in a tangible form (e.g., a triangle for the VI using a geoboard with rubber-bands and pins or wax-paper where lines can be scratched into the surface). These kinds of tangible solutions enable the student to follow some of the explanations but they are tedious and timely to create also they are not typically precise (Pritchard & Lamb 2012). In addition, the VI student cannot create the information by themselves and are reliant on assistance (Pritchard & Lamb 2012).

Over the last few years there has been more research and development of solutions in relation to aiding the VI. For example, the Talking Tactile Tablet (TTT) is built to aid students taking math tests (Landau et al. 2003). The TTT electronic device is connected to a host computer via USB and uses specially prepared paper with raised lines on them to create a tangible representation of mathematical problems. Furthermore, the touch screen of the device lets the user interact through different buttons and shapes with content and trigger audio-feedback. Overall this solution is a great step, but it is only a solution for testing environments. It cannot be adapted quickly to meet dynamic needs, or be used in a classroom setting, as the paper has to be specifically prepared. Also, the information has to be included within the program beforehand. Furthermore, it is not a stand-alone solution but requires a connection to a computer (Landau et al. 2003).

In relation to the TTT other researched has been performed. This focused on understanding how the VI gauge and compare distances, as well as how they create models according to their measurements (Hilton et al. 2012). These difficulties arise as the VI have a different understanding of mathematics due to the fact that visual cues cannot be interpreted, unlike their able classmates (Pritchard & Lamb 2012). This leads to the necessity of the teachers rethinking and adapting their teaching methods accordingly to support VI students (Hilton et al. 2012, Pritchard & Lamb 2012). This is challenging for teachers and, it is clear, they are in need of better assistance than what is currently available (Pritchard & Lamb 2012).

1.2 Problems, needs and research questions

During the education of a visually impaired student the teacher has to modify their teaching methods based on how visual information can be portrayed to the individual VI student (Pritchard & Lamb 2012). Currently this is done through the use of different teaching materials. For example, a geoboard or drawn representations that are etched into special paper (e.g., Polyester Film Sheets) - these approaches do transmit tactile information to the VI. These
methods, however, have similar shortcomings. Both take time to create, assistance from others and are often unsafe (e.g. the VI can hurt themselves on the pins needed to create the shapes on the geoboard) but the most important the representations are not precise.

Through a faster, safer and more accurate creation of information, through the use of an application and appcessory, for the VI the students should undergo a better integration into the classrooms. This will enable students to participate more and in general, have a better educational experience.

Leading from these problems and needs the following research questions were developed:

a) Considering the potential that tangible and tactile learning objects can play in the teaching of VI students, what features should a tangible digital system have to effectively facilitate the understanding of mathematical geometry for visually impaired children?

b) How can the combination of a tangible user interface and a tablet effectively support the learning of mathematical geometry by children with a visual impairment?

This thesis intends to answer these questions and lead to a conclusion.

1.3 Problem-Solving Approach

This thesis explores the potential of combining an appcessory and an application running on a tablet computer. It is important that the system can run without additional computers or input devices. The appcessory will enhance the application and make the interactions more tangible for the visually impaired student. To follow this approach, decisions about the device platform, as well nativeness were made. Furthermore, the appcessory was planned, printed and tested.

The platform, which was chosen for running the application, was based on price, and trending market shares for tablet sales and their forecasts. Android run tablet computers and smartphones are, overall, cheaper to buy than comparable devices such as iOs based iPads and iPhones. The market shares of Android devices, have risen over the last few years drastically - 2015 the share was 66% in tablet sales (Statista (2015)). This number, according to the forecast, will continue to stay stable (Statista (2015)).

3The word appcessory is a term that refers to “[a] physical device and counterpart application for a mobile device” (PCMag Digital Group (2015)).
Whether the application should be native or web run was decided based on the assumption that a native application will be more accessible and easier to use than a web-based one. If the application is present on the tablet and installed, navigating to it is less complicated and more easily accessible.

The assumptions were based on the following factors:

- Having a native application has a better integration with the sensors, better access to internal hardware,
- It is easier to access for the VI as there is no need to navigate through a browser to the correct url, access the information and interact with this process
- It provides more control of the screen (from a programming point of view)
- An additional point is that the whole functionality is only given with an Android device as other devices, e.g. an iPad, might not vibrate
- Also the establishment of different entry levels, within the application, might cause issues with different user accounts

A User-Centered Design\(^4\) (UCD) approach was applied to both the development of the application and the appcessory. UCD was used to verify and test the solution through user studies and interviews. This empirical exercise tried to ensure that the target group was able to use it without difficulty and that they were satisfied with the proposed solution. The expectations are that further information will be identified and the needs of the visually impaired will be clarified in terms of the development of this application.

1.4 Structure of Thesis

The thesis is structured the following way: Chapter 2 reviews the conducted background research. In Chapter 3 the methodologies are illustrated in detail. Chapter 3 describes the taken approaches concerning the design process, and which interview techniques were followed. In this effort the methodological framework by Scaife et al. (1997) was combined with a User-Centered Design. Within Chapter 4 Prototypes & its Evaluations a description of the concept and design of the application\(^5\) will be given. Additionally it is dedicated to illustrate the implementation approach and the user studies executed to

\(^4\)More information concerning the UCD can be found in Chapter 3.
\(^5\)The application is called Invisible Tangible Geometry, short ITG
verify the the application and appcessory. It also reflects upon the insights gathered in this process and the implications of future development. Chapter 5 *Discussions & Lessons learned* answers the introduced research questions, and presenting lessons learned. The finishing chapter is dedicated to *Conclusion & Future Work*. Within this chapter a summary of the performed work is given and a brief reflection is presented. In addition, the future work is presented.
2 Background

The overview of the research problem introduced in Chapter 1 was used as a guideline to frame the early attempts to identify the needs of visually impaired, current obstacles and teaching methods used to enable the VI to learn and understand. The research questions are:

a) Considering the potential that tangible and tactile learning objects can play in the teaching of VI students, what features should a tangible digital system have to effectively facilitate the understanding of mathematical geometry for visually impaired children?

b) How can the combination of a tangible user interface and a tablet effectively support the learning of mathematical geometry by children with a visual impairment?

This chapter is separated into multiple sections:

- Starting with the current ways and tools used while teaching the VI,
- then it continues with a view onto a current tool used developed to be used in testing environments,
- afterwards, the technology aspect will be highlighted which covers the tangible element and the need for it within this approach
- as a closing argument, the currently used mobile technologies, and the resulting problem-solving approach, will be presented.

2.1 Current Ways of Teaching the VI

To identify current teaching approaches research was conducted using Education Resources Information Center\(^6\). ERIC, as a database, was used as it was suggested during a librarian meeting. It was founded 1964 and every article has to pass their Selection policy, which is updated on a regular basis. This meeting was conducted to ensure that the correct database and search terms were used, as the researcher did not have previous experience with education-oriented research. Resulting from this research, important insights into teaching methods, and tools were gathered. In the following sections the teaching methods, and tools are described in detail.

During the research that was concerning teaching approaches, and methods, the following information was found. In general, the research pointed out that “[V]isualization is imperative in understanding geometry” (Pritchard &

\(^6\)Short called ERIC, accessible here: http://eric.ed.gov/
Lamb (2012), p. 23) but also that “[g]eometry is a visual subject, but visualization is not reliant solely on one’s eyes. ... see the beauty of this subject with ... hands ... [seeing] mathematics through ... [the] “mind’s eye””) (Pritchard & Lamb (2012), p.26).

2.1.1 Teaching aids

The teaching aids currently used for students with visual impairment are braille rulers, protractors, geoboards for graphic representations, audio calculators, and mylar polyester film boards (Pritchard & Lamb (2012)). The braille ruler, and the protractor helps the VI to both measure distances or angles. A braille ruler is similar to a ruler for the abled, however, instead of printed measurements, the measurements are represented in braille. A protractor is a half-circle with a straight bottom - sometimes equipped with a physical movable indicator that points towards an angle with braille writing (cf. Fig. 2.1).

![Protractor](http://goo.gl/6OKIYs)

Figure 2.1: Protractor
Source accessible here (http://goo.gl/6OKIYs).

A geoboard consists of a material (e.g. a wooden board), making up a base, with pins or screws in it. This enables the fastening of cords or a rubber band. With this, the visually impaired can either create shapes on their own or feel shapes drafted by someone else (cf. Figure 2.2).
A possible user scenario could be: a teacher draws a triangle onto the chalkboard and another student or an assistive teacher places rubber bands around metal pins on the board to recreate the shape drawn by the teacher.

Another possibility is that the board is made from cork-board, where several thumbtacks are pushed in and the rubber band is fastened around these pins to create the shape. This way it can resemble any shape without disturbing the exploration through other pins. One big problem is that the pins (on interaction or pressure from the rubber bands) can fall out or get loose and stab the visually impaired student or their assistant.

![Image of Geoboard](http://goo.gl/XGBDTP)

An audio calculator, as the name suggests, is a calculator that, by giving audio feedback, enables the VI to do calculations.

A polyester film board is (typically) a rubber covered board where a special paper is mounted on top (cf. Figure 2.3). The paper can be, for example, made from polyester film or wax paper. It is a piece of paper coated with a polyester film, which enables the creation of raised lines through pressure. When a pen is drawn over this paper a raised-line is created, which has a tactile feel to it. Using this line the VI student can feel a drawn shape.
Through these methods visually impaired students can gain an understanding of shapes, forms and geometric figures.

2.1.1.1 Note taking

An additional important feature of enabling the learning of mathematics and geometry is taking notes. It is a key-element of following and understanding this subject. Assistance is often needed for the VI to take notes. In addition, the VI student also has to complete scratch work (for example, sketching of information on wax paper) and search the taken notes all whilst trying to follow during class and solve complicated tasks. These tasks, in combination, can create unneeded challenges for the VI. Especially, the task of taking notes can be particularly daunting as braille takes up more space and often causing paper-stacks. Furthermore, the VI cannot easily scan that information, so finding information often becomes time consuming. An additional issue is that in braille there is no shorthand signs like the ones used in written Geometry that help sighted students. VI students must learn only the different meanings and the concepts instead of the shortcuts available to able stu-
2.1.1.2 Learning material

A big problem for the VI in classroom settings is that a special version of standard text books are needed. These books are often not published or available in time, thus the student has to work with other means (Pritchard & Lamb (2012)). Supporting teachers who can translate and transcribe assignments and other material into braille, are (typically) responsible for multiple VI students. This leads to them to be in high demand and thus they cannot be present at all times (Pritchard & Lamb (2012)).

2.1.1.3 Challenges

The challenges, as outlined in the above sections, put the teachers and assistants into a position where regular teaching methods cannot be simply applied but have to be either altered or drafted in completely new ways.

One teaching approach that is being applied is cooperative learning. Through the use of this approach, close collaboration between the students is established - the sighted students read the instructions out loud and open up the discussion, and the information to the VI. This approach is shown to be beneficial for all participants (Pritchard & Lamb (2012)).

Another solution to enable the visualizing of information for the VI can be achieved through the use of a simple thumbtack. Assistance and a sheet of braille paper with punched holes in it allows for shapes, and additional information, such as graphic numbers to be represented in a way that is easy for the VI. Working with assistance the VI can interpret this information accordingly.

Additionally, the use of building blocks, instead of trying to portray shapes through drawings for complex 3D figures, can be beneficial. Also building things with card stock, pens and lots of creativity is proven to be accessible for the VI and lets them understand more.

2.2 Digital Technology

2.2.1 Usage in Testing Environments

The idea that relates closest to the one described within this project is the Talking Tactile Tablet (also referred to as TTT) (Landau et al. (2003))(cf. 2.4, 2.5). The TTT is a device that makes “graphical elements from multiple-choice math tests more accessible to students who are visually impaired or
are otherwise print disabled ” (Landau et al. (2003), p. 86). The setup of the TTT is an “inexpensive electronic device connected to a host computer via the USB port” (Landau et al. (2003), p. 86). TTT works with specifically prepared sheets. These sheets are placed on top of the devices touch sensitive screen. Through the addition of sound, which can be activated through interaction with various shapes and buttons, the tablet becomes a strong source of information. The TTT is specifically catered to be a rather autonomous testing environment for the VI. The tablet combines tactile- and audio-feedback, an additional layer is the use of Braille in some parts.

![TTT with VI student using it](http://exceptionalteaching.com/talking-tactile-tablet-qtt/)

**Figure 2.4:** TTT with VI student using it


![TTT sheet with interaction and text](source (Landau et al. (2003), p. 87)

**Figure 2.5:** TTT sheet with interaction and text

*source:* (Landau et al. (2003), p. 87)

Some feedback from TTT testers was that adding some color to the TTT app, to make separation / association / differentiation of graphical aspects
easier, would be beneficial (Landau et al. (2003)). This idea emphasizes the need for more tailored environments for different needs and disabilities. Calibrating the TTT by the VI before start of a test, and having to re-prompt repetition of information is important. Furthermore, the repetition should be slower to ensure understanding. Use of bigger graphics can also ease interaction with the information as it makes it easier to interpret (Landau et al. (2003)).

Autonomous use could be beneficial as the VI might feel ashamed by their own incapability when others are watching. Otherwise, they have to ask the proctor to repeat or recreate things for them often. It would create a feeling of relief and ease if an autonomous method was implemented (Landau et al. (2003)).

During the testing phase of the TTT study, it came to the attention of the researchers that only four out of eight testers were able to read braille, because of this, the use of it should only be complementary and not as a main source of information. Furthermore, the sound feedback should be according to the VI's individual needs, (e.g. speed, volume, etc). This ensures that the VI can interpret the information audibly (Landau et al. (2003)).

2.2.2 Tangible Element aka. Appcessory

To include an appcessory was a choice inspired by studies including “Designing tangible magnetic appcessories” (Bianchi & Oakley (2013)) where new angles of interaction and manipulation mechanisms for tablet surface were explored. A appcessory is a term that refers to “[a] physical device and counterpart application for a mobile device” (PCMag Digital Group (2015)). The “techniques that lower barriers to entry, facilitate early stage prototyping and enable tangible systems on alternative platforms and form factors” (Bianchi & Oakley (2013), p.1). These alternative platforms and form factors are beneficial to the research community, especially, while working with the VI as it opens up possibilities for the developers, and future users.

Bianchi and Oakley state: “ubiquitous multi-touch capacitive sensing screens on tablets and smartphones can be appropriated to create tangible interfaces” (Bianchi & Oakley (2013), p. 1). This statement also strengthens the idea of using a tablet with the integration of a appcessory in order to create effective tangible interfaces. To create an appcessory for a tablet the process can be, in comparison to other complementary items, relatively easy and cheap to accomplish. Through the application of “conductive paint ... on physical blocks” (Bianchi & Oakley (2013), p. 1) and making use of “either human contact or active electrical components to simulate finger touch” (Bianchi & Oakley (2013), p. 1) the appcessory becomes interactive.
To make an appcessory interactive a means of transporting charge has to be added. Considering this, two means were explored and researched.

The use of conductive, also referred to as electric, paint, and copper tape. Conductive paint is a rather new product, having been developed in 2010 by a company, now called, Bare Conductive (Bare Conductive (2016)). Originating from the idea of conductive body paint it has evolved and can now be purchased through their website (Hickey (2014)). The paint is removable through the use of soap and water, is non-toxic, which ensures that the use is not dangerous even when working with young users. It can be applied to almost any surface (Bare Conductive (2016)).

Copper tape, on the other hand, is a rather commercial product. As copper has conductive qualities the application of this within an appcessory is intriguing. Within this setting a quick introduction was provided and the possibilities of building low-key appcessories was explored.

The need for a TUI was identified as a requirement as it is easier for a VI individual to “bring a familiar, easily usable physical element to the interface, whereas the GUI approach is very abstract”((Garber 2012), p. 16). “With a GUI, mice or keyboards enable input only. And neither onscreen icons nor their manipulation physically represent either the data being processed or the actions being taken with the information ”(Garber (2012), p. 15). With a TUI, the interaction can be perceived more naturally and makes the interactions more effective (Garber (2012)). A TUI “can be used independently; shuffled in a user’s hands, stuffed in a pocket, annotated and labeled, or even lost ”(Oakley & Esteves (2013), p. 5). This is, overall, appealing and opens up more interaction possibilities.

Some TUIs feature interactions through the use of touch screens, which “detect[s] touches by creating an electric field above their surface ... as objects with capacitance, such as [a] human finger, comes close to the surface, this electric field changes. The touch screen measures this change and reports a touch ”(Voelker et al. (2015), p. 351).

This concept can also be extended and manipulated through the application of conductive ink, metal, magnets, and copper tape. This opens up the possibilities for low-fidelity prototyping (Liang et al. (2013), Wiethoff et al. (2012), Weiss et al. (2009), Wolf et al. (2015)).

“Like other HCI technologies, tangible user interfaces (TUIs) strive to increase human productivity by making their digital tools easier to use. Tangible user interfaces achieve this by exploiting human spatiality, our innate ability to act in physical space and interact with physical objects. The desktop mouse is a powerful and early example of the impact this approach can have on HCI and productivity ”(Sharlin et al. (2004), p. 338).

A different approach to create a tangible element is to provide a display
that can shape, change and react to input. One way to create such a display is shown by Follmer et al. (2013) with inFORM. inFORM explores the possibilities of combining “dynamism of visually perceived affordances of GUIs” (Follmer et al. (2013), p.1) with “physical interaction by utilizing shape-changing UIs” (Follmer et al. (2013), p.1). With this “state-of-the-art system for fast, real-time 2.5D shape actuation, co-located projected graphics, object tracking, and direct manipulation” (Follmer et al. (2013), p.2) a new angle is being explored that can aid the user and creates a new way of interacting with objects as well as display information.

It is a complex system that has potential but cannot be easily transported or be used independently. Even though it is a great exploration in the field it would be hard to incorporate it within a school or make it available for the masses. As far as the interfaces and interactions are concerned it is an inspiring approach that can influence future technology.

Making use of these capabilities should enrich the VI interactions, and establish a quicker way into the material. As interacting in the physical space the entry level to geometry would be lower, which can only be positive to learn something new and, possibly, challenging.

2.2.3 Mobile Digital Technology

During the performed background research the following insights were gathered to be able to identify the features of, currently used technologies, and the requirements an application, like the one aimed for within this thesis, should have.

Within the field of mathematics two modes of communication are used. These are speech and graphical representation. Visually impaired lack the ability to use graphical information (Quek & Oliveira (2013)). To cater to this lack of information methods have been developed to establish a sense of understanding such as the use of swell paper, embossing or thermoform, geoboards, braille printers or paper raised-line drawings (Jayant et al. (2007), Toennies et al. (2011), Quek & Oliveira (2013)). This does partially suffice and communicate some of the information to the VI but it can be static, dangerous and slow when trying to keep up within a classroom setting. Furthermore, these solutions do not allow students to work autonomously and they need help to create the information methods.

Sound and the variations of sounds are well picked up by the VI. Consequently, the “use of tones with variation of pitch and loudness to guide an unsighted user” is very effective (Cohen et al. (2006), p. 280). In addition information was gathered that specific applications are developed for children (age 8-12) to fulfill their needs (Droumeva et al. (2007)).
The following leads and information were revealed concerning the technologies currently being used, and the ones, which are appropriate.

Currently used technologies are haptic mice, joysticks (Bussell (2003), Klingenberg (2007), Manshad et al. (2013), Milne et al. (2014), Tzovaras et al. (2004), Wall & Brewster (2006)), and PHANTOM devices (Crossan & Brewster (2008), Moll & Pysander (2013), Rassmus-Gröhn et al. (2007), Saarinen et al. (2005), Tzovaras et al. (2004)). These technologies serve their purpose but so far no standalone solution has been developed. This is a main aim of the application described in the section 4.1.3 of this thesis.

An important feature that was identified was to use tactile feedback. As it “aids the user and enables them to gather information more easily” (7.1, p. 7). Approaches that have been taken so far are sonification (Droumeva et al. (2007), Milne et al. (2014), Wall & Brewster (2006)), and audemes (Ferati et al. (2012)) and area hinting (Su et al. (2010)). “[A]udemes ... are short non-speech sound symbols, comprising various combinations of sound effect and music sounds” (Ferati et al. (2012), p. 937). Whereas, sonification is the addition of sounds to the use or interaction (for example, within an application), alternatively area hinting plays sounds when an area within a certain surrounding is touched. Different sounds are applied to different areas which enables an understanding of positions. The intention of displaying and “conveying visual information via a commercial tablet” with a “vibro-audio interface” (Giudice et al. (2012), p. 103) was not researched or done often therefore there is little information available. For the development of the application, it is important to involve end-users to be able to create an applicable solution. This is often an issue with current VI-oriented development, as many implementations lose focus and direction when they do not keep end user input in mind (Giudice et al. (2012)).

Concerning the functional and nonfunctional requirements the following information was gathered. In general, the application is good when the elements used are “balanced and contribute to a high fidelity, information-rich-environment” (Droumeva et al. (2007), p. 171).

A technique that should be applied for the conceptualization of the application is making use of an active display. This refers to the option that the fingers of the user can move freely over the screen in order to explore it (Xu et al. (2011)). Another option is to make use of a touchscreen as the implementation and use of the vibrotactile feedback is useful for the VI and fairly accessible during development. A screen fitting this description is, for example, an Android device screen.

The application might be used by more than one person therefore the implementation of profiles with different accessibility features and levels should be implemented to work towards these different needs. The start screen
should provide an access level that suits the most users and more specific needs through the use of a profile (Grammenos et al. (2009)).

The use of sound cannot be added to the application as an afterthought as it is a main feature. If not implemented correctly it could compromise the usability instead of aiding it. Area-hinting as a technique is to be considered (Droumeva et al. (2007), Su et al. (2010)).

2.3 Resulting Problem-Solving Approach

The approach described in this thesis combines an appcessory and an application running on a tablet computer. It is important that the system can run without additional computers or input devices to make it easier to set up, transport and use. The appcessory will enhance the application and make the interactions more tangible for the student with visual impairment. To follow this approach, decisions about the device platform, and the nativeness have to be made. Furthermore, the appcessory has to be planned, 3D printed and tested.

The platform that was chosen for running the application was based on price, and trending market shares for tablet sales and their forecasts. Android run tablet computers and smartphones are, overall, cheaper to buy than comparable devices such as iOS based iPads and iPhones (extended in Chapter 4). Furthermore, the market shares have risen drastically over the last years - 2015 the share was 66% in tablet sales (Statista (2015)). This number, according to the forecast (Statista (2015)), will continue to stay rather stable.

To decide whether the application should be native or web-based, the assumption was made that a native application will be more accessible and easier to use than a web-based one as it is present on the tablet and installed, which means there is no long navigation to the application needed. Both the application, and the appcessory were verified and tested through user studies and interviews applying a user-centered design approach (more information can be found in Chapter 3). This validation ensures that the target group is able to use it without difficulty and is satisfied. The expectations being that further information will be identified and the needs of the visually impaired will be clarified.
3 Methodology

Within this chapter the applied methodologies are explained. To be able to develop the application the methodological framework proposed by Scaife et al. (1997) was adapted and applied. The adapted framework, through its combination of approaches, allowed the collecting of rich in-detail information that in turn contributed to the creation of a prototype suiting the needs of the visually impaired. Furthermore, as the idea pursued within this thesis is aimed to aid the VI, it was especially important to integrate the target group within the development as early as possible.

The methodological framework was developed with the end-user in mind. It was used as an aid to schedule, plan and develop project stages, and testing and can be considered a general plan of action. The complete methodological framework can be seen in Table 1.

Within a user-centered design it is important that the “user [is] involved through the development of the project ... Specific usability and user experience goals should be identified, clearly documented, and agreed upon at the beginning of the project. ... Iteration through the ... activities is inevitable” (Rogers et al. (2002), p. 13).

The correlation between the methodological framework and the user-centered design approach was seamless. As the methodological framework focuses on the user, contact with them, and experts or informants and channels the insights, it was a useful step to enhance the approach with a channeling through the UCD. Within user-centered design there are three principles that can lead to a proper functioning system that supports the user. Firstly there is the early focus on users and tasks, secondly empirical measurements and lastly iterative design. Through this combination the user is in the center and the end-product will meet the needs of the VI.

With early focus on users and tasks refers to trying to understand the user’s characteristics. Studying the user while they perform tasks etc. would be necessary (Rogers et al. (2015)). Within this thesis, this was not performed the intended way but through research (Chapter 2.2) an insight was gathered. As it was not possible to get in contact with visually impaired children, who currently learn geometry, the broader target group (visually impaired individuals) were contacted. In addition to the research, two interviews and a guided tour with a VI individual took place (more in Chapter 3). The first interview was performed with an expert within the field of VI. The second interview was done with two visually impaired individuals. During the guided tour, it was demonstrated how he worked, used his computer and, which tools he had to make his day easier. For example, his devices
(e.g. computer screen) were set-up in a way of working with a black-white contrast and a zoom-function, which enabled him to read emails and interact with texts easily. Through these insights, provided through the guided tour, the development of the application and appcessory was lead.

During the empirical measurements phase the user gain access and react to first sketches, ideas and prototypes. Afterwards this information is evaluated and analyzed so that the idea can be developed further (Rogers et al. (2015)). This information leads into principle three: Iteration. Through the gathered information, problems, issues and thoughts from the measurements be implemented and will, afterwards, be tested within the measurement as often as needed (Rogers et al. (2015)). Through these loops the product will reach its potential. For some of the user studies the think aloud usability tool was applied. It provides an easy access to the inner thinking of the testers and insights are easily gathered. The users are asked to simply express their thoughts while interacting with an interface. This approach is an easy, robust and flexible solution (Nielsen (2012)).

“Evaluating what has been built is very much at the heart of interaction design. Its focus is on ensuring that the product is usable. It is typically addressed through a user-centered approach to design, which, as the name suggests, seeks to involve users throughout the design process. There are many different ways of achieving this: for example, through observing users, talking to them, interviewing them, testing them using performance tasks, modeling their performance, asking them to fill in questionnaires, and even asking them to become co-designers. The findings from the different ways of engaging and eliciting knowledge from users are then interpreted with respect to ongoing design activities.” (Rogers et al. (2002), p.13-14).

Within the scope of this thesis, two user studies were performed and two iterations were implemented (more in 4.4.2 4.4.5). The conducted studies took place with (in total) 4 adults who were not the precise target audience, as these are visually impaired students learning geometry, but as a beginning of validation of the idea it was a 'suitable choice'. In the future, tests need to be executed with VI children to ensure that their specific needs will be represented and that their thoughts are included in the design.

3.1 Speed Dating Method

The last user study was extended where an interview was performed. For this, the so called Speed Dating approach was taken. In this approach, short
stories will be provided to the participants and after listening to these, a discussion is encouraged. Important was that the stories do neither have to be true, realistic or have been established but can be fictitious.

The Speed Dating method was inspired by actual *Speed Dating*, which is (essentially) an event where single people come together and meet each other in a pre-defined, timed ‘date’. So applying this to a user-centered design, or in the case of this thesis a human-centered design, enabled the conductors to present the audience with multiple design ideas in a quick way to gather as much feedback as possible (Davidoff et al. (2007)). “[V]arieties of interventions, the design team gains insight into the social and contextual factors that most strongly influence a situation, helping them understand more about their user needs in the face of this potential intervention ” (Davidoff et al. (2007), p. 430). Often this is done through e.g. story-boards or sketches, which are highly visual wherefore it does not apply well to the target audience for this project - it was adapted to a storytelling session presenting participating users to envision the ideas without the visual aid. More information concerning this can be found in 4.4.5.1, and in the Appendix 7.4.1 where the complete scenarios will be available.

The Speed Dating method closely relates to UCD, and the methodological framework as it can be considered to be a User-Centered approach of gathering user information. It can provide a deep insight into wishes, hopes and dreams of the user group, which than can be used for validation, development and creation of ideas.

This is, within UCD, a main aim - creating objects that fulfill the user’s needs. Furthermore, the Speed Dating method opened up room for discussion without relying on having users with either a lot of background information or imagination as it can be difficult to think of new things when confronted with a topic without having time beforehand to think about it.
<table>
<thead>
<tr>
<th>Phase of Design</th>
<th>Informant / Design Team Contributor</th>
<th>Input</th>
<th>Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 0 - Basics &amp; Necessities</td>
<td>Conductor</td>
<td>Thesis Requirements; Hardware; Technology Requirements</td>
<td>Define programming scope</td>
</tr>
<tr>
<td></td>
<td>Informant (Interview)</td>
<td>Idea verification</td>
<td>Interview</td>
</tr>
<tr>
<td>Phase 1 - Define Domain &amp; Problems</td>
<td>Conductor</td>
<td>Specify problems; Identify Research Questions (RQ); Compare Learning material &amp; approaches; Begin prototyping</td>
<td>Meeting with librarian; Research; Preliminary sketches; ideas for representing domain</td>
</tr>
<tr>
<td>Phase 2 - Translation of specification</td>
<td>Conductor</td>
<td>Turn requirements into software specifications &amp; determine feasibility</td>
<td>Storyboard; sketching; scenario creation;</td>
</tr>
<tr>
<td>Phase 3 - Design low-tech materials &amp; test</td>
<td>Conductor</td>
<td>Test design assumptions</td>
<td>Mock-ups (paper &amp; low-tech)</td>
</tr>
<tr>
<td></td>
<td>VI (First Meeting)</td>
<td>Provide insight on building interface</td>
<td>Try out the prototype (user studies)</td>
</tr>
<tr>
<td></td>
<td>Informant</td>
<td>Feedback</td>
<td>Interview; Email Contact;</td>
</tr>
<tr>
<td>Phase 4 - Design &amp; test hi-tech materials</td>
<td>Conductor</td>
<td>Flesh out &amp; validate design aims based on output from above phases</td>
<td>Prototype hi-tech designs using a multimedia programming environment</td>
</tr>
<tr>
<td></td>
<td>VI (Testing 1)</td>
<td>Evaluate prototype, 1st feedback round</td>
<td>Try out the prototype (user studies)</td>
</tr>
<tr>
<td>Phase 5 - Iteration</td>
<td>Conductor</td>
<td>Change prototype according to feedback from phase 4</td>
<td>Change &amp; adapt prototype</td>
</tr>
<tr>
<td></td>
<td>VI (Testing 2)</td>
<td>Evaluate prototype, 2nd feedback round</td>
<td>Try out the prototype (user studies &amp; interview)</td>
</tr>
</tbody>
</table>

Table 1: Methodological Framework with integrated HCD approach according to Scaife, 1997, p.345 & IDEO.org 2015

Speed Dating Method (** explained below)
4 Prototypes & Evaluations

Within this chapter the concept, as well as evolution of the prototype is described. Building on the concept, the creation of the prototypes will be displayed. The prototype creation reflects upon programming the application in Android, based upon the gathered requirements and the additionally gathered ones, as well as the printing and assembling of the appcessory. Furthermore, the interviews with experts, target audience, as well as the user studies are presented.

4.1 Concept & Implementation

Within the concept and implementation section, a detailed description of the concept for the application and appcessory, as well as the implementation is presented. The concept section is separated into a description of the concept, followed by a description for the application and appcessory, as well as the correlation of these two items. Before the concept is elaborated, an expert meeting is presented. Within this meeting the idea was validated and afterwards further developed.

Leading from that meeting, the UML for the application is presented. Afterwards the use cases drafted, and used for creating the software requirements and implementing the application, are shown. Following the chosen programming language and a motivation for the chosen environment is given. Lastly, the implementation is illustrated. Including a description of the first high-fidelity prototype.

4.1.1 Interview with an Expert

The interview with Mexhid Ferati, held on 19.11.2014, had an informal structure and provided insight into his thinking process. He is an Assistant Professor at South East European University. Dr. Ferati is an expert on user interfaces for the visually impaired and has published a variety of papers concerning this topic.

Dr. Ferati has experience with designing ideas and tools for the visually impaired, as well as testing them with his target audience. Through the meeting a first validation of the concept was performed, which secured a further development. An important topic covered during the meeting was

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8The assembly instructions can be found in the appendix (7.5)
9UML = Use Case Modeling
10The notes for the meeting can be found in the Appendix 7.2
11His publications, as well as his profile can be accessed here: http://bit.ly/1w1L2vw.
his experience concerning user tests and approach on visualizing geometry. Firstly, the testing approach of blindfolding testers was verified. To verify the concept, idea and first prototype it is suitable to blindfold testers. This can show in which direction the prototype should develop. He has, in his efforts, performed this sort of testing to quickly verify his ideas as testing with the target audience is not an easy task. Secondly, it was inquired on how he would approach visualizing geometry to the VI. Within his research, he established audemes. An audeme is an audio cue used to create a visualization of a short text when an image is not accessible. Lastly, a discussion concerning the future within the field was held. According to him GUI’s created a dent in helping everybody else. The gap between the VI and us will decrease over time. Furthermore, he provided some more thought input, references, names and possible contacts, which could be pursued.

4.1.2 Concept

The general concept followed for this project was to produce an aid for the VI that can be used autonomously. One of the most important aims was to create a product that will be helpful to all. The use of an Android tablet, as well as a 3D printed appcessory, and the use of the copper tape, were low-cost solutions. The assumption was made that once the appcessory is ready for public use it could be ordered and printed by any 3D printing website, which would ease the gaining of access to this technology. Building instructions will be made available along with the printing template.

The concept of the application was as follows: The development of an application supporting multiple touches on a touch screen will allow for shape creation either through finger or model placing. Between the different touch-points on the screen connective lines will be drawn to create the shape. On contact, the lines, will vibrate. Additionally sound will be used to suggest, which part of the screen is being touched. Through the combination of the tactile feedback and the area hinting the VI could gather an understanding of the shape, as well as of the position the finger has on the screen. During the background study it was established that these two approaches of informing the VI are efficient and the VI respond to them well (Landau et al. (2003), Su et al. (2010)).

Separation of the screen into multiple areas, according to the lines and corners of the tablet, was planned to be able to apply sound feedback accordingly. Even though the input would be performed through multiple touches the exploration of the created shape would only take place with one finger for multiple reasons. Firstly, playing different sounds when a finger leaves the screen would be confusing. Secondly, the tablets only have one vibra-
tion motor therefore it would be hard to distinguish, which line triggers the vibrations and the understanding of the shape would be made more difficult. Lastly, the multi-finger exploration would take place on the printed appcessory. The appcessory is reusable and customizable in shape and size.

4.1.3 Application

The application evolved from the first sketch (cf. 4.1). In this sketch the previously described distribution of the screen according to the shape, lines and corners of the screen are shown. This idea evolved into a simplified approach where the screen is only separated into two areas - within and outside of the shape. Through this change the precise shape will not have an influence on the amount of areas on the display.

Having a varying number of sounds and areas could be perceived as confusing by the user. Additionally it could complicate the interactions. The current prototype with the distribution of the screen can be seen in Figure 4.2.

![Figure 4.1: First rough draft of screen with a square, connection lines and the distribution of the sounds according to the lines](image)

Figure 4.1: First rough draft of screen with a square, connection lines and the distribution of the sounds according to the lines
4.1.4 Appcessory

The focus of the appcessory was to create a versatile and interactive object. The idea evolved from a more stable appcessory with two fixed corner points (cf. 4.3). This lead into a more flexible approach in which the joints can move independently from each other and can be connected to one another (cf. 4.4, 4.5, 4.6).
Figure 4.3 illustrates the first concept for the appcessory. The purple-striped line (diagonal, solid line) resembles a flexible element, which could be created through a thicker rubber band, connected at the corner-points to the more stable parts of the triangle. The triangle can be moved and expanded, stretching the rubber band. This enables the user to be able to create a triangle with various angles. The little green dots resemble moving parts, which can be manipulated and establish a different shape. The two green-yellow, tile or green lines resemble the different sides of the triangle for identification purposes.
The sketches (Figure 4.4, 4.5 and 4.6 illustrate the idea for the interactive, manipulable element. There were two types of connection rods. One kind is hollow on the inside and the other rod fits into this shell. The stability will be achieved through little bubbles, which can fixate the position of each rod and establish the length. Through pulling and pushing of the different rods the length and shape can be manipulated. The corners were to be established through the inclusion of a ball. Around the balls copper tape was to be applied to ensure the connectivity between the appcessory and the tablet.
With these idea descriptions the printing of the model was approached. In discussion with a 3D experienced developer, the appcessory was designed and assembled. During this design process, the communication, exchange and discussion with the 3D developer, the idea evolved further into the prototype.

The final design consists of a set of ball-and-spoke components. Each one features a corner node connected to one narrow (5 mm) rod and one wide (11 mm) hollow rod (cf. Figure 4.7). As suggested in Triangle 2 these should be connected to one another but the narrow rod was printed smooth instead of adding little bubbles onto the rod. This way the pieces move very easily, which allows easy manipulation.
The nodes (top and bottom) are flattened and are covered with copper tape. This way, they can sit squarely on the tablet or table (Rühmann et al. (2016)) (cf. Figure 4.7, 4.8]. The inner cylinder is enclosed by three rings, the top and bottom of the node (cf. Figure 4.7]. The rings can be moved separately from one another and the rods (hollow and solid) are glued to them. The solid 5 mm rod is connected to the center ring, whereas the hollow 11 mm rod is connected to the slimmer outer rings (cf. Figure 4.9.

The measurements, lengths and sizing of the elements were a calculation based on the screen size of the tablet (Google Nexus 10 with the measurements: 263.9 mm by 177.6 mm), which was used for the application.
Figure 4.9: Corner node (without outer rings)

The assembled appcessory can be seen here\textsuperscript{12} (cf. Figure 4.10):

Figure 4.10: Assembled appcessory (dark) on wooden surface

\textsuperscript{12}Photographs of appcessory and appcessory on tablet (following) by Kevin Dalli (cf. Figure 4.11)
4.1.5 Correlation of both items

Combining the digital application with the tangible appcessory was planned to enhance interaction, as well as the understanding of geometric shapes. The idea being: that combining both elements and working towards other senses (touch and sound) the VI can simply explore the shapes in more detail. Exploration of shapes was\textsuperscript{13} performed easier when being able to explore the object with more than one finger, as well as having the option of exploring it in more than one direction. As the representation would not be one-dimensional but extend into three-dimensional space. This expansion of the understanding and plane has extended possibilities of understanding shapes. The VI are often challenged and have small understanding of how planes come together. In some cases, students stand on chairs and feel corners of walls to grasp an understanding of a 90 degree corner or the connection between multiple planes (Dick & Kubiak (1997)).

\textsuperscript{13}as an assumption

Figure 4.11: Assembled appcessory (dark) on tablet with application
4.1.6  Ideal flow application and appcessory

The ideal flow of interaction between the application and appcessory was the following:

- The teacher draws a shape (e.g., a rectangle) on the blackboard,
- a classmate quickly recreates that shape with the appcessory,
- VI student receives created shape according to depiction of the teacher,
- the VI can now follow the explanations while exploring the appcessory.
- The appcessory can be explored with multiple fingers to get a quick understanding of the shape,
- once the VI student is done exploring the appcessory (and wants additional information) the student places the appcessory on the tablet (while the application is open (in Mode 4)),
- the VI student touches the corners of the application and, through this, a digital representation of the appcessory is created on the tablet,
- once the representation is created, the VI student touches the button 'Draw Off',
- audio feedback is played, which states 'Draw Off' and the VI is informed, that the right button was touched and the exploration of the shape on the tablet is now possible,
- this interaction makes the screen freeze,
- the appcessory is removed from the tablet,
- the VI student can now explore the shape,
- through sound feedback and vibrations the VI student is informed on:
  - where the finger, which is being used for exploring the shape, is. Within or outside of the shape (sound) and,
  - whether the finger is crossing a line (vibration).
4.2 Software Specifications

In the following the UML, Use Cases, Requirements and motivation for technological choices are presented.

4.2.1 UML

A UML “can be taken as a simple description of what a user expects from a system in that interaction ... [it] represents a discrete task that involves external interaction with a system” (Sommerville (2015), p. 145). To illustrate the general idea and interactions within the application a UML was created. The application has one main activity, which is necessary for the following other interactions and possibilities (cf. Figure 4.12).

Figure 4.12: Use case diagram for basic interactions (included extensions in blue; future extensions, marked in a gray outline within the diagram)

Placing of the model or finger tips on the screen provides the input needed to execute the activity \textit{create shape}. When the user lifts the model or their
fingertips from the screen, create shape is executed. This includes draw lines, as well as calculate distances & angles. The activity identify shape is planned for future development. Within this step the shape receives the accurate descriptive title of the shape. Additionally the Sound Feedback activity, which is planned to be added in the future, provides the user with sound feedback that the shape is ready for exploration.

Create shape is extended with the main extension of the application. Explore enables the VI to receive feedback concerning what the shape ‘looks’ like. Explore, on the other hand, is extended with trigger vibrations and trigger of sounds. The extension trigger vibrations takes place when the finger moves over the display and crosses a line. Trigger of sounds takes place when the finger leaves the display. A feature of the application that is planned, but not yet implemented, is read out shape title. With this action the user could access the declaration of the shape. Additionally, another enhancement of the systems interaction was the reading of distances or angles to provide detailed information to the user. Through these features the user will receive detailed information the appcessory cannot provide. Being able to feel the shape, length and size of the angles with the exact data will enrich and strengthen the understanding of geometric figures.

4.2.2 Use Cases

To focus on important elements of the application during the development of the application user scenarios were drafted. Based on these scenarios the requirements (4.2.3) were defined.

In the following section the five main use cases are described. Additionally, the three personas used within these are introduced (cf. Table 2: Personas). Making use of personas is a good way of ensuring that the product is developed for the right target group as it eases picturing them interacting and using the software (?). This statement also holds true for use cases. These personas and use cases, overall, channel the thoughts and highlight, which parts of the application are crucial and need to be implemented. Crucial, in this case, refers to elements in the application that will make it usable by the VI.
<table>
<thead>
<tr>
<th>Name</th>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jennifer</td>
<td>Student</td>
<td>Jennifer is a technology affine student learning geometry in grade school.</td>
</tr>
<tr>
<td>Chris</td>
<td>Student</td>
<td>Chris is a VI who has been learning geometry for one year already and is now experiencing a new way of learning geometry. As he has previous experience with geometry. He is familiar with different types of angles and can make educated guesses as to which corner has which angle.</td>
</tr>
<tr>
<td>Mr. Carslon</td>
<td>Teacher</td>
<td>Mathematics teacher who is willing to try new technology to make the life of his VI students easier.</td>
</tr>
</tbody>
</table>

Table 2: Created Personas

For each scenario, the following items will be provided; Firstly, the persona in question, secondly a short description, and the detailed user scenario is provided. The user scenario is separated into nine topics. The first one the identifier with ID & Name. Followed by the Actors - who are the main conductor within this scenario. Stakeholders & Interests shows, as the title suggests, the different involved parties and what their interests are. The expectations towards the application and the results or interactions. The trigger describes what starts the application / interactions. Preconditions (if applicable) name what has to precede this specific user scenario to enable a seamless and error-free usage. Within the basic flow the list of interactions, actions and feedback are provided - these are in the correct order. Afterwards, the extensions, referring to possible errors or incorrect actions, are named. The post-conditions describe actions that take place after the main action has been performed. Lastly, the priority level (within the application) indicates how necessary this particular use case is to the application and the development.

4.2.2.1 Scenario 1

Persona: Jennifer

Description: Explore Geometry

Jennifer is asked to take and explore the haptic element to gather a sense of its shape, size, angles and form. Afterwards she places it on the tablet. Now a digital representation is created. Jennifer then signals to the app that she is done and receives feedback from the app that she can remove the model.
The signal could be, for example, a double-tap in a certain corner or a voice command.

*User Scenario 1*

<table>
<thead>
<tr>
<th>ID &amp; Name</th>
<th>UC1 - Model recognition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actors</td>
<td>Jennifer</td>
</tr>
<tr>
<td>Stakeholder &amp; Interests</td>
<td></td>
</tr>
<tr>
<td>Student: wants accurate realization of placing the model. No errors. Teacher: good “visualization”. No errors. Easy to use and explain. Self-explanatory app and model.</td>
<td></td>
</tr>
<tr>
<td>Trigger</td>
<td>placing model on device</td>
</tr>
<tr>
<td>Preconditions</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• app turned on</td>
</tr>
<tr>
<td></td>
<td>• model formed</td>
</tr>
<tr>
<td></td>
<td>• correct mode</td>
</tr>
<tr>
<td>Basic Flow</td>
<td>1. App recognizes touchpoints of model</td>
</tr>
<tr>
<td></td>
<td>2. Student signals app that she is done</td>
</tr>
<tr>
<td></td>
<td>3. App saves the current position of the corners</td>
</tr>
<tr>
<td></td>
<td>4. App calculates angles (no output)</td>
</tr>
<tr>
<td></td>
<td>5. App defines rectangle 14 (no output)</td>
</tr>
<tr>
<td></td>
<td>6. App gives feedback (sth.) to student → model can be removed</td>
</tr>
<tr>
<td></td>
<td>7. Student lifts model</td>
</tr>
<tr>
<td></td>
<td>8. The App recognizes lifting of the model</td>
</tr>
<tr>
<td></td>
<td>9. The app draws lines between the corners</td>
</tr>
<tr>
<td></td>
<td>10. App separates display into 5 areas (for rectangle)</td>
</tr>
<tr>
<td></td>
<td>11. App gives feedback that it is done</td>
</tr>
</tbody>
</table>
| Extensions | 1. Model not completely placed on device or app  
Corners not recognized  
(a) App provides feedback that the model is not placed correctly (voice output)  
(b) Student places model correctly  
(c) Feedback from app (sound)  
2. Student lifts model without signaling that she is done to app  
(a) same as 1(a)  
3. Student lifts model before corners are saved  
(a) Feedback voice  
(b) Reset app  
(c) back to 1 |
| --- | --- |
| Postcondition | • corners are saved correctly  
• lines are drawn  
• digital representation of model is “secured” and cannot be edited  
• Feedback is given (to user)  
• display has to be divided into 5 areas → sound is attached / according to areas |
| Priority | Essential |

Table 3: User Scenario 1
4.2.2.2 **Scenario 2**

Persona: Jennifer  
**Description:** *Explore digital representation*

When touching the corners a soft vibration 'comes' of the device. Moving to the right the vibration changes rhythm and soft music is played (sound 1) (cf. Figure 4.13). While exploring the digital representation she can get the angles read out loud to gain a better understanding. In the end, she can also discover, which type of square she was exploring.

The *I finished exploring* needs to be signaled to the app.

**Options:**

1. Rhythmic tapping (or certain *swipe gesture*)
2. Token that can be placed on the device

This signal needs to take place, so that Jennifer can move the model on the tablet and lift it without the application assuming that she is ready to explore.

**Notes:**

1. Student receives feedback (sound) when deterring of the lines
2. Reaching the corners the students receives a feedback (vibration)
3. Within the center the student receives no feedback and has a *calm space*
4. Figure (rough sketch):

![Figure 4.13: Rough draft - established before the actual implementation (based on original idea)](image-url)
Evaluation: two options of the separation of the display, corner to corner or like figure above 4.13.

Mode: Explore

User Scenario 2

<table>
<thead>
<tr>
<th>ID &amp; Name</th>
<th>UC2 - Explore digital representation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actors</td>
<td>Jennifer</td>
</tr>
<tr>
<td>Stakeholder &amp; Interests</td>
<td>Student: wants to have a good digital and an understandable representation of the model. No errors. Receives appropriate feedback. Teacher: good digital representation. No errors. Reliably represented. No errors.</td>
</tr>
<tr>
<td>Trigger</td>
<td>explore digital representation with fingers</td>
</tr>
<tr>
<td>Preconditions</td>
<td>UC1</td>
</tr>
</tbody>
</table>

Basic Flow

1. App recognizes touch of fingers on screen
2. Recognize movement
3. Calculate distance
4. Locate touch within “areas”
5. Give feedback (sound, vibration or silence) according to position in the areas (loop 2-5)

Extensions

1. Student moves off the device screen
   (a) Feedback (voice) when leaving
   (b) back to 1 how do they find screen again?
2. Student moves multiple fingers
   (a) Feedback (voice)

Postcondition Not Applicable

Priority Essential

Table 4: User Scenario 2
### 4.2.2.3 Scenario 3

**Persona:** Jennifer  
**Description:** *Receive feedback for the angles*  
While exploring the digital representation she can get the angles read out loud to gain a better understanding. In the end she can also discover, which type of square she was exploring.  
  
The *I finished exploring* needs to be signaled to the app.  

**Options:**

1. Rhythmic tapping (or certain *swipe gesture*)  
2. Token that can be placed on the device

**Mode:** Explore  
**User Scenario 3**

<table>
<thead>
<tr>
<th>ID &amp; Name</th>
<th>UC3 - Receive feedback for the angles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actors</td>
<td>Jennifer</td>
</tr>
</tbody>
</table>
| Stakeholder & Interests | Student : wants to receive accurate feedback on the size of the angles. Easy to access that information.  
Teacher : correct information to student |
| Trigger | tapping of corners |
| Preconditions | UCI |

**Basic Flow**

1. Student signals app to have read out loud, output information  
2. App recognizes signal  
3. App provides feedback (*voice*)

**Extensions**

1. (a) Signal for angle XYZ, 1. (b) Signal for figure  
2. none  
3. (a) App feedback for angle XYZ (*voice*), 3. (b) App feedback for figure (*voice*)
Postcondition

• Feedback is given to student (from the application)
• Angles are known

Priority

Essential

Table 5: User Scenario 3

4.2.2.4 Scenario 4

Persona: Mr. Carlson

Description: Task giving & preparation

Mr. Carlson prepares the rectangle to align with the requirements for the next task during the class. While preparing he forms the appcessory and places it on the tablet, he receives written feedback whether the angles align with the task. Afterwards he hands the model over to Jennifer.

Mode: Teacher

User Scenario 4

ID & Name
UC4 - Task giving & preparation

Actors
Mr. Carlson

Stakeholder & Interests
Student: Receive solvable task, and a precise representation of the task.
Teacher: Easy to build, define and test model or digital representation. Precise feedback from app.

Trigger
Placing of model an app.

Preconditions
UC1

Basic Flow
1. App retrieves data
2. App prints out data (written)

Extensions
Not Applicable

Postcondition
Not Applicable
4.2.2.5 **Scenario 5**

**Persona:** Chris  

**Description:** *Task solving*  
Chris is handed the prepared model from Mr. Carlson. He then explores the model to understand the geometric figure. For this task, Chris is operating the app in the *task solving* mode, which means he does not get the angles read out loud.

Chris places the model (after exploring it in the physical space) on the device and can now explore the digital representation.

*Behaviour is similar to Scenario 1, where the vibration and sound output is generated when the digital representation is touched.*

Once he is done he signals to the app that he would like to enter the required data now. [entering mode unclear]

**Mode:** Task Solving

**User Scenario 5**

<table>
<thead>
<tr>
<th>ID &amp; Name</th>
<th>UC5 - Task solving</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actors</td>
<td>Mr. Carlson</td>
</tr>
</tbody>
</table>
| Stakeholder & Interests | Student: Easy to build, define and test model or digital representation. Precise feedback from app.  
Teacher: Easy to build, define and test model or digital representation. |
| Trigger     | Placing of model an app.      |
| Preconditions | UCI & UC2 - task solving mode |
1. Signal for next stage (voice) (angle value input)
2. Signal which angle
3. Confirm instructions
4. Find corner (adjusted UC2)
5. App feedback correct corner
6. Explore angle
7. Signal *ready* to app
8. App signals *ready* for input (voice)
9. Enters the value
10. Confirm entry
11. App reads entered value (voice)
12. Chris confirms entry (signal or token)
13. Repeat steps (6 to 12) for all other corners
14. He confirms to be done overall

- see UC4 (Extensions 1a to 4b) & UC1 UC2
- 4(a). User did not understand instructions.
  1. Repeat instructions (back to 1 - *within basic flow*)
- 12(a). Correct value - yes or no;
  1. No, Go back to Step 9;
  2. Yes, proceed

Postcondition | Not Applicable
---|---
Priority | Low or Middle
4.2.3 Requirements

As a result of these scenarios the functional requirements for the application were drafted. Additionally, the non-functional requirements will be shown.

4.2.3.1 Functional Requirements

“Functional requirements These are statements of services the system should provide, how the system should react to particular inputs, and how the system should behave in particular situations” (Sommerville (2015), p. 105). Below the requirements are listed (cf. 4.14, 8).

<table>
<thead>
<tr>
<th>Key</th>
<th>Abbreviation</th>
<th>Use Case Identifier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical Interaction</td>
<td>PIM M</td>
<td>I</td>
</tr>
<tr>
<td>with model</td>
<td></td>
<td></td>
</tr>
<tr>
<td>with user</td>
<td>PIU U</td>
<td></td>
</tr>
<tr>
<td>Internal Interaction</td>
<td>II I</td>
<td></td>
</tr>
<tr>
<td>Use Cases</td>
<td>UC</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 4.14:** Legend for the functional requirements

<table>
<thead>
<tr>
<th>UC Abbreviations</th>
<th>X is use case number</th>
<th>e.g. I = internal identifier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td></td>
<td>(this starts with 1 and continues throughout the whole identifier Y, e.g. UC111, UC112, UC213)</td>
</tr>
<tr>
<td>Identified</td>
<td>Name</td>
<td>Type</td>
</tr>
<tr>
<td>-----------</td>
<td>-------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>UC1I01</td>
<td>app locates touchpoint</td>
<td>II</td>
</tr>
<tr>
<td>UC1U01</td>
<td>app recognize touchpoints fingers</td>
<td>PIU</td>
</tr>
<tr>
<td>UC1M01</td>
<td>app recognize touchpoints model</td>
<td>PIM</td>
</tr>
<tr>
<td>UC1I02</td>
<td>app saves corners</td>
<td>II</td>
</tr>
<tr>
<td>UC1I08</td>
<td>app draws lines</td>
<td>II</td>
</tr>
<tr>
<td>UC1I03</td>
<td>app separates display into areas</td>
<td>II</td>
</tr>
<tr>
<td>UC1I04</td>
<td>sound assigned &amp; attached to areas</td>
<td>II</td>
</tr>
<tr>
<td>UC1I05</td>
<td>app calculates angles</td>
<td>II</td>
</tr>
<tr>
<td>UC1I10</td>
<td>digital representation uneditable</td>
<td>II</td>
</tr>
<tr>
<td>UC1I13</td>
<td>app gives feedback voice</td>
<td>II</td>
</tr>
<tr>
<td>UC1I014</td>
<td>app provides button feedback (sound)</td>
<td>II</td>
</tr>
<tr>
<td>UC1U04</td>
<td>confirm mode</td>
<td>PIU</td>
</tr>
<tr>
<td>UC4I15</td>
<td>app prints out data</td>
<td>II</td>
</tr>
<tr>
<td>UC5I17</td>
<td>accept mode</td>
<td>II</td>
</tr>
<tr>
<td>UC5I18</td>
<td>load mode</td>
<td>II</td>
</tr>
<tr>
<td>UC1I02</td>
<td>app recognize lifting finger</td>
<td>PIU</td>
</tr>
<tr>
<td>UC1M03</td>
<td>app recognize lifting model</td>
<td>PIM</td>
</tr>
<tr>
<td>UC1I12</td>
<td>app gives feedback vibration</td>
<td>II</td>
</tr>
<tr>
<td>UC1I07</td>
<td>app defines shape</td>
<td>II</td>
</tr>
<tr>
<td>UC1I09</td>
<td>digital representation saved</td>
<td>II</td>
</tr>
<tr>
<td>UC1I11</td>
<td>app gives feedback sound</td>
<td>II</td>
</tr>
<tr>
<td>UC2I03</td>
<td>movement of multiple fingers recognized</td>
<td>PIU</td>
</tr>
<tr>
<td>UC1I14</td>
<td>app recognize signal</td>
<td>II</td>
</tr>
<tr>
<td>UC4I16</td>
<td>app retrieves data</td>
<td>II</td>
</tr>
<tr>
<td>UC5I19</td>
<td>provide instructions</td>
<td>II</td>
</tr>
<tr>
<td>UC5I20</td>
<td>instructions confirmed</td>
<td>II</td>
</tr>
<tr>
<td>UC5I21</td>
<td>feedback corner</td>
<td>II</td>
</tr>
<tr>
<td>UC5I22</td>
<td>accept input</td>
<td>II</td>
</tr>
<tr>
<td>UC5I23</td>
<td>accept value (input)</td>
<td>II</td>
</tr>
<tr>
<td>UC505</td>
<td>users confirms entry (signal or token)</td>
<td>PIU</td>
</tr>
<tr>
<td>UC5I24</td>
<td>confirm entry ok</td>
<td>II</td>
</tr>
<tr>
<td>UC5I25</td>
<td>read entry out loud</td>
<td>II</td>
</tr>
</tbody>
</table>

Table 8: Functional Requirements
(including the ID, Description, Type, referring Use Case and Status)
4.2.3.2 Non-Functional Requirements

“Non-functional requirements These are constraints on the services or functions offered by the system. They include timing constraints, constraints on the development process, and constraints imposed by standards. Non-functional requirements often apply to a system as whole rather than individual system features or services” (Sommerville (2015), p. 105). According to Sommerville (2015) and the non-functional requirements (NFR) have been drafted. Below the NFR are provided (cf. Table 9). For each type or category a short description and the restriction or requirement is given. The NFR are written in a way that they should be quantitatively testable.
<table>
<thead>
<tr>
<th>Identifier</th>
<th>Type</th>
<th>Short Description</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>NF02</td>
<td>User-Friendliness</td>
<td>The application shall be user-friendly and easy to access.</td>
<td>done</td>
</tr>
<tr>
<td>NF03</td>
<td>Response time</td>
<td>The application shall react quick and near instantly.</td>
<td>done</td>
</tr>
<tr>
<td>NF05</td>
<td>Physical constraints</td>
<td>The application shall work on an off-the-shelf product.</td>
<td>done</td>
</tr>
<tr>
<td>NF07</td>
<td>Maintainability</td>
<td>The application shall be programmed in a way that necessary changes can easily be made.</td>
<td>done</td>
</tr>
<tr>
<td>NF08</td>
<td>Enhanceability or Extensibility</td>
<td>The application shall be programmed in a way that new additions, changes can be made.</td>
<td>done</td>
</tr>
<tr>
<td>NF11</td>
<td>Memorability</td>
<td>Within the application it shall be easy to be remembered how shapes can be created, interactions executed.</td>
<td>done</td>
</tr>
<tr>
<td>NF01</td>
<td>User Interfaces</td>
<td>The application shall have an interface that supports the continuous, easy use.</td>
<td>in progress</td>
</tr>
<tr>
<td>NF04</td>
<td>Reliability</td>
<td>The system must handle any input without any errors.</td>
<td>in progress</td>
</tr>
<tr>
<td>NF09</td>
<td>Safety</td>
<td>The execution of the app shall not be terminated by the user.</td>
<td>in progress</td>
</tr>
<tr>
<td>NF10</td>
<td>Accessibility</td>
<td>The application shall have adequate feedback (e.g. vibration of the lines). The application shall provide audio feedback whilst interacting with buttons (e.g. &quot;Menu 1&quot; read out loud).</td>
<td>in progress</td>
</tr>
<tr>
<td>NF12</td>
<td>Operability</td>
<td>The application shall not crash and shall continuously function and have no down-time.</td>
<td>in progress</td>
</tr>
<tr>
<td>NF13</td>
<td>Usability</td>
<td>The application shall provide a good usability (different factors play into this: e.g. user interface, user-friendliness, reliability, accessibility ...).</td>
<td>in progress</td>
</tr>
<tr>
<td>NF06</td>
<td>Skill level</td>
<td>The application shall have different entry levels, which shall enable various users to be able to use the application.</td>
<td>future</td>
</tr>
</tbody>
</table>

Table 9: Non-Functional requirements (including the Identifier, Name, Description, and Status)
4.2.4 Programming language

The application described previously was programmed in Android. As the application is native it can, at a later stage, be made accessible within the Google Play, the marketplace where applications for Android devices can be downloaded. The market will make it widely and easily available to users.

Android is an object-oriented programming language, which enables good access and easy change or variation of code. “Object-oriented programming is a coding technique to formalize the relationships between interconnected variables and functions. To use two analogies, a class is like a blueprint, and an object is a building constructed from that blueprint; a class is like a recipe for a cake, and an object is the cake” (Reas & Fry (2014), p. 359).

The programming environment used to develop the application is Android Studio. Studio was released from Android itself, has a compiler\textsuperscript{15}, as well as an editor built in. Furthermore, it has the built-in connections to the SDK\textsuperscript{16}, which eases the overall interaction and makes it easy to use and up to date.

4.2.4.1 Motivation for technical choices

This section motivates the choice to make the application native and the reasons for using Android. The literature review showed that approaches that include area hinting, tactile feedback as well as user studies provide a, for the target audience, well-suited application.

When choosing Android as a platform for programming, the decision was based on multiple factors. One was the market share of Android as it has increased over the last couple of years. In 2013 Android sales held 61.9% of the global tablet market (Frizell (2014)). This leads to a market share of 67% in Q2, 2013 (Richter (2013)). The prognosis for the market share is that in 2018 iOs devices have 24. 5%, Windows 11. 4% and Android 64% worldwide (Statista (2015)). This trend suggested that using Android as a platform reaches the majority of possible users and has a long-term value.

In addition, having Android as a platform is also beneficial as Android has an OS that is provided by multiple companies and through the selection

\textsuperscript{15}“A compiler is a software program that compiles program source code files into an executable program. It is included as part of the integrated development environment IDE with most programming software packages.” ((?)

\textsuperscript{16}Software Developer Kit: “An SDK is a collection of software used for developing applications for a specific device or operating system. ... SDKs typically include an integrated development environment (IDE), which serves as the central programming interface. The IDE may include a programming window for writing source code, a debugger for fixing program errors, and a visual editor, which allows developers to create and edit the program’s graphical user interface.” ((?)

48
there are more devices to choose from where some are cheaper than iPads (cf. Table 10) (Frizell (2014)).

<table>
<thead>
<tr>
<th>Devices</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>iPad3</td>
<td>599 $</td>
</tr>
<tr>
<td>Samsung Galaxy Tab 4</td>
<td>599 $</td>
</tr>
<tr>
<td>Google Nexus 10</td>
<td>499 $</td>
</tr>
</tbody>
</table>

Table 10: Comparison of Amazon.com prices for 3 models the 3 models have 32GB and are WiFi only.

Additionally, the research showed that the iPad does not have the capabilities of vibrating therefore it is not a suitable device for the current approach. In the approach, the vibrations were one of the main feedback methods to communicate with the VI.

The application was programmed for Android devices because of this the decision was made to use Android Studio. It is a code editor created and provided free of charge by Android. “At the core of Android Studio is an intelligent code editor capable of advanced code completion, refactoring, and code analysis” (Android (2015)) therefore it provides an easily accessible programming environment. Also, it enabled the quick way to run the application on a device for that reason testing was possibly quickly.

4.3 The application ITG

Invisible Tangible Geometry (ITG) is the name of the application developed. The application went through different development stage in accordance to user testing and feedback iterations.

4.3.1 Usability and Accessibility

The VI rely on accessibility features to be able to use their devices. The biggest feature, with iOS and Android systems, is a voiceover or talkback function. This enables the VI users to interact with displayed content without relying on visual information.

During development there are certain aspects that need to be considered to ensure that the developed application provides a good usability, and accessibility. Google and Android provide checklists, guidelines and aids to ensure the proper implementation. The first focus needs to be 1on designing a clear and simple layout. The hierarchy within the application, navigation points, information layout and design of the menu, should reflect the importance of the element. Furthermore, the user should always know where within the app they are. This way, they will feel confident while using it. Additionally, various cues should be provided to the user to enable them to understand
important tasks. Through the use of more than one cue it heightens the accessibility and provides multiple entry levels (Google (2016)).

The layout used within the application should ensure that all elements are at least 48 by 48 dp big and, have 8dp space around them. This approach ensures that the object will be at least 7mm big, which ensures that it can be relatively easily interacted with. Related information, to e.g. a slider bar, should be placed in close proximity to the input or interactive lever (Android (n.d.), Google (2016)).

4.3.2 Implementation

The base of the application is the basic multitouch example by Android\textsuperscript{17}. Within this example the handling of multiple touches was illustrated, as well as the pinching and zooming interaction. Working with this base a variety of extensions were applied.

The addition of a main screen was performed, colors on the frame, as well as the background were changed. The touch-points were temporarily saved within a matrix to be identifiable later. From the main screen the user can access, at a later point, different usage modi. The main screen features four buttons - mode 1, mode 2, mode 3 and mode 4. Conceptually speaking, this will make space for interaction modes, even though only mode 4 has the complete action set functional (cf. Figures 4.15, 4.16).

The different usage modi were set-up as separate files with links and references to the main screen.

\textsuperscript{17}http://developer.android.com/training/gestures/multi.html
Figure 4.15: Main Screen Sketch showing different modi-buttons, 2 sketches
In the main screen (within android-project called MainActivity.java) the four modes are made accessible with their representative voice-feedback. Each voice feedback can be edited here and the sound output can be adapted through changing the speak definition (e.g. from Mode Four to Explore Mode (4.17)).

```java
public void mode4_start(View view){
    if (myTTS != null && !stopSpeek) {
        speak("Mode four");
    }
    Intent intent = new Intent(this, mode4.class);
    startActivity(intent);
}
```

Even though the modes were made accessible in the MainActivity.java
the layout (for this screen, and the modes) are stored in separate files. layout_index.xml provides the information concerning, which elements will be presented in the main-screen. For example, if in layout_index.xml the button for Mode 4 is not defined, it will not be shown in the main-screen even though the functionality to interact with mode 4 is provided through MainActivity.java.

The information stated on the buttons (Mode 1, Draw On etc.) were all stored within the file strings.xml. This enabled information to be easily changed since all values are stored in the same location.

As Android makes use of separation of concerns different values, inputs and definitions or executables are stored in different locations. This approach reduces the complexity in a file. Nevertheless, referring to different files, with different information, has a different complexity of its own. When programming in Android the connections between different files has to be understood and used but, in the end, this will ease the future development as values, interactions and layouts can easily be adapted with a few changes in one single location.

4.3.3 First High-Fidelity Prototype

The first high-fidelity prototype consisted of the application, which was equipped with the functionality of ‘drawing’ connective lines between the touch points. To be able to establish this functionality a limitation was set for how many touch points had to be provided, as well as in which order, as each touch point has a unique identifier. The application, at this stage, can only draw a shape with four connectors, as well as touch points. In future development efforts, the application will be able to support 3 touch points and it would display a triangle or more nodes (5+). This limitation was made consciously to be able to validate the concept and work on the complexity at a later point.

The application has a white background and draws black lines. The lines create a shape on the display, which is, to an able person, visible 4.18.
The application interaction was enhanced to create vibrations when the lines of the shape are touched. Furthermore, the screen was separated into within or outside of the shape. The outside, when the finger taps into this area, played a certain sound upon release, the inside another. For these steps Alisa Sotsenko was consulted to progress in the development. She aided through input concerning how to define the screen into separate areas according to the drawn lines, play a sound, as well as how to make the lines vibrate on touch.

The playing of the sound was enabled through the use of the functionality `MediaPlayer` within Android. Through the use of if-statements it can be verified whether the touch occurred within the shape or not. In addition, the functionality `vibrate` was introduced and used to make the lines vibrate when either touched or traced with the finger. To be able to explore the screen without moving the touch points a button was implemented that enables or disables the drawing functionality within the code. By doing so the draw area is in a frozen state and cannot be manipulated until the drawing mode is turned back on.

The `reset` button enables that the points on the screen are delete and the screen is refreshed. As this an application aiming towards aiding visually impaired in the use of geometry, as well as enhancing their interaction and knowledge level of shapes they need to be able to access more information. To perform this interaction, the application has to be able to calculate angles and lengths of the different parts of the shape. The distance between the
points needed to be identified and, as each display may have a differing DPI\textsuperscript{18}, the calculations need to reflect this. As this customization is time-consuming, the current calculations only work for the DPI of the Google Nexus 10.

To calculate the angle the Law of Cosines will be used and transferred into functioning and executable code. For this calculation it is important that the touch points will be created in a certain order as to ensure that their values are not perceived as negative since the position has to be identified and the x,y values are used. The calculated values were displayed within the top part of the screen to be able to check the validity and be able to identify errors. With this prototype the first user study will be performed.

4.4 User Studies & Analysis

As previously described, the prototype and accessory were scheduled for testing with the target group to evaluate the idea and to iterate upon the design.

The community that answered\textsuperscript{19} and seemed enthusiastic about the idea was US SYD\textsuperscript{20}. US SYD is a community that takes care of the needs of the visually impaired youth and is located in Kronoberg, Sweden. They provide (among other things) camps, meetings and discussion ground for the VI. They are also engaged in creating a discrimination free society. The first meeting took place on the 14th of September, 2015 with two VI in the US SYD office. Prior to the arrival, contact had been established via email with Laoko Sardar, who works for US SYD and was highly interested in a meeting and getting to know the idea in more detail.

Overall meetings and user studies with four people from the target audience were consulted (as can be seen in detail in Table 11).

\textsuperscript{18}DPI stands for \textit{Dots Per Inch}

\textsuperscript{19}To enable the evaluation of the idea and later the prototype it was tried to establish contact with either visually impaired groups or communities or individuals. Three contacts were pursued. Even though they all answered only one channel of communication was established as two contacts referred to other contacts, which did not lead to a meeting or further talks.

\textsuperscript{20}Their website can be found here: \url{http://www.ussyd.se/}. 
<table>
<thead>
<tr>
<th>User</th>
<th>Description (Gender, Age, Vision)</th>
<th>Contact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tester 1</td>
<td>Man, mid-30s, vision of 2%</td>
<td>First Meeting, Study 1 &amp; 2</td>
</tr>
<tr>
<td>Tester 2</td>
<td>Woman, early 50s, less than 2%</td>
<td>First Meeting</td>
</tr>
<tr>
<td>Tester 3</td>
<td>Woman, early 20s, higher visual capability than tester 1</td>
<td>Study 2</td>
</tr>
<tr>
<td>Tester 4</td>
<td>Man, 40s, lower visual capability than tester 1</td>
<td>Study 2</td>
</tr>
</tbody>
</table>

Table 11: Contact with target audience relating to ‘encounter’, age, gender, vision capabilities and referencing name

4.4.1 First Meeting

The first meeting had mainly an informative character. Attending this meeting were two VI, one man in his mid-30’s, and one woman in her late-40’s, and an interviewer. The meeting was audio-recorded. Tester 1 has a vision of 2%, the percentage for tester 2 is unknown even though it is below 2% as she stated herself that she could ‘see’ as much as tester 1. Tester 1 translated between the interviewer and tester 2 as tester 2 had issues understanding and speaking English.

At the beginning of the meeting the project was described as detailed as possible. Afterwards, a piece of the appcessory (single node with connector rods) was provided to the VI for examination and feedback. Following this, general input concerning the idea was gathered. The testers gave mainly positive feedback concerning the concept and physical prototype.

“[The project is] very exciting because when I was in the school never could I understand geometry the way I should ... I missed all the details so I wasn’t very in good in Geometry. ... I just heard what the teacher said ” (Rühmann (2015), tester 1).

Concrete comments covered the feasibility of the physical design: the VI attendees confirmed that the object was understandable and manipulable.

Furthermore, the key element of enhancing the 3D model for interaction with the tablet, the copper tape, was distinguishable for the VI. It fulfilled their needs in the way that it was distinguishable from the material of the
3D model and they could easily find the touchpoints. Comments and questions received during the meeting were as follows: “What about a circle? Because you need a circle and triangle” (Rühmann (2015), tester 1). This was a question posed by tester 1 during the conversation. The interest was there to extend this approach to more shapes - as the introduced shape at the meeting was for a quadrilateral.

“I hope you will succeed with this. Because we visually need this. ... This [referring to the appcessory, application and idea] is great. I miss[ed] it in the school” (Rühmann (2015), tester 1). This statement was very reassuring as it validates the idea by the target group. Even though they are no longer school-aged the feedback was important and shows their needs and desire for an integrative approach. Tester 1 recalled that during his school-time “there was a book and the teacher tried to explain it to me. ... But I missed a lot of information. ... It wasn’t interesting” (Rühmann (2015), tester 1). Having situations like the one described by the tester highlight that even though efforts were made to integrate and explain the information the VI had a hard time following the provided information since the visual clues were missing.

### 4.4.2 First User Study

The first user study\(^23\) was held on the 5th of October, 2015 at the US SYD location. Two VI were present and the meeting was being audio-recorded\(^24\). The attendees were tester 1, and one woman in her 20’s (referred to as tester 3). Her visual capabilities were higher than tester 1’s but she was not able to identify the percentage.

The user study followed this procedure:

1. Short introduction round, including the organizer, and the project
2. Exploration phase of the application (with think-out-loud encouragement)
   
   (a) Individual use of application by present testers
3. Discussion and Feedback phase
   
   (a) Playing of sound - verify length to be appropriate

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\(^{23}\)Original notes to the user study can be found in Appendix 7.3

\(^{24}\)Except for the first 10 minutes due to technical difficulties
4.4.2.1 Introduction Round

In the introduction, everyone introduced themselves, why they were here and which background they had. A short insight into the research and a detailed description of the idea was provided. This was especially important for tester 3 since she had not been present at the previous meeting or heard about the project in detail. She was an intern at US SYD trying to gather some work experience and impressions. Tester 3 felt more comfortable speaking German than English therefore conversations and interactions with her were performed in German.

4.4.2.2 Exploration Phase

Task 1: Becoming familiar with the basic interactions and the feedback provided by the application. After waiting a couple of minutes and providing the study participants time to individually become familiar with the application, a square was created on the display to enable them to use all implemented functions and feedback options properly. Having created a square on the display, the Draw on was turned off and the tablet handed back to the testers. Tester 1 started with the interaction and passed it on to tester 3. Before the first task, the testers were asked to express any feelings or thoughts and feel free to ask any question they had with the think-out-loud method (described in Chapter 3). The think-out-loud method was used, to receive information as detailed and rich as possible.

Task 2: Interact with the application. During the exploration phase the users were observed and their interaction with the application\(^{25}\), their comments, and problems were noted.

Tester 1: While interacting with the application he had no problems. He described that a black background with white lines would be beneficial to him. He explained further that all his technical devices are color-coded in this matter. Since he has some vision he can make information out better when a high color contrast, in the provided content, is given.

Tester 3: She was very reserved while interacting with the model and not very expressive while using it. As her visual capabilities are higher than those of tester 1, she expressed that she would like more prominent colors. This way it might be easier for her to make out the specifics of the shape on the screen.

General Observations: One of the things observed (with both testers) was that the creation of a shape on the display was a bit tricky\(^{26}\) and the draw-

\(^{25}\)The appcessory was not tested within this study
\(^{26}\)The touch-points had to be executed in a precise order and their fingers left the
ing of the lines is not as fluent and easy as it needs to be. Furthermore, the users’ expressed their need for more prominent colors, such as having black background with white lines, as well as adding thicker lines to make them more obvious. Another suggestion was to make the sounds more distinctive from another. Since this will make it easier to distinguish the position on the screen, and within the figure. The sound length (3 seconds) was convenient and does not need to be changed. Additionally, it was observed that sometimes the application does not recognize the passing of the finger across the line wherefore no vibration occurs. This needs to be improved to insure a proper feedback to the user at all times.

4.4.2.3 Discussion and Feedback Phase

The discussion and feedback phase consisted of letting the users interact with the application, ask questions concerning the application, and the project. **Demonstrate Sound:** The interviewee replayed the sounds and inquired from the testers, whether or not they perceived these to be easily distinguishable, and proper in length. **Response Sound:** The testers provided feedback that the sounds were not as easy to distinguish as they would like. The length of the clips were adequate and received well. The use of sound, overall, is perceived very well.

Overall, feedback and suggestions were to include a synchronization possibility, and user preferences. The synchronization would (theoretically) provide the user with the option of saving their work (created shapes etc.) connected to their account and retrieve it (once logged in) on another device. This would also require the possibility of saving the current work to make it retrievable. The user preferences would be good (as well saved for a specific user) to e.g. always have the black background with the white lines without having to set it up every time. This could also lead to being able to configure the background, lines etc. to fit each user’s personal needs. Furthermore, it was suggested to make sure that the application reflects the user age or school levels. This would mean to have various difficulty or operation modes, which fulfill the needs either an elementary student has or the needs of a high school student. Through choosing, e.g. the correct operational mode, it would be ensured that the necessary functions are available.

Tester 1 reported that, during his university time, he was equipped with a webcam, which enabled him to film the contents of the board and have it transcribed onto his computer. This was a good approach to enable him to follow the class but it was tedious as he never knew where the information interactive part of the screen since it was not clear to them where this part starts.
was displayed on the board. The continuous scanning with the camera was necessary, which lead to him being delayed while retrieving the information in comparison to his classmates. In addition, it was hard to scan the whole board wherefore he did not have all information available at once. Leading from this insight tester 1 suggested that it would be nice to have a way of taking a picture of a page in a book, which displays, e.g. a geometric figure and have this digitized and made accessible within the app. This seems especially important as school books change every year wherefore an easy way to access the information would be highly beneficial. Tester 2 described that she was provided with tactile interaction pieces, which were bulky, not very precise, as well as not being relatable to actual size or angles of the object.

4.4.2.4 Open Questions

At the end of the user study following questions were posed by the testers:

- With how many fingers can I explore the shape?
- Can I use a pen to explore it [referring to the shape on the screen]?
- Will it (at one point) be accessible through the Apple Store (aka iOS devices)?
- Can I synchronize or save my shapes (on a computer)?
- Input only works with fingers or model?
- Will the app talk to me?
- What about circles?

The open questions were discussed with the testers. The exploration of the shape can be performed only with one finger. The model, on the other hand, can be explored with multiple fingers. Can I use a pen to explore it or Input only works with fingers or model - in theory: Yes, but this depends on what kind of pen it is and how well this can transfer the vibrations to the user. A regular stylus pen might be able to provide the feedback, but it might make it harder to identify the shape. This would need to be tested and evaluated at a later point.

A big question, previously asked within the first meeting, was the accessibility on Apple devices (e.g. iPad and iPhone). The issue with using an iPad, which was explained to the testers, is the missing of a vibration motor.
Through this a crucial part of the application would be dysfunctional and an additional object would be needed to establish the functionalities.

Concerning can i synchronize or save my shapes - this will be part of the future work. Including this functionality within the application would enable making use of a created shape later and expand the interactions. Additionally it would ensure that the user can stop while exploring a shape but continue working with it at a later point. It would also provide the opportunity to be able to share the shapes and for example submit the created work to a teacher. Saving the shape on a computer, on the other hand, is something that is not planned within the current approach. The application should not, at any point, be reliant on another device. The stand-alone construction of the application is a crucial feature.

Whether the Input only works with fingers or model? - the answer is: Both. It is possible for the user to establish the shape on the application either through placing the model on it or creating touch points with their fingers. Ensuring that both input methods work and are suitable for the VI users, is crucial to ensure that the system of exploring, creation and interactivity is given and works.

Will the app talk to me? Yes. This extension, as discussed and explained during the user study with the testers, is crucial to the usability since it provides the accessibility for the VI. Making use of the talkback function in Android was not possible as it stopped the possibility of interactions within the application.

The recurring question what about circles? refers, overall, to the extension of shapes made accessible through the application. It was decided that for testing and development purposes, the complexity did not need to be stressed as the concept is testable nevertheless. In the future, a variety of shapes is planned to be able to communicate a variety of geometric figures and concepts.

4.4.3 Resulting Implications for the prototype

These question were an additional lead into, which direction the app should develop and what is important to the VI. Overall, the feedback during user study 1 was very positive and reassuring. The lines felt good and the idea seemed to provide great potential (to the two present testers). According to the study a list of preliminary requirements for the improvements of the app for the next user study was created. This included:

- making the lines thicker,
- application with black background and white lines,
• ensure that appropriate feedback is provided when the lines are being touched,
• include some sort of talkback that enables the VI to use the app independently,
• change sounds to be more distinct from one another,
• add option to have the values for angles and lengths read out loud,
• add a feedback for \textit{shape created}.\footnote{This has not been implemented in the next prototype}

These requirements were going to provide an aid for the adaptations made for the next user study.

4.4.4 Application Iteration

The first user led to results, which was applied to the application. Suggestions were that the color scheme should be reversed for some VI as that might be easier to identify. A black background with white lines might be more suitable. Furthermore, the lines should be thicker and the colors of the dots more prominent (cf. Figures 4.19, 4.20, 4.21, 4.22). Additionally the sounds played should be more distinctive from one another and shorter.

The most important feedback\footnote{which was known as a necessity}, was the request of inclusion of speech within the application enabling a more autonomous use of the application whereas in user study 1 the conductor had to strongly aid the tester.

These suggestions were introduced into the application to prepare for the second user study. An additional change was the update on the vibration algorithms making it more stable to ensure that vibrations always take place when the lines will be either crossed or followed with the fingertip. Changing the colors of the application was not a hard change as it only required few minor changes. Furthermore, the change of the sounds was easily done as well. To be able to do this, the sound-files had to be replaced and the referring code-snippets had to be changed too (as the name of the files changed). The length of the soundtracks were chosen to be around 2 seconds as to provide the feedback without being too long. Also the sounds were suggested to be changed wherefore the change was made to have the sound of a drill, as well as rain drops in a forest. These were distinct from each other so that they can be clearly told apart.

Additionally a problem was addressed, which occurred during the testing before user study 2. When the screen was touched multiple times, while the
sound was still played, the application stopped working and restarted, as it could not handle the multiple input.

A big addition was implementing voice feedback. As the design of the application did not support the use of the native talk-back function within Android, an application intern voice feedback needed to be implemented. The native talk-back did theoretically function but disturbs functionality of touching buttons or interacting with the draw screen on which the touch points are recognized and displayed. The TextToSpeech.OnInitListener was implemented and enabled the reading of labels and provided some feedback to the user what is happening on the screen (as previously described in Section Implementation).

![Application, for shapes, before first user study](image.png)

Figure 4.19: Application, for shapes, before first user study
Figure 4.20: Changed Application, for shapes, after first user study, white

Figure 4.21: Changed Application, for shapes, after first user study, black
Figure 4.22: Changed Application, showing the menu, after first user study, black

**Summary of the feedback with implementation status:**

<table>
<thead>
<tr>
<th>Improvements</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>making the lines thicker</td>
<td>done</td>
</tr>
<tr>
<td>application with black background and white lines</td>
<td>done</td>
</tr>
<tr>
<td>ensure that appropriate feedback is provided when the lines are being touched</td>
<td>done</td>
</tr>
<tr>
<td>change sound to be more distinct from one another</td>
<td>done</td>
</tr>
<tr>
<td>include some talkback that enables the VI to use the app independently</td>
<td>in progress</td>
</tr>
<tr>
<td>add option to have the values for angles and lengths read outloud</td>
<td>future</td>
</tr>
<tr>
<td>add a feedback for <em>shape created</em></td>
<td>future</td>
</tr>
</tbody>
</table>

Table 12: Summary of the feedback with status of implementation
4.4.5 Second User Study

After 10 days the application had evolved and the next testing session was scheduled. On the 15th of October, 2015, participants and interviewers gathered at US SYD for the second user study. Present for this meeting were tester 1, tester 3, and a man in his 40’s who has a lower visual capability than tester 1 (from now on referred to as tester 4). In addition, two conductors were present, Alisa Sotsenko and Lisa M. Rühmann. This user study was video-recorded. The procedure for this meeting was the following:

1. Providing four stories to the testers (according to Speed Dating method)
   (a) short discussion after each story between testers - aimed to gather pro’s and con’s of each story and general feedback

2. Testing of the application and model
   (a) free interaction with app and model;
   (b) help provided from the conductors as much as necessary

3. Ask for description of:
   (a) the way they learned geometry in school and,
   (b) how they could imagine geometry could be taught in school better?

4. Room for additional thoughts.

4.4.5.1 Observations and Resulting Implications for the prototypes

The beginning of the second user study was done with providing the four stories written within the Speed Dating method. Each story was presented to the three testers and after each story an open discussion was held. Following the four stories are described.

Phase 1: Speed Dating Method - Story Telling

1. Story 1

   • Jennifer is sitting in her regular seat in class.
   • She has a special table - featuring a different surface.

29The video is accessible here (in an edited and anonymous version):
https://www.youtube.com/watch?v=0JTbDsgH0go
• It can detect the placement of your fingers and create a haptic object that can be explored with the fingers.
• The object consists of little pins that are extracted from the table.
• This lets Jennifer explore the shape during geometry class really easy.
• Her teacher just needs to enter the data in a certain field on the smartboard.

2. Story 2
• Jennifer is working in a group with other classmates.
• They are exploring a certain rectangle - for Jennifer the teacher brought a set of specific lego-pieces, which can interact with her tablet, the rest of the class has regular lego pieces.
• Jennifer and her group-mates built the shape with assistance of both her tablet, and her classmates.
• For Jennifer this way of interacting with geometry is easily accessible as she can work together with her peers and interact in the regular classroom.

3. Story 3
• Jennifer has an iPhone in class, which she is allowed to use to follow things that happen on the board
• While explaining a new geometric shape the teacher takes 2 seconds to take a snapshot with another iPhone (using a specific app) - this information is than transferred to Jennifer’s phone and through sound (she has one earphone in her ear) the shape is explained through her software

4. Story 4
• Jennifer is in class and she has a smart geo-board
• The geoboard can create shapes according to input, so when the teacher explains something to the class there is a connection through the smartphone to the geoboard and indicate the corner to which the angle etc. is connected. According to that data the geoboard creates connections and gives a sound feedback (e.g) a pling-sound to Jennifer when it is done.
Feedback to the stories: These stories helped provide some more validation concerning the VI’s needs and expectations toward technology. Based on story 2, it was possible to identify that the VI’s require that their material is identical (in the visual sense) to the others because they want to be treated and viewed the same way. The VI individuals do not want to be different. In addition, the feedback for story 3 was very positive. They liked the idea of receiving a digital recreation of a shape in a quick way (here through taking a picture) - as suggested by tester 1 during user study 1.

In addition, the concept of building things with classmates appealed to them. It would create collaboration, and interaction with their peers. Concluding, it is important to the VI that the created tool is usable by them independently, and it needs to be easily accessible and transportable.

Overall, the group discussion was neither as extensive, nor as useful, as expected. Even though good information was gathered, a bigger turnout was expected. This might have been due to language differences. The testers felt the most confident when speaking Swedish. The conductors were not able to provide that possibility due to lack of knowledge.

Phase 2, Exploration Phase: Testing of the application and model

Within this phase, the testers were asked to simply explore the application and model on their own. As sound feedback was included the testers were (theoretically) able to create shapes and navigate the app on their own. It was stressed, to the testers that only Mode 4 provides all functionalities implemented so far. The testers passed the application and model around and, once more, were asked to follow the think aloud approach.

Application:

Having conducted the first part of the user study the testers were handed the tablet with the application, and the model. From that session the feedback for the Android application was very extensive, brought good insight and helped define the needs for the future development.

One remark was that an option should be included to take a picture of a shape and have the information transferred to the app (as story 2 suggested). Additionally it was very important that there should be voice feedback in all stages. The VI needed to know: which button is pushed; where (within the application) they are; in which part of the screen their finger is.

In total, a better orientation while moving around the display is needed. Building on this it was also suggested that there should be feedback when a shape is created (also a result of user study 1), the screen is touched, touches are recognized and whether the finger is within the draw area.
Additionally, a thought to be considered was that there is no need for
the draw on or off. It might be easier for the VI to create a shape without
having to turn the drawing on or off. Simply creating the touch input once
(model or fingers) would establish the shape and automatically freeze the
screen. This way it would not accept additional touch to change the shape.
Furthermore, this change would stop accidental moving of the touch points.

During the user study, no additional feedback concerning the vibrations
were provided whereas there is no immediate need to make changes to the
vibrations. In addition, the sounds within the app got positive feedback but
it might be an interesting idea to include a theme option that would enable
the user to pick their own sounds.

The appearance of the application received positive feedback but one
suggestion that was made is to include an options menu. This menu would
let the user pick the color scheme (e.g. background color black with white
lines or reversed), and it would let the user change the thickness of the lines
or have more distinct colors associated with the shapes displayed with the
application. These colors might make it easier for the VI to make out the
shapes.

Furthermore, it was observed that the navigation buttons within the An-
droid tablet are interrupting the interactions within the app. Wherefore it
needs to be ensured that the home and navigation buttons will be disabled
or are not accessible while operating and interacting with the app and the
appcessory.

The interaction with the application was mainly done through the use of
one finger. Nevertheless there is the need to explore the one-finger exploration
further and establish whether there are different preferences concerning the
exploration. Tests evaluating the use of one-finger exploration vs. multiple-
finger exploration should take place. Different users might have different ways
of interacting and this needs to be examined to ensure that the approach
fulfills the needs of the most users. Within the group tester 4 expressed
that he prefers one-finger exploration, while the other two testers were not
able to make a statement but would like to test it to be able to make out a
preference.

**Model:** While evaluating the model, the following feedback was gath-
ered: the model itself needs to be more stable and the connections between
different elements need to be stronger.

The testers did not feel *safe* while interacting with the appcessory. They
feared to possible break it - which was a valid concern as at one point,
one of the rods came loose and lost connection to the node. Wherefore a
stronger connection is needed that would ensure that the model does not fall
apart. Additionally, the connection would transport a good, secure feeling
to the user. A thought that could be examined would be to use magnets to create the connection between the nodes, this was a suggestion by a tester 1 during the user study. An additional idea gathered during the user study was to somehow mount the model to the tablet, which would ensure that it cannot fall to the floor or be lost. As the VI cannot see if the model falls of the table or moves off of the tablet it would be hard to retrieve and might require assistance, which is something visually impaired do not necessarily feel comfortable with.

Furthermore, it would be beneficial if the model provides better information towards the user where the touchpoints that transfer the input onto the tablet, are. Even though the copper tape as a conductor can be felt well, improvement would be possible. In the future, the possibility of creating different shapes should be investigated. Shapes such as letters, circles and triangles could be considered. This would be part of the future work.

**Phase 3: Description of personal experience & improvement & Phase 4: Open Thoughts** After the exploration phase the testers were asked to describe their personal history of being in school with a focus on learning math. The most valid feedback was given by tester 3 who had a special set-up for math class. She had a special teacher where she was taught in an individual class and everything was described to her in detail and explained catering to her needs. The other testers did not have anything to describe due to the fact that they did not have a differing teaching method\(^{30}\) for math during school. It did not become quite clear if this was the case because they were able to see while going to school or if it was due to lack of resources. Nevertheless, it was a good insight to the use of resources (according to experience from tester 3) which concluded the main part of the user study.

Afterwards, feedback in general was gathered. This extended and covered the following points: it is a great idea and that it could be very beneficial for students learning geometry in school, the testers hope to see it in classrooms soon so that the VI could benefit from it.

During the testing session, it became obvious that the application, and the appcessory need a good introduction to the class, and the students using it. The model needs to be explained in detail and the VI should have time to explore it to make sure they are familiar with it. Furthermore, the interaction possibilities between model and application should be described, and demonstrated. The VI and other students need to be made aware of what can be done with the app.

\(^{30}\text{in comparison to able students}\)
The participants also reported that creating / building things with classmates would be nice since this strengthens the collaboration, and between peers. In addition, the developed tools need to be easily accessible, independently usable by the VI, transportable and it should not be different from ‘what the others have’. Furthermore, the appcessory, as well as the app, should be able to be used by everyone - not just the VI - so that they are not singled out. Highest praise was received when the participants stated that they wished they would have had this to learn geometry in school. Overall they believe it has great potential.

Based on this user study goals for the future were identified. A necessity that the application should fulfill in the future is, to be able to be used on more than one operating system (OS). Enabling the use of different shapes and user modi should be included and supported. A personal sign-in to save preferences, shapes and created information should also be added. Additionally, providing information through voice (e.g. angles of each corner) is necessary. In the current prototype the striven for autonomous use is not yet implemented because of this, the angles have to be read out loud by an able person. Overall more support, through sound and vibrations, has to be included to provide a better accessibility. The inclusion of a menu that would lets users access the sign-in, and the settings would be a necessity.

In the future tests should be held to see how the exploration of the application by the VI's is performed. It needs to be established whether multi-finger or one-finger exploration is preferred.

Feedback from user study 2 According to the feedback gathered during the second user study, the speech function needs to be extended and made better. Currently the speech function can only state simple interaction feedback, for example, if the user taps on the button for "Mode 4" the voice feedback will say "Mode 4". In the future these functions would have to be more extensive. Ideal would be to create the possibility of using the native speech function provided from Android. Another issue that needs to be addressed is the disablement of the native menu within Android that can be accidentally opened while interacting with the application. Alternatively, it would be necessary to just hinder the activation of the menu in a way. This has to be explored. Since this disturbs the flow within the application it is a very important subject that needs to be looked into. This feedback was noted but not yet implemented but is part of the future work to push the development of the application further. Furthermore, a sort of stopper needs to be achieved, which communicates to the users that their finger leaves the display and is touching the frame around the touch-area. As this information
is currently not communicated the finger could leave the screen and the VI would not know how to find their way back onto the reactive display. As the outside area does not provide sound feedback or vibrations the VI can feel insecure about using the application.

A summary of the above information can be found in Table 13:

<table>
<thead>
<tr>
<th>Feedback</th>
<th>Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extend speech-function</td>
<td>high</td>
</tr>
<tr>
<td>Switch to Android (native) speech function</td>
<td>high</td>
</tr>
<tr>
<td>Disable of native menu</td>
<td>high</td>
</tr>
<tr>
<td>Stabilize appcessory</td>
<td>high</td>
</tr>
<tr>
<td>Improve reactivity of appcessory-tablet</td>
<td>high</td>
</tr>
<tr>
<td>Application executable on multiple devices &amp; OS</td>
<td>medium</td>
</tr>
<tr>
<td>Communicate end of touch-area</td>
<td>medium</td>
</tr>
<tr>
<td>Digitalize taken pictures of shapes</td>
<td>medium</td>
</tr>
<tr>
<td>Personalized sign-in (user-profiles, accessibility levels, color-schema)</td>
<td>medium</td>
</tr>
</tbody>
</table>

Table 13: Feedback from 2nd user study with priority level for future implementation
5 Discussion

This chapter looks at the knowledge gained with the design process and tries to relate it to the conceptual background that informed the work. The chapter also describes the current limitations of both the application and the appcessory. Additionally, the technical limitations concerning the extension of the application and appcessory with a different amount of input are presented. Furthermore, the section ‘Lessons learned’ reflects upon the activities carried out and the pros and cons of the approaches followed.

5.1 Discussion

Based on the design, development and evaluation tasks, the discussion will provide some insight concerning the two research questions introduced in the Introduction (Chapter 1). More specifically, a short reflection upon the previously provided information will be given. This will also include ideas for improvement and elements that could be extended over time.

5.1.1 Research Question 1: What features should a tangible digital system have in order to effectively facilitate an understanding of mathematical geometry for visually impaired children?

During the background research, multiple approaches and features have been identified for this topic. The following are a recollection of these techniques\textsuperscript{31}. Approaches were: sonification (Droumeva et al. (2007), Milne et al. (2014), Wall & Brewster (2006)), area hinting (Su et al. (2010)), use of audemes (Ferati et al. (2012)), a cellular touchscreen, vibrations, speech, and making use of commercial tablets, colors and adding a personalized calibration option for the different users (Landau et al. (2003)) Within this approach strong use was made of vibration (tactile feedback), speech, color, and sonification and area hinting. Furthermore, a cellular touchscreen built into a commercial tablet was provided for the interactions.

Enhancing the application with area hinting and sonification enabled the testers to gain an understanding of the shape, and interact with the created shape. The addition of voice feedback within the app additionally permitted the more autonomous usage of the application and received positive feedback during testing.

Leading to the following answer: Through the use of sonification and enhancing of the application with speech, sounds and vibrations, children with

\textsuperscript{31}Detailed description of all the named techniques can be found in Chapter 2
visual impairment should be able to gather an understanding of shapes and it may effectively facilitate the understanding of geometric figures. Additionally, it is to be said that even though extensive research has been conducted, there are still features that have not been able to be identified. One key element was that the interaction safety within the application needs to be stronger as the VI might, for example, accidentally trigger the menu of the Android system. This way the VI user can no longer interact with the application but is stuck in a different part of Android. Further testing, and research has to be conducted to be fully able to answer this question. The conducted user studies have not been with children but with adults. This was as a first validation of the approach and idea by the broader target audience. Nevertheless, ITG needs to be presented, tested and discussed with VI children in the future. As applications are developed with children in mind, it is extremely important to include them within the design process (Droumeva et al. (2007)).

Features that should be included in an application to facilitate an understanding of mathematical geometry for visually impaired children are vibrations, color, sonification and speech. Furthermore, the application should reflect the different entry levels and profiles, since this can ensure that the user does not get conflicted with information they are not interested in or might overwhelm them.

5.1.2 Research Question 2: How can the combination of a tangible user interface and a tablet effectively support the learning of mathematical geometry by children with a visual impairment?

Based on the performed study it became apparent that to effectively support the VI when learning geometry using a tangible user interface and a tablet the following points have to be pursued during the development and introduction:

- Creating a stable appcessory that makes the user feel safe while using it,
- Ensuring a good interaction of the model and tablet to provide quick, stable feedback to the user,
- Tailoring to different needs (profiles for different users with different preferences, different colored markers on the screen to represent touch-points),
- Providing a good introduction to the application, which is installed on the tablet, and to the tangible user interface.
These four points cater to the basic needs of the VI. Extending this with information gathered during the progress of this thesis, and the information displayed in section (5.1.1). It is important for the VI that the appcessory instills a feeling of security, so that they can use, feel and interact with it without having to worry about breaking or losing it. Furthermore, appropriate feedback when placing the model on the tablet, and while interacting with the application is a necessity. As reported during the user studies the VI were afraid of breaking the model and a concern they had was losing it while interacting with it. As they cannot see where the model is on the table or tablet and this creates insecurity while using it.

This research question has a very big scope and refers to a big picture, which could not be answered within the scope of this thesis. Nevertheless this question was necessary because it acted as a guide towards gathering information and insights that were essential for the foundation and exploration of the rest of this study.

5.2 Limitations Application

A short recall of the current limitations concerning the application:

1. The order in which the touch points have to come onto the screen to ensure that the calculations, and the drawing of the lines, is executed correctly,

2. the calculations, even though mathematically correct, sometimes do not lead to the expected result and are not 100% reliable and

3. supported within the application is only a quadrilateral shape / figure as four touch points are required.

4. The main screen provides four modes but only one is fully functional.

Additionally, not a direct limitation but a current hindrance, the calculation of distances, in cm, between touch points only works for the Google Nexus 10 due to the DPI of the tablet, which defines the display resolution. This issue is easily fixed, since every device has a DPI value available, which can be identified and used to make the calculations accordingly.

5.3 Limitations Appcessory

The appcessory is in the first main prototyping phase and has a few limitations, and room for improvement. These limitations are the following:
1. The appcessory is assembled and held together through the use of super glue, which works but is not as stable as it can be wherefore it can fall apart,

2. The connections between nodes do not have a stopper, as imagined in the original concept, wherefore it can easily be pulled out, which leads to loss of figure and connections, and manipulation of the form during exploration phase.

Lastly, the reactivity on the screen were not very good and, in most cases\(^3\), a maximum of three nodes were recognized at the same time. Furthermore, the order, which was needed for the interaction with the application cannot be maintained at all times wherefore the calculations were not accurate.

5.4 Technical Challenges

Technical challenges concerning the expansion of the geometrical models is mainly within the Android application. In the current version only four input points are accepted. To accept more input the Android code needs to be altered to be able to save, process and display the input points accordingly. The physical model can easily be changed and altered to support more or less input points as it is built modular. Different corner nodes can be added or removed to create a different shape.

Changing the application to being able to display different shapes could be possibly achieved through adding an additional layer within the application. With creating this layer choosing which shape is going to be created could direct the app as to how many input points to expect as well as reject incorrect input. The layer would work the following way:

- opening mode 1 (for example),
- choosing the shape from a menu with voice feedback and / or input - e.g. ‘triangle’,
- the application is prepared to accept three touch-points,
- the user can create any triangle,
- after creation and signaling that the input is done, the user can explore the shape as usual.

\(^3\)8 out of 10
• If another input is wanted, the ‘reset’ will trigger the return to the layer where the shape can be chosen.

If the user should require a different shape than the offered ones, the application could be equipped with an entry field which the user can use to enter the amounts of corners. Based on that value the application could possibly be programmed in a way to be flexible and reflective on user input. Extending the application this way might complicate the user interaction and make it more complicated for the VI to use it. This would have to be tested and see how it can be applied.

5.5 Lessons Learned

The first lesson learned was that even though when coming to a meeting and feeling well-prepared this may not be the case. The first meeting with the target group was scheduled and upon arrival it became apparent that both meeting partners were visually impaired wherefore the prepared presentation would not be of much use and the plan had to be rearranged.

Reflecting upon the used methodologies (UCD, and the methodological framework) they were of good use and enabled a well structured, user-friendly interaction with the target group. It also provided a good outline and roadmap for the preparation and execution of the thesis. Through the use of UCD information that might have been missed otherwise were able to be gathered.

Additionally assumptions that could have ruined, influenced or changed the end-product were either changed or did not happen wherefore the result it close to the users needs. This was especially important when working with such a specific target group such as the VI. When talking to this target group more issues can be encountered and the right contacts were needed to be able to approach them as they were not easily reachable group. The UCD proved to be a very valuable and good approach to provide a good user-friendly product.

The encountered problem between java and Processing highlighted how a bigger community with lots of support may help solving problems and provide an easier troubleshooting solution. Even though the Processing community exists and is active when the problem occurred it took around 2 months for an answer to take place.

The development of the application has to be flexible as new requirements and needs from the users can be revealed during user studies, test results or communication with the target group. This, for example, took place when it was revealed that some VI might require a black-white contrast within the application to be able to see the shapes etc.
Concerning the appcessory the assumption was made that the size of the model would work well to be able to have the model on the tablet and being able to interact with it properly. During the interaction it became apparent that the appcessory should be downsized. The assumption that the model would fit well onto the screen, was proven to be false. Through the possibility of changing the size of the appcessory, it can become bigger than the screen size. This is a problem, as the VI cannot see the difference between display and the non-functional border of the tablet.

Furthermore, the use of super glue to assemble the model only works so far. Therefore in addition to having to test different conducting materials and application of these to create a well working prototype, the assembly method has to be revisited as well.

During this work a lot of information and insights were gathered and the idea developed from a thesis topic to a bigger project. Creating an autonomous application with a tangible interface that will enable the visually impaired to learn and interact with geometry became highly intriguing to aid them reach a higher independence. During the research and development it became apparent how under represented and unsupported the visually impaired community seems to be.
6 Conclusion

Within this chapter a summary of the previously provided information will be given. As a closing note a description of how the here presented work could be extended and further developed is given.

6.1 Summary & Reflection

To summarize the information presented within this thesis the following statement can be made: The visually impaired appreciate the effort and idea presented to them and would hope for it to become a school tool in the near future (cf. 4.4.5). The current research concerning the visually impaired and creation of tools to support them proved to have room for improvement. Some information was hard to retrieve or non-existent and the lack of information was discouraging. Overall, it seems that visual impairment is more of a niche-research area even though the VI have specific needs these seem to be more or less unexplored.

To establish a good base for the idea, research has been conducted. During this research other approaches have been identified, and elements to look out for. Over the last years, the research field has been extended and more researched is being performed. Approaches have been taken to provide more tools for the VI but these often do not support autonomous use or are otherwise very narrowed done.

Within this thesis a first prototype of an Android application was programmed that can recognize, temporarily save, and display multiple touch-points on the screen. Furthermore, the application has a main screen, which displays the concept of having multiple modi, which will support the user differently. Within mode 4 the touch-points will be connected through lines. These lines will, when touched or crossed, vibrate. If the finger is lifted from within the shape one sound is played, if lifted from outside of the shape another. The application has an internal voice feedback enabling a somewhat independent interaction for a visually impaired user.

The appcessory, the external tangible component, is easily created and each corner can be separately manipulated to create a variety of shapes. With adding or removing corners the shape can be adapted, e.g. a triangle or five-sided figure can be created. As the appcessory consists out of different corner-parts, which are only stuck into one another.

During this project multiple meetings and interactions with the target group were performed. Additionally, one expert interview was conducted, which validated the idea at the beginning. The communication with the target group was conducted through one meeting with two users, and two in-
individual user studies where users interacted with the prototype and provided a detailed insight. This enabled the further development and structuring of the idea to suit the needs of the VI. Gathered insights such as this validate and maintain the connection, and user friendliness of the end-product.

6.2 Future Work

Within the future work section an outline of what should be pursued to establish a more esteemed version of the application, and the 3D model is presented. For the application a continuous development and extended functionalities need to be included.

The appcessory on the other hand needs a bit more work, the interaction with the application is not always as stable or reactive as it should be. In addition, the model sometimes falls apart and there is an issue of the rod to stay within the hollow counterpart of the model. In the future, a better connection between the rods needs to be established. This could be pursued through either using magnets to have a stronger connection or some other sort of security object between the rods. Furthermore, the interaction with the screen could be improved through the use of e.g. stylus tips as they transport human charge well.

A crucial step within the future development of this project is that the evaluation with the specific target group has to take place. Performing user studies, testing and evaluating the approach with VI children currently learning geometry is key to be able to improve the application and appcessory further. As their needs might be even more specific and vary from the ones of adults as their attention span differs, and their experiences are different as well.

Leading from the second user study\textsuperscript{34} two project ideas have been identified. One of them is the implementation of a mode where it is possible to take a picture of e.g. a whiteboard with a shape on it, which then is digitized and accessible to the user of the application.

When taking a picture of the whiteboard the digital representation will be created on the tablet. Afterwards this representation will be enhanced with vibrations and sound feedback making it interactive for the VI user. This idea is already being implemented and will undergo testing in the near future.

A more futuristic and longtime project that came from user study 2 is the use of 3D objects to interact with the application. For this the application would have to be remodeled and the drawing mode has to be taken out. With

\textsuperscript{34}more information can be found in Chapter 4.4.5.1
this remodeling of the application the *draw mode* would be removed. Leaving an app that can take in a shape but leaves no possibilities for changes. After placing the shape, the VI user can interact with it. This way there is less movement and interactions necessary for the VI students, which might be too difficult to manage. The model would have to be created with a special material, which is currently undefined. Creation of these objects would require time and effort but is something to be explored. The main exploration and interaction would be through the 3D model instead of through the app. By placing the 3D model on the tablet the application recognizes it and through sound navigation the user can interact with it. Navigation through sound is accessible to the VI. The figure is connected with a vibration on each element of the figure, which has the benefit of enabling the VI to interact and understand the figure. In more detail the screen should be frozen in this stage, and disabling the back / home button (which is native to Android) to ensure that the user or the VI do not close the application on accident. The main goal of the application would be to explore the 3D shape instead of using the application as the main exploration. The additional exploration of the shape on the application is done through the use of sound and vibration.

Overall it is to be stated that the further development of ITG has a lot of potential and, based on the contacted users, the community seems to be highly interested. The research towards creating an autonomous application and appcessory is one that should be made and would benefit the visually impaired. Efforts will be taken to achieve this goal and create a better inclusion of students whilst learning geometry.
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7 Appendix

7.1 Mini-Thesis
Background study to identify relevant aspects on how to facilitate learning of geometry for visually impaired with the aid of a tangible user interface

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INTRODUCTION

This paper is an investigation of the technologies and systems used to aid the visually impaired and facilitate knowledge of geometry and math using a touch device. Worldwide 285 million people are estimated to be visually impaired¹. Being visually impaired may mean that they either have a low or no vision. Within these 285 million 19 million are children below the age of 15 and 1.4 million “need visual rehabilitation interventions for a full psychological and personal development” (World Health Organization 2014) because they are blind and will be for the rest of their lives (World Health Organization 2014).

As part of their upbringing these children will be attending school which is harder for them due to their disability. Part of the curriculum is geometry – a very visual subject due to the content. In the current school setting a student may have the aid of a geo-board, a braille print or another object they can touch to transform the visual information into a ‘haptic’ setting. These tools are very useful but they are not as precise as they need to be, take some time to be arranged and are also possibly expensive. A braille printer can cost 9.395 € (Viewplus 2014).

Many students have an assisting teacher (vi teacher) who helps with developing the visual objects in the classroom into an object the vi student can use. If such a teacher is not present the teacher has to work alone with the student to be able to explain the figure and create it, e.g. with a geo-board (Toennies et al. 2011). The geo-board is often used to replicate a drawing, for example, of a triangle on the blackboard but it is not a precise replication and it takes some time to create this wherefore the vi student cannot participate in the class in the same speed because the information is lacking. Often taking away the possibility of group discussions in the classroom as well as participating actively in class.

To make the learning and understanding of geometry easier for people with a vi an application will be developed that will have a tangible user interface transporting the information to the user. This application will be used on a touch-device. In addition the application should be a stand-alone object that can be used at all times and does not rely on another person helping the user. As a platform a mobile device, android system, will be used for the use of the application. This is based on the fact that at least 22% of the world population owns a smartphone nowadays and at least 6 % will own a tablet. In comparison only 20% own a computer (Heggestufen 2013). The global smartphone sales increased from 54.51 million (2010 – 1st quarter) to 282.16 million (2013 – 4th quarter). This is an increase of 227.65 million sales within a 3 year time span. The most used operating system is Android since 2010, 2nd quarter – 10.65 million android systems in comparison to 8.74 million smartphones with iOS. In the 4th quarter, 2013 Android can credit 219.61 million sales and smartphones with iOS “only” 50.22 million sales (Statista 2013).

Next to just displaying geometric objects, it should also be able to include additional information about the object. Additional parameters, such as the technology used to present the tangible user interface as well as the way of communication with the vi students, are not yet defined but these requirements will be defined within this report. To identify these parameters a background study will be done and with this knowledge the need for such an application will be shown. Furthermore a set of requirements applicable for this mobile application will be derived.

The report is structured into the following sections: Purpose, stating what will be done during the scope of this project; Technical approach, providing an insight how the application could be set-up; Initial research and related work, giving a first insight into the topic; followed by the methodology used for this report as well as two scenarios described in the section scenario. In the section Background Study the main focus of this report is described going into detail of the research that has been performed and providing the outcome. At the beginning of the background study the limitations are defined. The next chapter is an interview with Mexhid Ferati an expert within the field of technology for the visually impaired. Afterwards follows the discussion and the future work.

¹ The term visually impaired may also be referred to as „vi“ in the rest of the report.
Purpose of the work to be conducted as part of this mini-thesis

The application that will be developed during the master-thesis has to be based on clearly defined requirements to ensure that it can fulfill the need. To find these requirements an extensive background study needs to be done. The focus of the study will be:

- visually impaired
- pedagogy papers on math & teaching geometry
- technology used for this purpose
- pedagogy papers on teaching visually impaired
- technology used for this purpose
- information and communication technology (ict) for the visually impaired
- user interfaces
- for visually impaired
- for teaching math

Technical approach

During the master thesis an application will be developed that suits the visually impaired and eases the learning of geometry and provides independence. Even though the main focus is on the vi other users should be able to use it as well. This application will not use braille but a tangible user interface. Braille is not a suitable solution approach due to the variety as well as complexity within different countries, topics and the problem that a lot of students as well as teachers are not able to read or write in Braille. In addition it is complex and rather unsuitable to display geometric information (Mascret et al. 2012; Ferati et al. 2011).

Initial research and related work

During the initial research a few papers were identified that are concerned with the visually impaired and try to establish applications that aid the vi through sounds and/or vibrations. The combination between sound and vibration is not always applied. The approach of using only one out of the two exists. There are solutions relaying only on sounds (Cohen et al. 2006) another one on actual music (Alty & Rigas 1998). A solution that combines both (vibration and sound) is the vibro-audio interface (Giudice et al. 2012). An additional approach that can be taken is the possibility to enable the user to choose whether audio- and/or haptic\(^2\)-feedback is wanted (Toennies et al. 2011).

Furthermore the use of Cinderella\(^3\) is being considered. Cinderella is an interactive geometry software. Using Cinderella as a basis for an application could be useful because it is a functional software giving the user many options to interact, manipulate and explore geometry. With using this either as an orientation of what such an application should be able to do or as a “software provider”, the focus of the application could be mainly on the user interface instead of trying to gather all the different parts of geometry.

In addition several “experts” of the field were contacted during the initial research. Asking for input, advice or their expertise on the idea and the different elements considered. The people that have been contacted are:

- David Salisbury (Senior Research Writer at Vanderbilt University)
  He forwarded my inquiry to Dr. Jenna Gorlewicz an assistant professor at Southern Illinois University Edwardsville. She developed an application in 2012 that has relevance within my topic. It is an application providing an aid for learning for the visually impaired\(^4\).
- Mexhid Ferati (Assistant Professor at South East European University)\(^5\)
  Dr. Ferati is an expert on user interfaces for the visually impaired and has written multiple papers on this issue. Therefore a personal contact, with the possibility of an expert feedback for the developed user interface, would be beneficial.
- Ulrich Kortenkamp (Professor at Halle University)\(^6\)
  Dr. Kortenkamp is co-author of Cinderella and professor in mathematics (didactic of math). His expertise could be very useful to gather information about how math is taught adequately and which elements are important to stress.

Methodology

\(^2\) Haptic meaning that the user feels vibrations on the finger that is on the touch-display.
\(^3\) Cinderella software is available and explained in detail here: http://bit.ly/1tp00pB.
\(^4\) A video with a presentation of the application can be accessed here: http://bit.ly/1B0Bhj6.
\(^5\) His publications as well as his profile can be accessed here: http://bit.ly/1w1L2vw.
\(^6\) His profile is available here: http://bit.ly/1w1KUF1 . (Unfortunately it is only available in German.)
For this background study the concept of “Goal-Question-Metrics” was used (Ya-hong et al. 2013) (cf. Figure 1). The goal is to identify a set of requirements for an application that can facilitate a learning experience for the visually impaired geometry using an off-the-shelf device – providing them with relevant feedback and information to be able to be included within society. This device should be portable, affordable and suitable for the use within a classroom setting.

The questions derived from this goal are:

The main research question is accompanied with two sub-research questions:

1. Is there a need for a mobile application that facilitates the learning of geometry for the visually impaired?

   **Sub-research questions:**

   2. What technologies should be used for this application?

   3. What are the functional and non-functional requirements for this application?

   The metrics have not been performed as strictly as the method suggests but all the data-items were noted down, in connection to a “topic” and are brought in correlation with a research question.

   The background study will be performed within the ACM Digital Library because of the focus within the research. ACM stands for Association for Computing Machinery and the articles, publications and papers available have the a connection with the topic “Computer” which is necessary for the research even while researching within the context of math, geometry as well as pedagogy / education.

**Scenarios**

A vi student wants to learn something new in geometry. For this purpose she takes her android tablet with the installed application and then navigates through the menu to the instance she is interested in. This process is aided through a vibro-audio interface. A vibro-audio interface provides feedback to the user through sound as well as vibrations (Giudice et al. 2012). The different options in the menu are read out loud and whenever a new

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7 Also referred to as “RQ”


9 Whether this is an adequate feedback process has to be established during the background study.
field is being touch there is a vibrational feedback. The geometric form is then displayed and the user can touch it and make it “visible” for them. If the VI leaves the line of the geometric figure auditory feedback is provided to the user in addition to the tactile feedback. The figure will provide additional feedback such as name of the variables and possibly the angle between the lines (cf. Figure 3 A).

An additional element is the option of manipulating the figure and gathering further information. This information can be the equation leading to the figure or certain dependencies that enable the graphic to happen.

A scenario that should also be realized is the connection between the classroom and the application. To establish this, a connection between the (black)-board and the application has to be created. A possibility would be to use a smart-board that is connected with the app and creates the figure on the device while the teacher is drawing it on the board. This would be an ideal situation (cf. Figure 3 B). Another option would be that the vi teacher enters the requirements of the geometrical figure into the application and the vi student can feel the figure afterwards\(^{10}\). But this would stop the vi from actively participating during the classroom interaction.

**BACKGROUND STUDY**

For the background research the database ACM Digital Library has been used as a resource to find appropriate papers. The following search terms were used (cf. Table 1):

<table>
<thead>
<tr>
<th>Search phrase</th>
<th>Results</th>
<th>Included</th>
</tr>
</thead>
<tbody>
<tr>
<td>visually impaired AND tool AND geometry AND app</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>visually impaired AND pedagogy AND geometry</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>visually impaired AND geometry</td>
<td>164</td>
<td>21</td>
</tr>
<tr>
<td>pedagogy AND math AND visually impaired</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>education AND geometry AND visually impaired</td>
<td>56</td>
<td>20</td>
</tr>
<tr>
<td>education AND visually impaired</td>
<td>732</td>
<td>9</td>
</tr>
<tr>
<td>Results:</td>
<td>965</td>
<td>56</td>
</tr>
</tbody>
</table>

Table 1: Research with terms, results and the papers included for the background study

For the different search strings the titles were read and (if the title sounded appropriate) the abstract was read. This process was done from “most fitting results” to “least fitting results”. If a paper sounded promising it was included for the background study, downloaded and included in the citation list. For processing the papers they were mainly read from A to Z (according to title). The search strings “education AND visually impaired”, “education AND geometry AND visually impaired” as well as “pedagogy AND math AND visually impaired” and “visually impaired AND geometry” were included in the research to ensure that the aspects of education are included when designing the application. It would be a waste of effort if the application that was developed would not be able to facilitate a good learning experience as well as ensure an appropriate display of information. Searching within ACM library there is still a connection to technology based on the venue.

The total of 56 papers is the basis to create a list of requirements for developing the prototype during the master-thesis (cf. Figure 4)\(^{11}\). Unfortunately one paper was not available from any source wherefore it could not be included or reviewed within the background study. The 56 identified papers are then numbered\(^{12}\), read, evaluated and ‘graded’ on a scale from 0-10. 0 meaning, that the paper is not relevant at all or shows logical, grammatical or referencing errors. Papers graded this way were just not prepared well enough to count within the background study. If a paper receives a grade between 1 and 3 it is unlikely to be used a lot – it might contain one or two aspects that are useful which might be considered. Between grade 4 and 6 the papers are likely to be

\[\text{Figure 4: Display of all reviewed papers}\]

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\(^{10}\) These scenarios are a possibility but can be defined in greater detail according to the requirements established during the background study.

\(^{11}\) All papers are included in Appendix 3. The annotations have been mainly performed using pen and paper wherefore they cannot be found in the pdf-files.

\(^{12}\) With the numbers from 1 to X. Additionally papers could be numbered 1 A and 1 B if B was an updated version of A. This could be indicated by either a similarity of the title or something along these lines.
included within the background study and showed some strong points that are worth to be considered. The papers with a grade of 7 and higher will most likely be included and provide the most matching or influential information.

While reading the papers additional papers were identified due to the fact that they were very influential for the paper read or delivered a main idea. When possible and appearing logical the use of 2nd hand referencing is to be avoided and the original source was considered. During this process 5 additional papers were identified and included in the background study. On the other hand papers that did not bare a correlation with technological aspects or the angle pursued for this report were excluded after having been analyzed. In addition to the papers scoring with a 0 or 1 a total of 20 papers were disregarded wherefore 40 papers are included for this report.

The list of papers that were reviewed and graded can be found here: Appendix_1 – “Papers_Reference_Grades” Tab.

Limitations

Within this report only one database was used as well as only a limited amount of search terms were applied. Following this research another research approach should be pursued with additional keywords that have been identified during the background study.

During the research there were also multiple guidelines identified (partially as references within the researched papers) that could be investigated further in ensuring that the functional requirements (RQ3) are set correctly (S. Wall & Brewster 2006; Manshad et al. 2013; Ossmann et al. 2006; Atkinson et al. 2006; Giudice et al. 2012; Rassmus-Gröhn et al. 2007).

Research Question relation

The information gathered is separated according to the GQM towards the different research questions. The data-items that correlated with the different research questions were marked accordingly in the Excel-Spreadsheet that displays all information gathered for the relevant papers (cf. Appendix_1 – “RealData” Tab). The gathered knowledge has the clearest combination with the 2nd research question (cf. Figure 5). With the combination of the different data-items within the metrics enables the answering of the overall research question (RQ 1).

Research Question 1

Main research question “Is there a need for a mobile application that facilitates the learning of geometry for the visually impaired?” can be answered if the motivation within the area of visually impaired as well as the educational aspect are considered. Furthermore the other input will be channeled into answering this research question.

During the research a few quotes were identified that have are significant for RQ1:

“Geometry is one of the most difficult subject[s] to teach to blind pupils and one of the most useful at the same time: they need to build a coherent spatial representation of the world and to share with sighted people a set of common point of view (our language is full of geometrical references for example).”

(Hutchison et al. 2007, p.598)

“almost all my mathematical thinking is done visually and in terms of nonverbal concepts, although the thoughts are quite often accompanied by inane and almost useless verbal commentary, such as ‘that thing goes with that thing and that thing goes with that thing’ ”

([7] p. 424) ”

(Quek et al. 2006, p.327)

"design of the new hardware / software is frequently driven by engineering principles without solid theoretical knowledge of relevant perceptual and cognitive characteristics of the human end-user; the system developed generally have a steep learning curve and rely on unintuitive sensory translation rules; many solutions necessitate purchase of expensive single-purpose hardware; assistive technology often is built-around non-
Leading from there additional statements and points have to be considered. First is the discussion of the necessity it is important that the visually impaired get to experience “auditory event[s]” (Cohen et al. 2006, p.279). Within the field of ‘STEM’ the use of such an aiding applications could be very beneficial due to the fact that concepts within science are motivated through showing a graph and afterwards diving into to concept of algebra e.g. (Ludi et al. 2012; Cohen et al. 2006). A big problem that visually impaired students are confronted with is that they “cannot resolve the teachers deictic references towards the instructional materials as she speaks” (Quek & Oliveira 2013, p.4:5) wherefore a connection between the auditory information from the teacher needs to be connected with a form of graphical representation the vi can perceive. It would be a great accomplishment if the vi could be enabled to become a creator of media instead of just being the receiver (Cohen et al. 2006). There has been research done where an auditory interface has been implemented to teach geometry and math to the visually impaired (Droumeva et al. 2007). Within the field of math there are two modes of communication. These are ‘speech’ and ‘graphical representation’ – the visually impaired miss out on one of two modes which is unfortunate and results in a lack of information (Quek & Oliveira 2013).

So far the ‘graphical representation’ of information has been provided through various, more static, representation methods such as swell paper, embossing, thermoform, geo-boards, the use of braille printers and paper raised-line drawings (Jayant et al. 2007; Toennies et al. 2011; Quek & Oliveira 2013). The use of paper raised-line drawings was rather easy to use for the visually impaired but takes time to prepare as well as being more rigid and cannot be a flexible part of teaching within a classroom setting. A method to display tactile graphics to visually impaired is “[t]rajectory playback with a haptic device [that] can be used to allow the users to perceive shape[s]” (Crossan & Brewster 2008).

Using auditory-feedback is important so that tools for the visually impaired can be developed – this option would be especially useful for children (Droumeva et al. 2007). Visually impaired are good at picking up “variations of sound” and the “use of tones with variation of pitch and loudness to guide an unsighted user through the diagram” is very effective (Cohen et al. 2006, p.280). Furthermore there is the problem that so far “little work … [has been done] that explores the design of complex auditory displays for children’s interactive technologies” (Droumeva et al. 2007, p.171). An additional point is that there are a few prototypes that combine sound and feedback displays for the use with visually impaired children (Droumeva et al. 2007). The role of tactile graphics specialists is also being investigated which can result in information of how images and graphical representations have been prepared and created so far (Ladner et al. 2005). Furthermore applications are being designed especially for children (8-12) (Droumeva et al. 2007) which hints at the need for a target-specific application. For teaching in primary school two perspectives are followed that aid students learning and interaction with one another. These are development psychology and the socio-culture perspective. The integration of vi children in the learning context is important so that knowledge construction can take place. Furthermore the context in which the learning is done is very important (Sallnas et al. 2007). Additional learning techniques that could be important are verbal and social learning (Moll & Pysander 2013; Giudice et al. 2010).

Research Question 2

What technologies should be used for this application?

The technologies used and investigated vary from a simple audio feedback over to a vibro-audio interface that supports the visually impaired. There are various insights gained and all the different technical solution approaches can be found within the Appendix 1. The ones that seem to be the most interesting solution approaches are those facilitating a tangible interface using vibrations. There are several ways how to bring the user in contact with a vibration to enhance a graphical representation. To mention just a few, there are haptic mice and joysticks that can enable the user to “feel” the representation, special tablets that can transport braille print (Bussell 2003; S. A. Wall & Brewster 2006; Tzovaras et al. 2004; Klingenberg 2007; Manshad et al. 2013; Toennies et al. 2011; Milne et al. 2014) as well as the use of PHANTOM devices (Moll & Pysander 2013; Tzovaras et al. 2004; Crossan & Brewster 2008; Saarinen et al. 2005; Toennies et al. 2011; Rassmus-Gröhn et al. 2007). These technical solution approaches proved their usability within conducted studies but they do not enable the user to use them as standalone solutions where only one technical object is needed. In addition, some of the mentioned solutions are costly to produce, and buy as well as maintain wherefore they are not applicable for an easy access or use.

In addition to these mentioned technical solutions are the solutions that are more reasonable to be included possibly for the system that is aimed to be produced within this context. There is, for example, the option to include a pen-based input (Cohen et al. 2006) which makes it easy for the visually impaired to transfer data using the pen. In addition the option of using trajectory feedback (Crossan & Brewster 2008) could be useful to be able to lead the visually impaired through a certain geometrical shape if they should not be able to explore the shape...
properly on their own. The application of gestures within the use of a touch display is also an option (Vidal & Lefebvre 2010). But this is only one part of the application that should be considered. The combination of audio and tactile feedback aids the user and enables them to gather information more easily. Some of the approaches to include audio-elements within an interface are sonification (Milne et al. 2014; S. A. Wall & Brewster 2006; Droumeva et al. 2007) as well as audemes (Ferati et al. 2012) and area hinting (Su et al. 2010).

The intention of displaying and “conveying visual information via a commercial tablet” with a “vibro-audio interface” (Giudice et al. 2012, p.103) is not something that has been researched or applied often. Most systems approach the tangible feedback with the application of an external source or they combine it with a computer to be able to provide the necessary information wherefore these systems are not mentioned in detail while evaluating the solution approaches for applicability to the here proposed application. Nevertheless the input might be useful when creating the application because of their experience and received feedback.

Reasons why technology approaches are not as successful or have to be adapted are the possibility that “confusion can result when visually impaired students encounter intersecting lines … [and] sharp corners on the outer edges of shapes can be disorienting, since this causes the user to suddenly lose contact with the shape” (Bussell 2003, p.513). A main reason for the failing of solution approaches as well as technical solutions is, that the developers or engineers, that develop the application / technique do not have the right point of view to work within the domain. Their insight, perspective or input can be naïve assumptions and that they ‘forget’ to involve feedback of the actual end-users (Giudice et al. 2012).

The use of a mechanical actuator for the tangible feedback is not useful due to the fact that they have a limited spatial resolution and dynamic range as well as the problem of a costly production and maintenance. Furthermore it is very obvious that the user has a disability (Xu et al. 2011).

Research Question 3

What are the functional and non-functional requirements for this application?

According to this research question it needs to be defined at the beginning what functional and nonfunctional requirements refer to. Rainardi defines it this way: “Functional requirements define what the system does. They contain the features … [the] system should have. Nonfunctional requirements guide and constrain the architecture” (italics in original) (2008, p.61). This means that the functional requirements will focus on what the application will be able to do, how it will react to input and what elements of information will be displayed. The nonfunctional requirements on the other hand will define the availability, price-range as well as the platform compatibility.

The functional requirements derive both from the technologies mentioned within RQ2 as well as the elements identified during the background study relating to RQ3. The application has a good ecology if the elements used within are “balanced and contribute to a high fidelity, information-rich-environment” (Droumeva et al. 2007, p.171). The system will have an active display which means that the finger moves freely across the display and receives feedback according to the location (Xu et al. 2011). For the force-feedback applied in the application it is best when it lies between 80-100 % (Bussell 2003) furthermore the use of a ‘cellular touchscreen’, such as an android device has, is very useful because it provides the simplest way for creating vibrotactile feedback (Toennies et al. 2011). The pulse frequency can be considered to be applied using 60x60 pixel (Giudice et al. 2012) even though this would be needed to be investigated during the user study once the application is developed to see how the users have the best feedback and user experience.

If gestures should be applied within the application these could be based on the gestures vocabulary according to Hutchinson et al. (2007). On a computer visually impaired apply vertical scanning wherefore this should be considered if a form of scanning is applied within the application (Grammenos et al. 2009). An additional functional requirement that should be considered is that the application might be used by more than one person wherefore there might be the need for profiles as well as different accessibility features and levels. A challenge that comes with this requirement is the start-up screen that has to reflect the different accessibility features and should display the accessibility that is useful for ‘most of the users’ (Grammenos et al. 2009). The playing of sound or music is one of the main features the application will have wherefore it should be placed thoughtfully and never as an ‘after-thought’ (McElligott & van Leeuwen 2004). The main option is that a movement will trigger the playing of a sound. This could be either done through area hinting where the display is separated into sections and will trigger a rain dripping sound, e.g., if the user leaves the line towards the left top section (Su et al. 2010; Droumeva et al. 2007).

A possible limitation of the application that needs to be considered is the different skills within the target group – knowledge and options vary within depending on the time the visually impaired took place (Moll & Pysander 2013).

The nonfunctional requirements for the application can be condensed to the following: The application should be deployed as an android-application used mainly on an android tablet and has to be a ‘off-the-shelf’ product to make sure that the costs are low and the availability is well established. Furthermore is there a need for the device to be able to transport a vibration to the user wherefore the use of an iPad (e.g.) is not possible due to the lack of this function. An additional requirement is the possibility of playing sounds – which is usually
given with a ‘normal’ device. Whether the application will be native or web-based depends on the access of the different sensors and functions within the device. Most likely it will be a native application so the user can install on their device and does not have to navigate through a website every time they want to use it.

**INTERVIEW**

In addition the background study a meeting with Mexhid Ferati was arranged. This meeting took place on Wednesday the 19\textsuperscript{th} of November at the Linnaeus University Library Café. It was a rather informal meeting that worked as an idea exchange as well as a small intellectual debate and brain storming. I presented my current status of the mini-thesis. As a preparation of this meeting I prepared some initial questions as well as questions leading to tips and tricks from an expert within the field. Dr. Ferati was very open to my ideas and provided a lot of additional information and input I can use when developing my idea further within my master thesis\textsuperscript{13}.

Questions we discussed:

**Topic related questions**

a) *Do you have suggestions as to what I should or should not do concerning sound "effects"?*

\textit{MF}\textsuperscript{14}: Sound is used in many forms. ‘My’ way has to deal with enabling the reader to remember the content of a text better. If you see a picture with a text you can comprehend the text better. I developed sounds that transport the same as an image would – they are called ‘audemes’. An audeme gives the context of the text. To test the functionality I went into a classroom with visually impaired and separated them into two groups. In group A the text was read for them and in group B the reading was aided with the playing of the audemes. Two weeks later a small test was given to both groups and group B performed better which proofed that the use of audemes is beneficial. Considering teaching math it might be beneficial to get in contact with Bruce Walker (works at Georgia Tech) whom has been working within this field.

b) *Do you think that a first testing phase for a prototype is ‘ok’ with normal users who are blindfolded so they can explore the interface "like a VI"...? I have read that there are studies showing that using people who are blindfolded instead of VI the results are rather similar and the differences are not too great - especially for teaching auditory graphs and tactile maps (Guidance et. al., 2012)*

\textit{MF}: For a pilot / in this phase this approach is ok. There is a real difference if someone is born blind or ‘turned’ blind. They have a different perception of the world. This is what I did: To try to get closer to what I should prototype I just used my classmates to see if the idea was promising.

c) *How do you do a preliminary test?*

\textit{MF}: This really depends on the resources. Sometimes (now I have a blind student at my school) I would just go to him and I would ask what he thinks. An idea – you could contact administration to see whether there are visually impaired at Linnaeus and then ask them to contact them and if they would be willing to talk to you they could do that.

“**Personal questions”**

d) *How come you are working within this field?*

\textit{MF}: During my master thesis I had to program an application for a guided tour on campus using audio-feedback in correlation with the geolocation. This was in 2006 and those mobiles were ‘old’. As a hobby I always liked psychology and then I found the program of HCI. A combination of computer science and HCI seemed appealing. I talked to professors and advisors and that is how I got the idea of developing something for the visually impaired.

e) *How do you perceive the future concerning the field of technology, visually impaired...? What could be ‘the next big thing’?*

\textit{MF}: There used to be a gap from helping everybody and GUI was a dent in helping everybody else. After a couple of years we started working on something for everybody and it is much more versatile. In the future the gap between ‘us’ and the visually impaired will be decreased. There might still be problems but everything ‘I’ can get ‘they’ can get as well. Year’s back there was a vision that everything will move to touch and everyone said ‘No’ but it is not all about the hardware techniques.

Overall was the meeting very useful as it helped gain a new focus and considered additional elements such as approach techniques considering the visually impaired as well as the providing / hinting of additional experts within the field that could be beneficial to work with. The meeting was more an intellectual discourse that is useful and established a good connection with Ferati for future collaboration.

**DISCUSSION**

Having performed the data-analysis according to the focus of the research questions there is a need to discuss...
the results as well. The identified data shows that the focus of previous research has been on the use of computers, computers with an additional device such as a tactile mouse or joystick or the combination computer with a tablet for providing some sort of interface for the visually impaired either tactile or auditory. This is rather interesting due to the fact that just using a tablet with a touchscreen has, in my opinion, more potential due to the fact that it is easily transportable, the user can move freely and integrate the application into their daily life instead of having to adapt their living situation to the software. A big plus of using an ‘off-the shelf’ device is that the user does not signal to every other person that they are disabled according to the device they use because it fits in with the others.

Overall there is a need for developing and providing an application for the visually impaired that facilitates the learning of geometry. During the research there was no application identified that provides the focus or use of technology aimed for within this application. A stand-alone solution is a good approach to ensure that the use is unrestricted to having an aid by an additional person which increases the independence. Providing visually impaired with an application they can use on their own also strengthens their self-worth, self-confidence as much as their knowledge (Ossmann et al. 2006).

FUTURE WORK

In the future there is a need to investigate additional literature focusing on topics such as ICT, education practices for the visually impaired (without focus or relation to technology) as well as establishing contact to people with a visual impairment to discuss the approach and gather first feedback to the idea. Furthermore the application needs to be developed according to the requirements and user tests have to be performed. For the initial user tests the principle of blindfolding users can be applied to gather a general feedback concerning usability. Afterwards the application needs to be refined, bugs fixed and the usability enhanced. As a following step a usability test with visually impaired children should be performed to gain feedback of the target group.

To be able to develop the application the system architecture needs to be defined as well the software that will be used. Guidelines identified during the background study need to be reviewed to ensure that the application will be beneficial for the user and does not include unintuitive and interrupting elements.
REFERENCES


World Health Organization, 2014. WHO | Visual impairment and blindness. Available at:


7.2 Interview-Notes with Mexhid Ferati
Questions:

- What do you think of this idea?
- Your suggestions
  - Do you have suggestions as to what I should or should not do concerning sound "effects"?
  - for math / objects
  - sound used in many forms : his way - if you see a picture to a text better comprehensions
    - he developed sounds that transport the same as an image "audemes"
    - audemes gives the context of the text
    - he went to the blind class and separated the class
    - one group: hear the essay // hear the essay and play the sound
    - 2 weeks after test - sound helped remember
    - semantic level of sound
    - back to teaching math with sound: sonification -> bruce walker from georgia tech (he is been working a little bit on this) (good starting point)
  - Which elements have you worked with and received positive feedback from users?
  - If you use different devices for your studies, which device has received the best feedback by the community based on your opinion?

- User Tests
  - Where / How did you recruit visually impaired users for your usability tests and user studies?
  - Do you think that a first testing phase for a prototype is 'ok' with normal users who are blindfolded so they can explore the interface "like a VI"...? I have read that there are studies showing that using people who are blindfolded instead of VI the results are rather similar and the differences are not too great - especially for teaching auditory graphs and tactile maps (Guidance et. al., 2012)
    - for a pilot / that phase it is ok
    - real difference if born blind or "turned" blind
    - different perception of the world
    - that is what I did - trying to get closer to what I should prototype : I just used my classmates to see if the idea was promising
  - How do you do a preliminary test?
    - depending on the resources
    - sometimes (now blind student at school) - game for the blinds went to him and asked
      - maybe contact administration see if they want to contact me
  - What things do you think should I look out for during a user test?
  - how many iterations do you usually apply before you are satisfied with the feedback?

- Programming
  - What programming languages do you use for "creating" sound in your solutions?
  - Do you have some tips concerning programming an application / service for VI?
  - Which elements do you perceive as necessary to provide a VI with a good user.
About you:

- Name: Mexhid Ferati
- Age: ?
- Gender: Male
- Currently...  
  - What is your current position?
  - What are you currently working on?
- Inspiration  
  - How come you are working within this field?
    - master thesis - guided tour on camous or sth - audiofeedback & geolocation
      - 2006 / mobiles were OLD
      - always liked psychology (hobby) - porogram of HCI - combo of comter science & HCI
      - talk to profs and advisors
      - idea of developing sth for the blind
  - How do you perceive the future concerning the field of technology, visually impaired ..? What could be "the next big thing"?
    - there used to be a gap from helping everybody
    - gui was a dent in helping everybody else
    - after a couple of years we started working to work on sth for everybody
    - it will much more versitile
    - gap will be decreased between VI and "us"
    - there still problems but everything i can get they can get
    - had a vision that everything will move to touch
      - everyone said "No" - its not all abot hardware tecti

Stephen bruster : Glasgow (check out)
Guitarre on a tablet ! CHECK out!
termo-forms - what is it? (thermo) who does it? nothing digital // "print" shapes
contact blind schools or something of sorts to test it
blind students at university? but maybe too familiar with the topic
concentrate on identifying the shape vs.
fear that we find sth and th

contact blind schol - teaching methods? for geometry

// association for the blind or sth - just atalk for an hour
- split class ( 15 traditional - 15 tablet) - do well or similar benefits? shapes easier on tablet

maybe ask jenna to see if i can work on hers for a bit
7.3 User Study 1

7.3.1 Original Outline

1. Ask if recording and documenting this session is ok
2. Record name, degree of VI, age, personal experience

3. Let them explore
   (a) show them where the button is for draw on / draw off
   (b) click draw on : they can explore the lines & interactions
   (c) birds = outside ; rain = inside
   (d) currently only rectangular shapes

4. Question and Answer - with app
   (a) I create a shape square
      make a screenshot of the shape
      • Are you inside or outside the shape?
      • Where are you now?
      • Describe the shape of the object?
      • angles big or small, seem to be even?
   (b) Create a second shape rectangle
      make a screenshot of the shape
      • Are you inside or outside the shape?
      • Where are you now?
      • Describe the shape of the object?
      • angles big or small, seem to be even?
   (c) Can you make a shape?
      I turn off draw and turn it back on
      • Creating a shape easy?
      • Explore the shape: was it accessible?

5. Question and Answer - without app
   (a) Were the vibrations helpful?
      • the interaction / reaction with the vibration ok?
      • good guidance?
do you have an idea of the shape / position of the line with the vibrations?

(b) Is the sound-length ok?
- too long?
- too short?
- sounds ok?
- good guidance?

(c) Overall -
- was the interaction enjoyable?
- did you gather an understanding of the shapes?
- what should I change?
- are you missing something?
- suggestions for improvement?

7.3.2 User Study 1 - Evaluation

Notes
- Two testers (tester 1 & tester 3)
- Tester 1: born 1979 - 2% vision
- Tester 3: intern at US SYD - around 20 years old - sits in a wheelchair and seems to have other disabilities as well
- Language: Tester 3 was uncomfortable speaking English, Communication between Interviewer and Tester 3 in German

Procedure
- let them explore the app after each other
  - started with tester 1, passed it on to tester 3
    * Tester 3: more reserved and shy, took a bit longer until confident to explore app
  - I created a square that was explorable: to make sure the lines would connect properly (slightly rectangular)
- observed them use the app
- discussed how the interaction worked and what they thought off it
Outcome

• creating the shape was a bit tricky

• the drawing of the lines is not as fluent and easy it needs to be

• idea: adding sound feedback when fingers touch the screen
  – finger 1 : sound
  – finger 2 : sound
  – finger 3 : sound
  – finger 4 : sound

• accessible measurements
  – include the measurements in a way that they are accessible to VI
  – read out loud / comparison to a ruler

• introverted colors
  – black background with white lines ; easier accessible for Tester 1 (e.g.) because he can make out information better with a high contrast

• thicker lines & more prominent colors

• more prominent difference in the sounds
  – length is good

• vibration should continue while being ON the line
  – not just when the finger crosses the line

• synchronization & saving of ...
  – preferences
  – created shapes
  – user

• user preferences
  – mode for alternative backgrounds etc
  – better contrast, different colors ...
• scanning content from books and make it accessible in app
  – TextGrabber (e.g.)
  – Tester 1’s thought: having a math book and being able to scan the page: app grabs necessary information and translates it into the shape on the display

• make sure to have different user levels
  – ground school students easy version of app with basic functions

• include option to make it more complicated over time according to user’s needs
  – provide more functions for high school students

• tactile help in school was very chunky / bulky so not precise
  – just being able to feel without little relation to actual size / angles etc

• Questions:
  – with how many fingers can I explore the shape?
  – can I use a pen to explore it?
  – will it (at one point) be accessible through the Apple Store (aka iOS devices)?
  – can I synchronize / save my shapes (on a computer)?
  – will the app talk to me?
  – what about a circles?

General Feedback

• the idea is very good
  – very helpful and interesting
  – Tester 2 thinks it has potential and can be very useful
  – the line feels good

Resulting To Do

1. make lines thicker - DONE
2. create option menu to change colors
   - black background / white lines - DONE

3. make vibrations so that they are always on when touching the line

4. create a way so that talkback is possible to have included

5. include angles & length of the shape with voice output

6. change sound strips to more distinct sounds - DONE

7. feedback for shape created
   - Mainly referring to feedback that the fingers are on the display and provide feedback if fingers are lifted that the lines aren’t crossing, the shape is correctly displayed etc.

7.4 User Study 2

In the following the prepared thought-outline, as well as the stories presented to the present testers are shown. Questions, tasks and ideas are described in detail. Following are the notes elaborating the evaluation and thoughts leading from this user study.

7.4.1 Original Outline

Thanks for coming today and taking the time to participate in my user study. Before we start I would like to ask you if it is ok if I video-record our session today. This way I can focus on what you are saying and do not have to worry about missing anything. The recordings are for evaluation purpose only and will not be used for anything else.

I am Lisa, from Germany and I am currently finishing my master at Linnaeus University. I study Social Media and Web Technologies and for my final project I am working on creating a learning environment for visually impaired to learn geometry using an android application and a model. With me is Alisa, she is a PhD-student in my department is helping me with the development of my application.

May I ask you to provide a short introduction of yourself. Your name, your age and (if you feel comfortable) your level of impairment. And if I may contact you again for a follow-up study in the future. If so maybe I could get the contact details from Tester 1.

But before we go into more detail about the application I would like to tell you a couple of futuristic, innovative scenarios for achieving the goal I
have set myself. The stories I will tell you are not necessarily realizable but are to inspire you.

The exact procedure for today is the following:

1. I tell you my stories - after each story you discuss pro’s and con’s of the idea
2. We give you the tablet and the model
   (a) please interact with the mode and the app freely
   (b) we have 2 versions and we would like to hear your feedback
3. Describe to me:
   (a) how did you learn geometry in school?
   (b) how could you imagine geometry being taught in school better (e.g. through help of the app)?
4. Any additional thoughts?

So let me start: May I introduce Jennifer. She is a 12 year old girl going to school. Her favorite subjects are Biology and English. She is visually impaired from birth and has a very low visual capabilities. So let’s imagine how her school life could look like - with a focus on math class where the current topic is Geometry.

1. Story 1
   - Jennifer is sitting in her regular seat in class.
   - She has a special table - featuring a different surface.
   - It can detect the placement of your fingers and create a haptic object that can be explored with the fingers.
   - The object consists of little pins that are extracted from the table.
   - This lets Jennifer explore the shape during geometry class really easy.
   - Her teacher just needs to enter the data in a certain field on the smartboard.

2. Story 2
   - Jennifer is working in a group with other classmates.
• They are exploring a certain rectangle - for Jennifer the teacher brought a set of specific lego-pieces which can interact with her tablet, the rest of the class has regular lego pieces.

• Jennifer and her group-mates built the shape with assistance of both her tablet, as well as her classmates.

• For Jennifer this way of interacting with geometry is easily accessible as she can work together with her peers and interact in the regular classroom.

3. Story 3

• Jennifer has an iPhone in class which she is allowed to use to follow things that happen on the board

• While explaining a new geometric shape the teacher takes 2 seconds to take a snapshot with another iPhone (using a specific app) - this information is than transferred to Jennifer’s phone and through sound (she has one earphone in her ear) the shape is explained through her software

4. Story 4

• Jennifer is in class and she has a smart geo-board

• The geoboard can create shapes according to input, so when the teacher explains something to the class there is a connection through the smartphone to the geoboard and indicate the corner to which the angle etc. is connected. According to that data the geoboard creates connections and gives a sound feedback (e.g) a ping-sound to Jennifer when it is done.

Interaction with App & Model

• Start with B Lisa Thesis
  – How are the colors?
  – Voice feedback accessible and ok?
  – Do you feel confident interacting with the object?
  – Is the feedback from the app sufficient?

• Continue with A Lisa Thesis
  – Which version do you prefer?
– Version A or B?
– Would you like a menu where you can change the colors on your own?
  * Switch between white on black / black on white?
  * Are there other options you would like to have in the menu?

• How do you like the model?
  – Easy to manipulate?
  – Stable?
  – Interactivity ok?

Your own story

• Please describe how you learned geometry
  – Did you have assistance in class?
  – Did you use specific tools?
    * if yes - which ones?
    * did you prefer one?
  – How efficient was your learning of geometry?

• Imagine a different way of learning geometry in class ...
  – What would you like to have in a classroom?
  – What would you suggest?
  – Tell me a little story about your way of learning geometry in school

7.4.2 User Study 2 - Evaluation

Here the evaluation of user study 2 is presented\textsuperscript{35}

1. Participants : 3

2. App

  • Include option to take pictures and have the information transferred to app
  • voice feedback in all stages

\textsuperscript{35}A link to an anonymized video is accessible here.
- which button is being pushed?
- where within the application am I?
- in which part of the screen am I?
- better orientation while moving

- home and native navigation buttons should not be easily accessible
  - the buttons interfere with the interaction within the app
  - need to be removed or turned off for time being

- Option menu
  - changing of color scheme (black / white vs. white / black)
  - thickness of lines

- No feedback to vibrations

- The sounds are good
  - include maybe theme options where the sound can be chosen by the user

- better feedback when ...
  - shape is created
  - the screen is touched
  - the touches are recognized
  - the finger is within the draw area

- draw area
  - possible of not having a draw area
  - touchpoints take place and the area automatically freezes and does not accept additional touch = no accidental movings of TP

- appearance
  - fatter lines and buttons
  - more distinct colors : for those with low visual percentage (easier to make out)

- exploration
  - probably better with just 1 finger testing to see what happens more often (future)

3. Model

- needs more stability
– connections between different elements need to be stronger
– could be established through magnets (suggestion by tester)

• *sticking* to screen
  – when it falls it could break or be lost as it is not obvious where it is

• better information from the model
  – where are the touchpoints that transfer the input?

• possibility of creating different shapes (later) (future)
  – letters, circle etc.

4. General

• VI want to have the exact same
• no difference between *them* and *others*
• app & model should be usable by all so that VI aren’t singled out
• great idea
  – would be very beneficial in schools
  – they hope to see it in classroom

• needs a good introduction
  – needs a good introduction
  – explain the model in detail
  – the interaction possibilities between model & app
  – what can be done with the app
  – how does the model react
  – accessibility
  – good introduction for classroom

• being able to create / build things with classmates would be nice
  – collaboration and interaction

• developed tool needs to be easily accessible, usable by the VI independently, transportable, should not be different from what the others have

5. Idea

• idea is great, lots of potential
• they would have liked to have it while learning geometry
• should be very beneficial

6. Personal Experience / Opinions

• Youngest tester had a separate class with a different teacher
  – sounded like individual class
  – everything was described and explained catering to her needs

7. Future

• more than one OS
  – apple: solution for iPad which doesn’t vibrate would be necessary
• enable different shapes, user modi
• personal sign-in to save preferences, shapes, created information
• providing of information through voice (e.g. angle of each corner)
• more support
• menu
• test how exploration is being done
  – one-finger vs. multiple-fingers
• adapt model
  – more stable
  – fixing to the screen
• taking picture of something having information digitalized accessible (see 8

8. Alisa Input

• Project Idea 1
  realizable
  Take a photo of white board, visualize it on the tablet with vibration and sound feedback of each object from the screen/photo
  Tasks:
  – take a photo of white board
  – convert it to Grayscale (everything that is not white -1, white - 0)
  – use TouchImageView to check the touchable point in the image, if it is 1, then vibrate 0, not vibrate.
- Detect figures
- Add sound to figures

• Project Idea 2

future

Use 3d objects to interact with application

- create a 3d object with special material (a lot of time and effort)
- app should detect this 3d object on the screen
- sound navigation
- vibration on each element of a figure
- no drawing mode, only touchable mode
  * so blind people should not draw anything,
  * they can have a figure on the screen only by interacting through 3d object.
  * Otherwise it is difficult to manage all movements.
- Screen should be frozen for this app, and back/home button should not work, so that blind people do not close the app by mistake.
- The main goal is to explore the shape, and to create a shape by using 3d model not the app. The app will allow to explore the shape with vibration and sound support.
- Implementation time for first prototype 3 weeks, but without good 3d model it will not be done at all.
- Problems: 3d model

• Research

- Example: https://blahti.wordpress.com/2012/06/26/images-with-clickable-areas/
- TouchImageView: https://github.com/MikeOrtiz/TouchImageView
- Detect Figure objects:
  http://marvinproject.sourceforge.net/en/plugins/edgeDetector.html
  https://developer.vuforia.com/library/articles/training/object-recognition
- Free library for geometry objects recognition:
  http://marvinproject.sourceforge.net/en/plugins/edgeDetector.html

• Estimate:

- Implementation time for second prototype is 2 months
• Problems:
  – Detect Objects on the figure to add sound (inside/outside)

7.5 Assembly Instructions 3D Model
Assembly Instructions for the Appcessory

One corner node as a step-by-step instruction

Needed for the assembly are:
• super-glue
• self-sticking copper-tape
• printed pieces
• time

1. Take flattened small part of the printed node (will be top / bottom of the node)
2. Take a piece of the copper tape
3. Place it on the inside (center) of the node (flat surface area)

1. Wrap copper tape around top (curvy part)
2. Try to stay as center as possible, covering the flattened part

1. Place copper tape (inside of the piece) over the other tape
2. Make sure, that all copper pieces are connected

For each node, two of these wrapped pieces will be needed. They will be either top or bottom of each corner node.
1. Take cylindric inside
2. Wrap the copper tape (center of the shape) around
3. Make sure, that copper tape touches and overlaps

1. At the end of these steps, the pieces should look something like the picture above
2. It is not necessary to have a cross on the top / bottom - during our assembly it was one approach - a single line running through the center is enough
1. Place the cylinder on one of the flattened shapes
2. Take one of the small, hollow, rings and
3. Place it over the cylinder

1. Take the wider, hollow, circle and
2. Place it over the cylinder
3. This way, you have the following: bottom, small ring, wider ring

1. Take the next small, hollow, circle and
2. Place it over the cylinder
3. This way, you have the following: bottom, small ring, wider ring, small ring

The finished corner node would look like this (see right). The flattened part is placed on top.
1. Take the cylinder and the super-glue,
2. place a tiny drop on top of the copper tape
   (while it sits on the table - see left)
3. Place one flattened part on top of it (flat
   side connecting to the cylinder)

1. (if the rings have fallen off -
   replace them in the correct order (small,
   wide, small))
2. Place a drop of super-glue on top of the
   copper tape and add the other flattened
   part (flat part connecting to the tape)

1. Apply pressure to the node and
2. give the glue time to dry
3. Carefully remove excess glue so that the
   rings can still move
1. Take the small rod (5mm) and
2. place a tiny drop of glue in the center of the wide ring
3. With the slightly curved edge, press the rod onto the glue
4. Apply pressure until it connects & dries

1. Take the big rod (11mm) and
2. place a tiny drop of glue in the center of each small ring
3. With the slightly curved edge, press the rod onto the glue
4. Apply pressure until it connects & dries
5. When dry, remove excess glue and
6. ensure, that the rings can turn separately