UiA University of Agder

Master

Effective use of Augmented Reality to Support Reading for People with Dyslexia

An investigation into affordance of augmented reality technology as an assistive tool for people with dyslexia

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Abstract

As technology keeps getting developed it has the possibility to become more and more useful and one such technology is augmented reality. This thesis examines the possibility of using augmented reality to assist dyslexic people in reading written content. Dyslexia is the most common learning disorder and affects approximately 10% of the world's population. People with dyslexia often have troubles with reading which can affect their academic performance as well as their daily lives. Being able to assist dyslexic people can in turn help a lot of people worldwide.

Using known design principles such as the human-centered design process, this research explored design choices to develop an augmented reality application that can assist people with dyslexia. The human-centered design process incorporates the target group into the design process which makes it possible to enhance the effectiveness and efficiency of the application, which in turn can make the app more satisfactory to use. The thesis also goes into detail on how the app was designed using the human-centered design process as well as the methods used to develop the augmented reality app for a mobile phone.

This study investigated if the human-centered design process could be used to design and develop an effective augmented reality app. It takes use of user testing with the target group and uses qualitative interviews and questionnaires to measure how the participants experience using the app and if they enjoyed using the app or not. The results of the user testing showed that the participants had an overall positive attitude towards using an augmented reality app to assist in reading.

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Chapter 1

Introduction

Dyslexia is a learning disability that can affect a person's ability to read, spell, and write and affects roughly between 9 and 12 percent of the population and is the most common learning disorder[1]. Text can be found everywhere such as in newspapers, books, emails and street signs, and since we use so much text to communicate, it can be a challenge for people with dyslexia as they have to spend significantly more time when reading or writing. As technology advances, it provides an ever increasing number of tools and options that can empower people with dyslexia through their daily lives.

Augmented reality is a technology that has much potential to provide innovative solutions. By superimposing digital content onto the real world through your mobile phone, augmented reality can create both personalized and interactive experiences that could help people with dyslexia have more choices on how to go about their reading. As a designer and developer, getting an understanding of the struggles people with dyslexia have, is very valuable and important for being able to design a product that is useful.

The following sections will introduce the background and motivation for the project as well as the problem statement. Following this is the background for the project. Followed by the problem statement, and the the aim and objectives. Then the scope of the project is explained and limitations and constraints is mentioned. Lastly is the report structure, which details the structure of the rest of the thesis.

1.1 Background

As a student studying the field of "Multimedia and educational technologies" at the University of Agder, being able to design a solution that could make a real difference in the lives of people is exciting. Multimedia is an ever evolving field which presents exciting opportunities and Augmented Reality is an exceptionally fascinating area that has much potential through the power of mobile phones which keeps getting better every year.

Together with the supervisors, an idea to see if Augmented Reality can be used to assist dyslexic people in their learning came up. As dyslexia is a very common learning disability, making an augmented reality application that could help in learning would be very useful to a lot of people.

1.2 Problem statement

Dyslexia is the most common learning disability, representing at least 80% of all learning disabilities[2]. By assisting people with dyslexia in some way, it might be possible to make learning easier for a lot of people. There are many different assistive tools for people with dyslexia, but as technology is ever-evolving, there will always be new possibilities to innovate and make things better. Augmented reality is one type of technology that is rapidly evolving thanks to mobile phones getting more and more advanced. Being able to combine the aspects of already existing assistive tools with augmented reality technology could provide new and exciting possibilities for people with dyslexia and in turn also make reading and learning more enjoyable.

1.3 Aim and objectives

1.3.1 Aim

The aim of this project is to apply known design principles to design and develop an augmented reality application prototype that fulfills the wants and needs of people with dyslexia, as well as test the effectiveness and practicality of this approach.

1.3.2 Objectives

- Investigate gaps in the area of using augmented reality technology to support people with dyslexia.
- Design an effective augmented reality prototype that supports people with dyslexia in reading written contents.
- Collect data by user testing through observation, questionnaires, and interviews on how the users experience using augmented reality.

1.4 Research Questions

RQ1 - How to design an effective Augmented Reality application that can assist people with dyslexia in reading written materials?
RQ2 - How do people with dyslexia experience using Augmented Reality to assist them in reading?

1.5 Scope

The scope of this master project is to design and develop an AR application prototype that can assist people with dyslexia by making reading easier or more enjoyable. To design and develop this AR application the human-centered design process will be used which includes interviews with dyslexic people to gather information about their needs. By Also looking at other studies on the topic of assisting dyslexic people with augmented reality, it might be possible to learn and innovate on previous ideas. Following the human-centered design process, after gathering data and confirming the context of use and user requirements, the app was developed in the Unity game engine and then tested in user testing by dyslexic people.

The study includes two groups of five participants totaling ten participants. The first group participated in preliminary qualitative interviews as part of the human-centered design process to gather information about the requirements of the application. The second group of participants partook in user testing after the application had been developed to gather data on how people with dyslexia experience using AR to assist in reading. The research methodology used is qualitative dominant mixed-method research and is used to answer the research questions.

Dyslexia can manifest differently in people and some people struggle more than others with the effects. Some people can have issues with both writing and reading, while others only have issues with writing. Based on the answers gathered from the preliminary interviews as well as previous studies, the scope was narrowed down to focus on only enhancing reading and not writing as doing both would be too large of a project in the timeframe given.

1.6 Limitations and constraints

The main limitation in this project is gathering participants as the participants need to have dyslexia, speak and read Norwegian, and also be able to meet physically at the University campus in Grimstad.

There was an attempt to contact some major Norwegian dyslexia associations, but the associations did not want to partake in this study. This meant that the gathering of participants had to be done by asking people with dyslexia to participate through friends and colleagues. After recruiting a few participants, a linear-snowball sampling method was used to gather further participants.

1.7 Report structure

Chapter 1 Introduction is followed by chapter 2 state-of-the-art, which presents some theory on dyslexia and augmented reality technology, and the state-of-the-art of assistive tools for people with dyslexia as well as the state-of-the-art of Augmented Reality and the use of AR to support people with dyslexia. Chapter 3 explains the methodology used to gather and analyze data, how the human-centered design process was used, the sampling method used to gather participants, and some biases in research. Following this is chapter 4 "Design and Development". This chapter presents the process of developing the AR application and what software and hardware was used in this process. Chapter 5 “Findings and discussion” presents the data that was collected by conducting user testing with dyslexic people and how the data is used to answer the research questions. The last chapter is Chapter 6 "Conclusion and future work" which presents a conclusion to the research questions as well as how the application can be iterated on in the future.

Chapter 2

State-of-the-art

This chapter presents some theories around augmented reality, the current assistive tools and technologies used by dyslexic people, the state-of-the art within augmented reality technology, and how AR technology have been used to assist people with dyslexia.

2.1 Dyslexia

Dyslexia is a learning disability that primarily affects the skills involved in accurate and fluent word reading and spelling[3]. The main characteristics of dyslexia are "difficulties in phonological awareness, verbal memory and verbal processing speed[3]. Some dyslexic people only have issues with writing, while others struggle with both writing and reading. This can make things like learning difficult, as one is often required to read or write during learning. Even though dyslexia often affects a person's ability to read, it is a specific learning disorder that differs from general reading difficulties and typically results from a deficit in the phonological component in the brain due to a disruption of neural systems[4]. However, dyslexia does not affect a person's intelligence and can sometimes lead to an individual gaining skills in fields such as: architecture, engineering and creative arts[1]. Since people with dyslexia experience dyslexia differently it can be thought of as a continuum and dyslexic people can have varying degrees of difficulties in reading and writing.

2.2 Assistive tools for people with dyslexia

There are various tools and methods available on the market for people with dyslexia that can support them in some way. Some of the tools available are specifically meant to support people with dyslexia, while other tools could be technologies that supports the general public, but that greatly benefit those with dyslexia.

2.2.1 Text-To-Speech

Text-to-speech(TTS), or speech synthesis is a piece of technology that today is very common and is used a lot by people with dyslexia. It is the process of converting written text into speech[5]. For many years, text-to-speech technology sounded very robotic and was one of the main reasons people didn't use it. Later years however the technology has become better, and with the latest computer learning, it is possible to synthesize speech that is almost indistinguishable from normal speech. Most computers and mobile phones nowadays have TTS capabilities built in and can often be activated either in the settings of the device, or by downloading an application. There are also some TSS software that have the capability of highlighting the words that are being read out, so that the reader can have an easier time reading along with the text.

2.2.2 Grammar checkers

Grammar checkers are not specifically meant to only assist people with dyslexia, but it is still very beneficial as people with dyslexia can have some trouble when writing text, especially when spelling more complex words. There are many grammar checker tools available but they for the most part serve the same purpose, which is to check the grammar of the text written and either auto-correct or in some way let the user know that there is a mistake somewhere in their text. Grammar checkers can be found on most computers and mobile phones, and they are one of the most commonly used assistive tools for dyslexic people.

2.2.3 Text scanner pens

A text scanning pen is a handheld device that can be used to scan text by moving the pen over text just like a highlighter. It can be used to transfer text from a book or a piece of paper to a digital application such as a computer and can often have the text be read out loud[6]. Some text scanner pens can even translate text into a preferred language.

2.2.4 Reading Rulers

Some people with dyslexia have an easier time reading text if they get some text focus support. One type of such a support tool is a reading ruler, which come in different forms, but serves the purpose of guiding the reader while reading. A reading ruler is often colored but at the same time transparent or have a see through hole, and the reader places the ruler on the text to isolate the text being read. This helps the reader focus on the part that they are reading and not forgetting where they are.

2.2.5 Text readability

Since one of the main characteristics of dyslexia is a reduced ability to read, improving the readability of text can greatly help people with dyslexia in reading.

Font type

One part of readability will of course come from the choice of font used in the text. Since people are different there will always be some sort of difference in opinion on font preference, but there are certain fonts that are generally better than others. One study that tested the effect of font type on screen readability for both dyslexic and non-dyslexic people, Recommends text to be a sans serif font and monospaced such as Arial and Courier[7].
Another study done on text readability for dyslexic people, shows that the word and line spacing can greatly affect reading fluency and accuracy[8]. Giving words more "air" around them makes it so that it is easier to focus on each word.

Text-color and background-color

Most people are probably used to reading black text on white background. This however might not be the best for everyone. Luz Rello and Jeffrey P. Bigham did a study on different background colors with black text for readers, both with and without dyslexia[9]. Warmer background colors such as orange and peach decrease reading time while colder colors such as blue and gray increase reading time and that this is consistent for both dyslexic and non-dyslexic people[9]. It is also possible to change the text color which can be combined with different background colors. Having more options can be beneficial, but not all colors seem to work. If the colors are too similar it can be hard to distinguish the text and reduce readability [10]. Using a black background with a light colored text seems to work well for people with dyslexia[10].

Dyslexic browser extensions

As a lot browsers and websites are designed with the intent of looking good and not being useful to people with dyslexia, there are ways people with dyslexia can make the websites more readable. Some browsers allows add-ons or extensions which makes the web browser customizable. Some people have therefore made browser extensions that can make websites be more readable to dyslexic people. One such extension is the "OpenDyslexic for Chrome"[11] which changes the font as well as formats websites to make them more readable.

2.3 Augmented reality technology

Our world we live in is considered the real world as it consists of a real environment. In contrast a computer video game could be considered a virtual world since it consists of a virtual environment. It is however possible to add virtual environments to the real world through technology. This can be called mixed reality as it consists of both real and virtual things[12]. Reality can therefore be viewed as a spectrum and depending on how much virtual environment is added to the real environment you can get a reality that is closer or further from a completely virtual reality. Milgram et al. describes this concept of reality and virtuality as a continuum which is illustrated in figure 2.1 below.

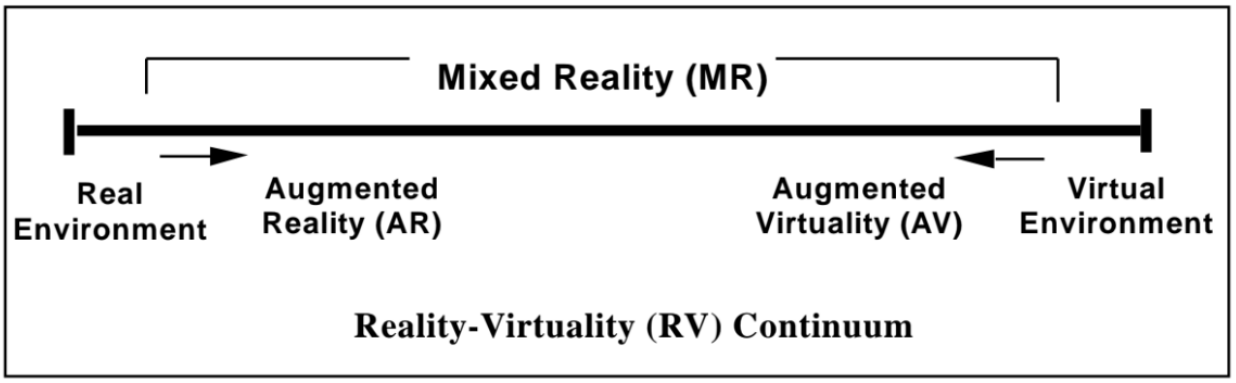

Figure 2.1: Representation of a reality-Virtuality continuum from [12]

The concepts of a real world and a virtual world is on opposite sides of the continuum and anything between these two opposites can be viewed as mixed reality, such as observing the real world with some virtual additions. The real-world environment is completely constrained by the laws of physics, while a virtual environment can exceed these bounds.
A completely virtual environment is when the user is totally immersed in a world which may or may not mimic the properties of the real world such as gravity or time[12]. The technology that exists today to simulate a virtual environment is called virtual reality, but it is not quite at the level of total immersion yet. It is however possible to feel some immersion by using mediums that simulate a virtual world.
Augmented reality or AR is a type of technology that can augment the user's physical reality by superimposing virtual computer-generated information upon the real world[13]. Augmented reality can therefore be categorized as a form of mixed reality as the user can see both the real world and virtual objects at the same time. In the book: *Understanding Augmented Reality: Concepts and Applications*[14], Augmented reality is defined as: "A medium in which digital information is overlaid on the physical world that is in both spatial and temporal registration with the physical world and that is interactive in real time." This essentially means that you can place digital items somewhere in the world and observe and interact with it through a device without the item actually existing in the real world. Augmented reality technologies can come in various forms, but to view virtual objects, a

medium is needed. Typically this medium is in the form of a display screen such as a smartphone or computer. The AR software often uses one or more cameras to track the real world in order to project the virtual objects through the device which can then be interacted with.

2.4 Augmented reality hardware and software

As mentioned earlier in this chapter, augmented reality needs some sort of medium to show the virtual information that it is projecting. There are also different types of AR software that serves different purposes and have different goals.

2.4.1 AR hardware

There are different types of hardware that can use AR, but some of the most used types today are smartphones, AR-glasses and AR-Kiosks. They all offer AR, but in slightly different ways.

Mobile phones

The most common place you can find augmented reality solutions today are on smartphones. Smartphones are widely used today and also have the advantage of being readily available when needed. Smartphones also keeps getting more processing power every year, which allows for more and more complex AR software.

AR-glasses

Augmented reality can come in different forms. One of these forms are through AR-glasses, also known as smart-glasses. AR-glasses are a pair of glasses that have a built in camera and a screen in one or both of the glasses so that you can watch videos, play games or use AR features while still seeing the real world. Some AR-glasses also have voice commands or hand gesture features to navigate its options.

Figure 2.2: An example of a pair of AR-glasses by Vuzix, from[15].

Microsoft HoloLens

The Microsoft HoloLens is a mixed-reality headset that allows for augmentation of the real world through a headset[16]. A mixed-reality headset is a combination of AR-glasses and a

virtual-reality headset. The HoloLens features hand tracking, voice activation, eye tracking, and spatial mapping which can work together to make a seamless experience[16].

AR-Kiosk

AR-Kiosk is a term used for different types of stationary interactive AR-Installations that have more computing power and more sensors than a mobile phone. The kiosks often offer interactive immersive experiences with low entrance barriers to users. A british company with the name "Magic Mirror" offer a variety of different AR-Kiosk options such as the MirrorBooth[17]. The MirrorBooth is a photo booth that lets you use AR to enhance and augment your appearance and see the results live before the picture is taken.

Smart Contact Lenses

Smart contact lenses is a type of augmented reality hardware that is still in its early stages of development, but aim to make it possible to have AR features inside a small contact lens.The lens is placed directly on to the eye, which requires the screens to be very small and therefore also very small pixels. A company by the name of Mojo Vision is trying to develop an augmented reality contact lens[18]. The lens is still far from being done and is not on the market yet and MojoVision does not offer much info on their website, but one source claims that the Mojo Vision Contact Lens features a 14,000 pixel-per-inch display[19].

2.4.2 AR software

There are many uses for AR and therefore many different AR software solutions. Some types of AR software are meant purely as entertainment while others are meant to be useful to people in some way. Below are some examples of AR software that can can be found on the market.

Pokémon GO

One of the most popular AR apps on the market is Pokémon GO[20]. Pokémon GO is an application that is primarily used for entertainment and is a mobile game that lets the user find and catch digital creatures while traversing the real world. The game uses the mobile phones GPS to know where you are and will vibrate once you are close to a Pokémon. You then open the app and try to find the creature by aiming the phone camera around you. The Pokemon will appear as an overlay onto the real world on your phone and you can interact with it through your phone[20].

Snapchat

Another very popular application with AR features is Snapchat, which is also primarily used as entertainment. Snapchat is a messaging and social media app that have AR features called filters[21]. These filters lets users augment and change the way they look, or add clothing or other items to their videos and pictures and is done in real-time while they film themselves.

AR subtitles

XRAI Glass have developed an app that uses AR glasses to lets the user get real-time subtitles from conversations and is meant to assist people who are deaf or suffer from some form of hearing loss. The app supports more than 140 languages and also features translations and the possibility to record conversations for later use[22].

2.5 Supporting dyslexic people through the use of AR technology

There is not a lot of dyslexic support tools that utilize augmented reality on the public market yet. There has however been a few attempts by academics to test the use AR to assist people with dyslexia.

2.5.1 Augmented Reality Based learning System for Children

In a study by Bhatti et al[23]. augmented reality flashcards were used to test if it could help children with dyslexia learn about objects by interacting with an AR version of the object. The users would scan a 2D picture and a 3D model would appear in the app, which lets the user interact and learn about the object. This is a very basic AR application in itself, but the study managed to reveal that the participants was more engaged in the interactive learning.

2.5.2 Improving Accessibility for Dyslexic Impairments using Augmented Reality

One AR application developed and tested in 2019 by Gupta et al[24]. Had the intent of making text more readable and in turn increasing the reading speed of people with dyslexia. The application features the possibility to track text and lets the user change the size of the font and height of lines. It also allows for text-to-speech as well as changing the color from black text on white background to black text on yellow background. The app was tested on children aged 12-14 and found that reading time while using the app was decreased by an average of 21% and that 86% of the participants preferred black text on yellow background over the standard black on white[24].

2.5.3 Using AR to improve spelling for people with dyslexia

Bailey et al[25]. tested if it was possible to assist people with dyslexia in spelling words using AR. They created an AR application that utilized the Microsoft holoLens[16] to assist people with dyslexia as an attempt to improve writing. The users were able to hand-write words and the application would recognize the words and provide spell check. The results from the tests showed that the users were engaged and had fun while writing which can help promote learning.

2.5.4 Augmented Reality as an educational support tool for dyslexic students in higher education

A 2022 study investigated the potential benefits of using AR as a support tool for dyslexic students[26]. The project tried and tested three potential uses of AR to support dyslexic students to find out what works and what does not work.

The first test was font manipulation. The test allowed users to scan a QR code which presented a text where they could customize the font style, font size, and font color. Most of the participants enjoyed the idea and felt like changing the size and color of the text increased readability.

The second test consisted of allowing the user to scan a QR code to reveal text and then use a text-to-speech option. The text-to-speech feature also allowed for customizing the reading speed and and had the possibility to highlight parts of the text that was being read. The participants felt like text-to-speech was very useful when reading.

The third and last test consisted of using AR to change the background color of the text. Both static background colors and dynamic backgrounds were tested and the text color consisted of either contrasting colors or just black text. The participants did not enjoy using the dynamic background colors as they thought it looked like the text was moving too much, but they enjoyed using different color backgrounds when the background colors were static.

Chapter 3

Methodology

This chapter presents the research methods and data gathering methods used to procure data, as well as describing how the human-centered design process was used to develop an app which was used in testing. Furthermore this chapter contains the process of how this master project was conducted through preliminary interviews, followed by the development of the app. Then the user testing which consisted of pre-test interviews, testing and observation, post-test questionnaires, and interviews. This chapter also explains how the results were analysed.

3.1 Research Methods

To be able to answer a research question it is crucial to gather data. The more data that is gathered, the more validated the research becomes. To gather the right data needed for the research, the correct research methods should be used and this section details the data gathering method used as well as the method used to analyze said data.

3.1.1 Qualitative dominant mixed-method research

When conducting research the researcher often wants to collect some sort of data to be able to respond to a research question. Depending on what kind of data needed the researcher can in general take advantage of three different types of approaches, qualitative, quantitative or mixed methods. Qualitative methods are often used if textural data is needed, while quantitative methods are used when numerical data is needed, and a mixed method approach is used when both numerical and textural data is needed for the research question[27]. If the qualitative and quantitative methods are of equal use and importance it can be called a "pure" mixed method[28]. However, it sometimes makes sense for a researcher to focus on one research method but also use some of the ideas from another method to support their work.

This research primarily uses a qualitative method but also takes use of some quantitative methods to support the research. This makes the research mixed method, but it is at the same time a qualitative dominant mixed method. As stated by Johnson et al. in [[28] p. 124] "Qualitative dominant mixed methods research is the type of mixed research in which one relies on a qualitative, constructivist-poststructuralist-critical view of the research process, while concurrently recognizing that the addition of quantitative data and approaches are likely to benefit most research projects". As seen in figure 3.1, a mixed method research can be thought of as a spectrum.

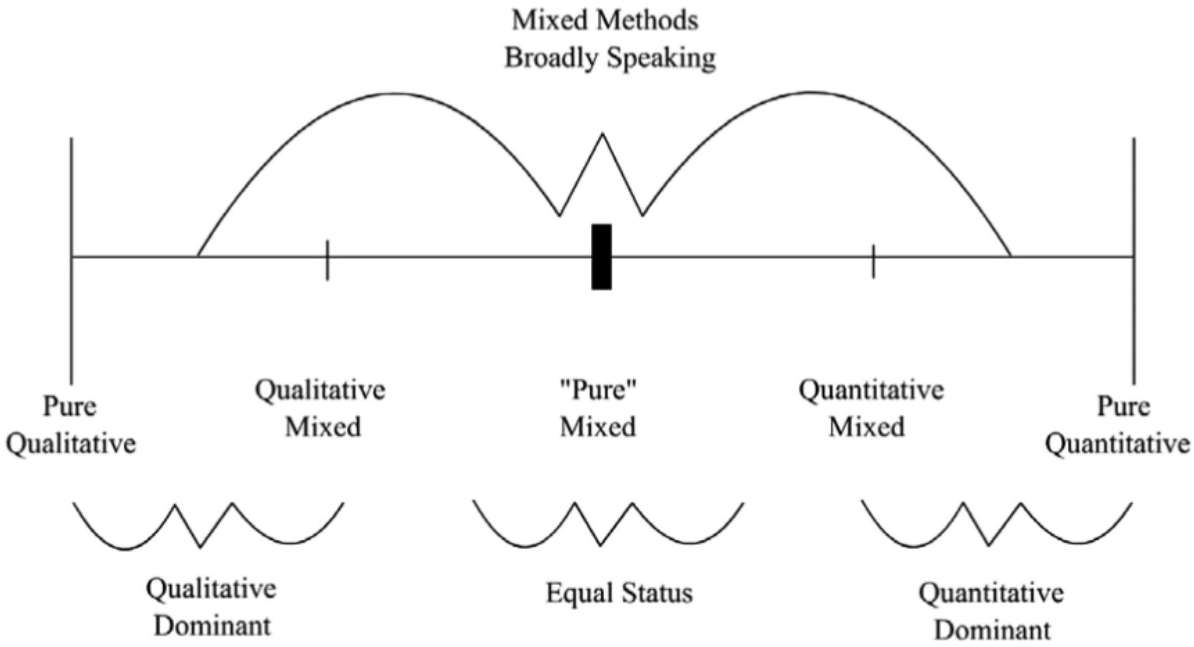

Figure 3.1: Graphic of the Three Major Research Paradigms, from[28].

3.1.2 Data analysis

After a researcher has finished data collection, the data then needs to be analyzed. There are different analysis methods for different types of studies and the analysis method should depend on the aim of the study, the type of data and the observation method used[29].

Thematic analysis A thematic analysis is a data analysis method for identifying and categorizing themes within collected data. It is mostly used with qualitative data and has several advantages like its flexibility, low difficulty to use, and that it can highlight similarities and differences in the data set. A thematic analysis searches for certain themes or patterns across the entire data set instead of focusing on individual interviews from one person[30]. It is therefore very useful when conducting several qualitative interviews as the researcher can categorize the data and see if there are recurring themes in the data. What can be considered a theme will vary from research to research and can be used to express something important about the data in relation to the research question[30]. The researcher therefore has to use their own judgment in a case by case scenario to determine how to categorize the data.

To analyze the data collected in this research a thematic analysis method was utilized due to the aim, data type and observation being mostly of qualitative nature. Qualitative research often involve interviews with participants and to the researcher there might be a clear relationship between the questions asked, but for people not involved in the research the questions can seem random and it is therefore crucial to be clear about the connection of the questions used in the interviews[30]. By following a framework, the analysis can help the reader see the relationship between questions with the use of themes. The framework of a thematic analysis consists of a process that is divided into six phases[30]. Each phase can be moved to and from when needed, making the process very flexible. However, each step is important and should not be skipped. The six phases are as follows:

1. Familiarizing yourself with the data.

2. Generating initial codes.

3. Searching for themes

4. Reviewing themes

5. Defining and naming themes

6. Producing the report

After the user testing was completed and all the interviews were done, a full review of the data was done to analyze the data. Notes from the user testing was used to get familiarized with the data. The data was then coded and put into tables. Themes were then looked for and added to the tables. The notes, codes and themes in the tables were then summarized and translated to English. The thematic analysis is discussed in chapter 5 - Findings and discussion and the tables containing the thematic analysis can be found in Appendix B.

3.2 Human-Centered design

When designing any interactive system, an appropriate approach should be used. The human-centered design process (HCD) is an approach on how to design an interactive system with humans as the focus by making sure the user is involved throughout the design process[31]. It focuses on the users needs and requirements to enhance effectiveness and efficiency, as well as improve satisfaction and accessibility[31]. The HCD consists of principles for design and activities that should take place during the design. These activities are important as they make sure the requirements are met and not forgotten during development. According to the human-centered design approach[31], there are four activities that should take place during the design: Understanding and specifying the context of use, specifying the user requirements, producing design solutions, and evaluating the design. These four activities ensures that the designer never forgets about the user as the user is in focus the entire time. The last activity in the HCD process is to evaluate the design against the requirements. When evaluating against the requirements, the designer checks if the design solution meets the requirements, if not, then the designer can go back to a previous step and iterate until the design meets the requirements. This can be seen in figure 3.2 which depicts the HCD process.

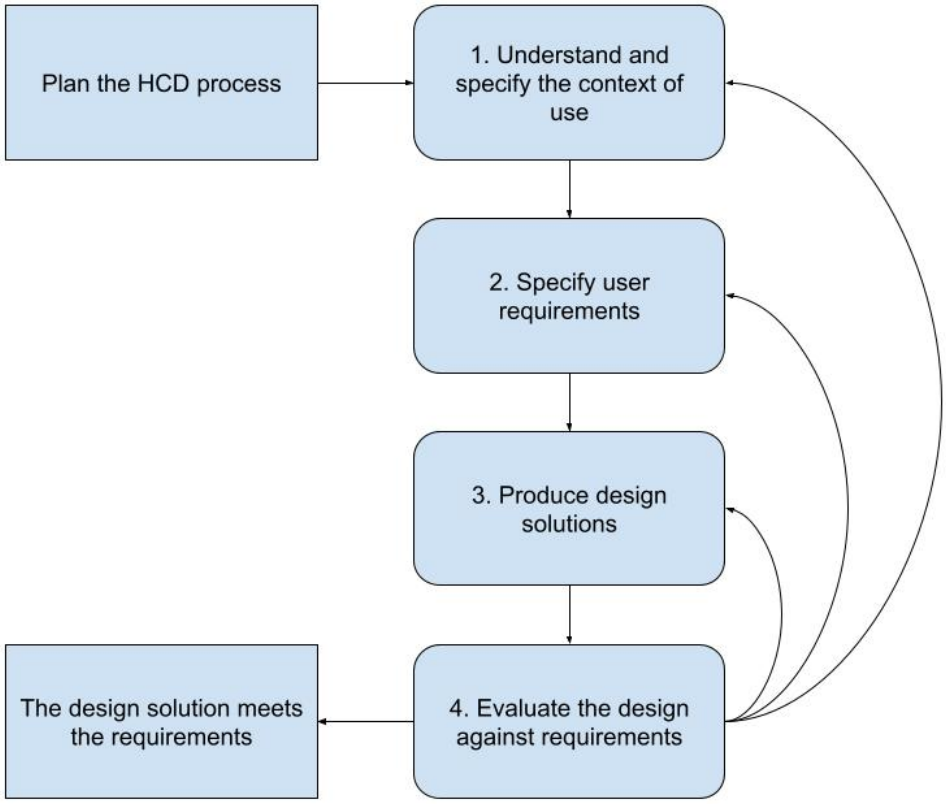

Figure 3.2: The Human-Centered Design activities, adapted from [31]

3.2.1 Understanding and specifying the context of use

As part of the human centered design process, understanding the context of use should be done before producing solutions. To help understand the context of use, some activities took place at this stage. The first activity was to do some research into related studies on the subject of augmented reality and dyslexia, to see what kinds of ideas and designs had been done before.
Following this, preliminary interviews were conducted with five people who all had diagnosed dyslexia as it is important to involve the people who would use the system. Different kinds of interviews can be used for different purposes, and can generally be divided into structured, unstructured, and semi-structured interviews. The interviews used for this research followed a semi-structured interview guide with several open-ended questions regarding their experiences with dyslexia. A semi-structured interview guide often includes main open-ended questions with follow-up probe questions for the interviewer to refer to throughout the interview[32]. This means that the guide is meant to open dialogue between the interviewer and the interviewee. Semi-structured in-depth interviews are the most widely used interviewing format for qualitative research and can occur either with an individual or in groups[33]. Most commonly they are only conducted once for an individual or group and take between 30 minutes to several hours to complete[33]. In this research, five participants partook in preliminary interviews and were a mix of students and professionals. The interviews were all in Norwegian with native Norwegian speakers and each interview was conducted with one participant at a time and lasted for about 50 to 60 minutes. The interview guide was in Norwegian, but the English translated interview guide consisted of the following topics:

1. What are the symptoms of your dyslexia and when did you discover that you had dyslexia? How does it affect you when it comes to learning in school or in a job?

2. What kinds of methods or technology do you currently use to help you cope with dyslexia?

3. What other kinds of tools have you used in the past and how do they work?

4. What are the main issues with the methods or tools you have used in the past and why did you stop using them? What works well for you and what does not work?

5. If you had to learn something from a book or text, would you rather have an assistive tool that helps you read the text, or would you prefer not reading altogether?

6. If you had the possibility of using your mobile phone to assist you in reading, what kind of functionality would you like it to have? what are the most important things or tasks you want to do?

7. Do you have any recommendations when it comes to assistive technology for people with dyslexia?

The words augmented reality was never mentioned to the participants as this could influence how they answered. During the interviews the participants was encouraged to answer however they felt was right and not think of what kind of answers the interviewer was looking for. This was done to help avoid bias and to get a clear understanding on what people with dyslexia want and need from an interactive system.

3.2.2 Specifying the user requirements

After the context of use was specified the next step was to specify the user requirements. Volere atomic requirement shells, also known as Volere snow cards were used to help define what the requirements for the system would be[34]. The Volere template separates requirements into functional and non-functional requirements.The functional requirements describe how the product should work and what functions the user can interact with. The non-functional requirements describe things such as the product's looks and feel, the product's usability, and its performance[34]. Two of the Volere snow cards that was made to specify the user requirements used can be seen in figure 3.3 and 3.4.

Requirement #: 3 **Requirement Type:** 9 **Event:**

Description: Being able to change the spacing of words on the digital text.

Rationale: In order for the user to change the text to their own preference.

Originator: Software developer

Fit Criterion: The user will get plus and minus buttons that lets them increase or decrease the word spacing.

Customer Satisfaction: 3 **Customer Dissatisfaction:** 2

Priority: 2 **Conflicts:**

Supporting Materials:

History: Created 25.03.2023

Figure 3.3: Volere snow card containing a functional requirement

Requirement #: 7 **Requirement Type:** 11 **Event:**

Description: The digital text in the app should be in the Arial font type.

Rationale: The arial font is a font type that is easier to read for people with dyslexia.

Originator: Software developer

Fit Criterion: User can see that the font has been changed compared to the physical/printed text.

Customer Satisfaction: 3 **Customer Dissatisfaction:** 3

Priority: 3 **Conflicts:**

Supporting Materials:

History: Created 25.03.2023

Figure 3.4: Volere snow card containing a functional requirement

There was a total of eight Volere snow cards made, which is summarized as a table in figure 3.5. The rest of the Volere snow cards can be seen in Appendix A.

Requirement number	Requirement type	Description
1	9	App must be able to track a marker/QR code
2	9	App will add an overlay containing a digital text canvas with text, on top of the physical/printed text
3	9	Be able to change the spacing of words on the digital text
4	9	Be able to change the line spacing of the digital text
5	9	Be able to change the size of the font on the digital text.
6	9	Be able to change the color of the font and background of the digital text
7	11	The digital text should be in the Arial font type
8	9	The user should have the option to enable text-to-speech

Figure 3.5: A table containing the list of requirements from the Volere snow cards

3.2.3 Produce design solutions

After specifying the user requirements the next step is to produce a design solution to meet the requirements. While designing the solution it is important to have a firm grasp on how the system will work before doing any developing such as programming. Programming can take a long time and if there is no plan on how the system is supposed to work, then chances are that the programmer needs to go back and change the code later. To avoid having to redo a lot of programming and wasting unnecessary time, it can help to make a model of the system before starting with the development.

To visualize how the app would be structured, a conceptual model was created. Conceptual models are abstract representations of the system and how the tasks should be carried out[35].

Before developing the AR app, a flowchart was created and used as the conceptual model which can be seen in figure 3.6 below. The blue squares represents actions that the user can take, while the red squares represents what the system does in response

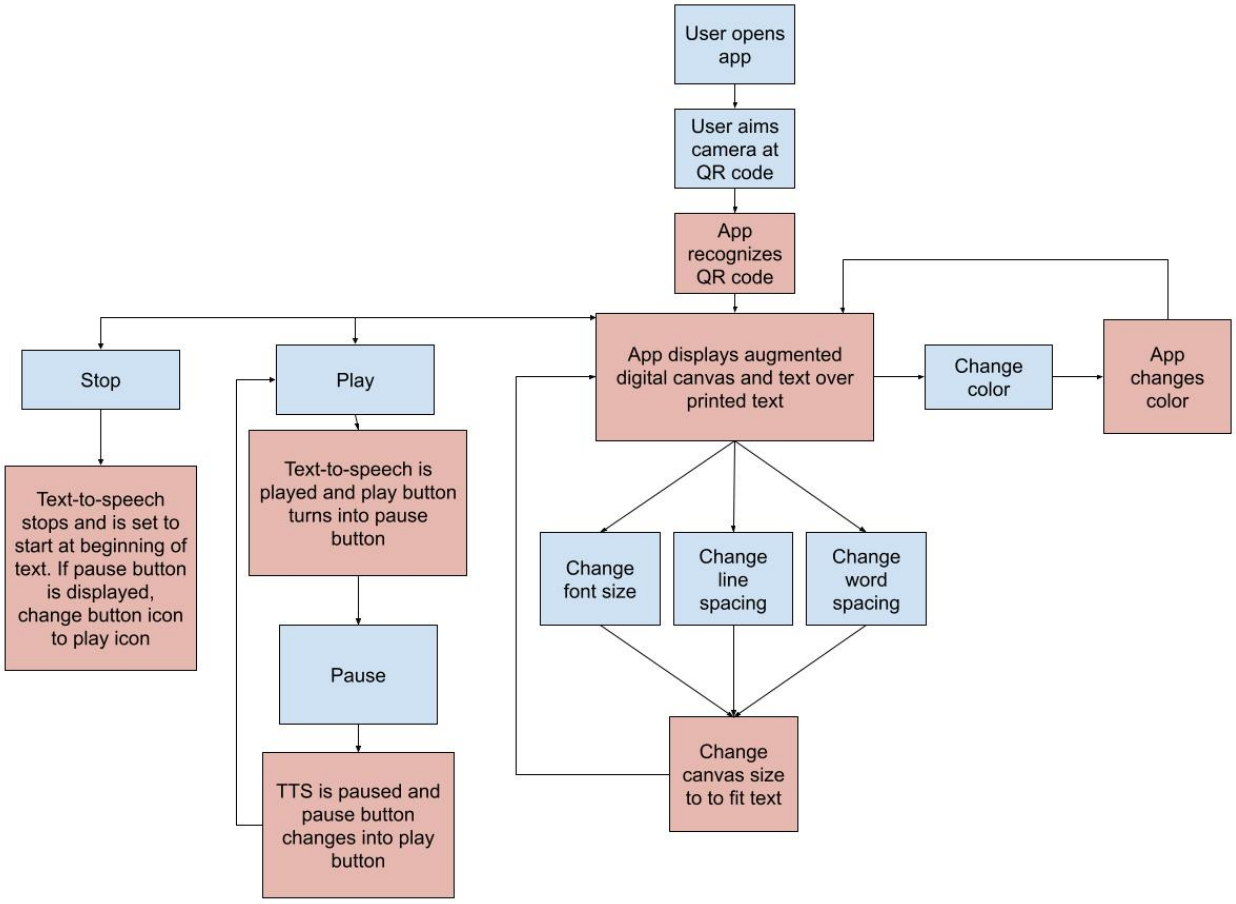

Figure 3.6: Conceptual Model

After creating the conceptual model, the development of the app could start. Since the visuals of the app are very simple and just containing some buttons as actions, there was no need to make a low-fidelity prototype as the visuals and placements of the buttons can always be changed later. Work got started on a high-fidelity prototype right away instead which includes all the user requirements from the Volere snow cards.

3.2.4 Evaluating the design

Following the human-centered design, after a design solution is developed it must be tested to see if it satisfies the user requirements. This is the final activity in the HCD process and is where the researcher gathers data to see if the interactive system meets the requirements or not. If it does not meet the requirements, the designer should go back to a previous stage and iterate on the design. There are many ways a designer can evaluate a design, but when using the human-centered design, involving the actual users of the system is key as they are the ones who can provide the most accurate feedback. To gather the data needed to evaluate the design, usability tests were conducted. The full usability testing consisted of a pre-test interview, testing and observation, a post test questionnaire, and lastly a post-test interview.
The usability testing was conducted with five different participants whom all had dyslexia. The participants that partook in the usability testing were not the same as the ones who participated in the preliminary interviews conducted prior to the development of the app.

This means that the participants that partook in the user testing had no prior knowledge about the app and its purpose. The tests were conducted over a one month period in November 2023 and were all done with one participant at a time totaling five user tests.

3.2.5 User testing

In advance of the user testing, a usability test plan dashboard was made in order to more easily manage and carry out the tests. The usability test plan dashboard is a single page document that is used to organize and make it clear what needs to be done. The plan can be seen in figure 3.7.

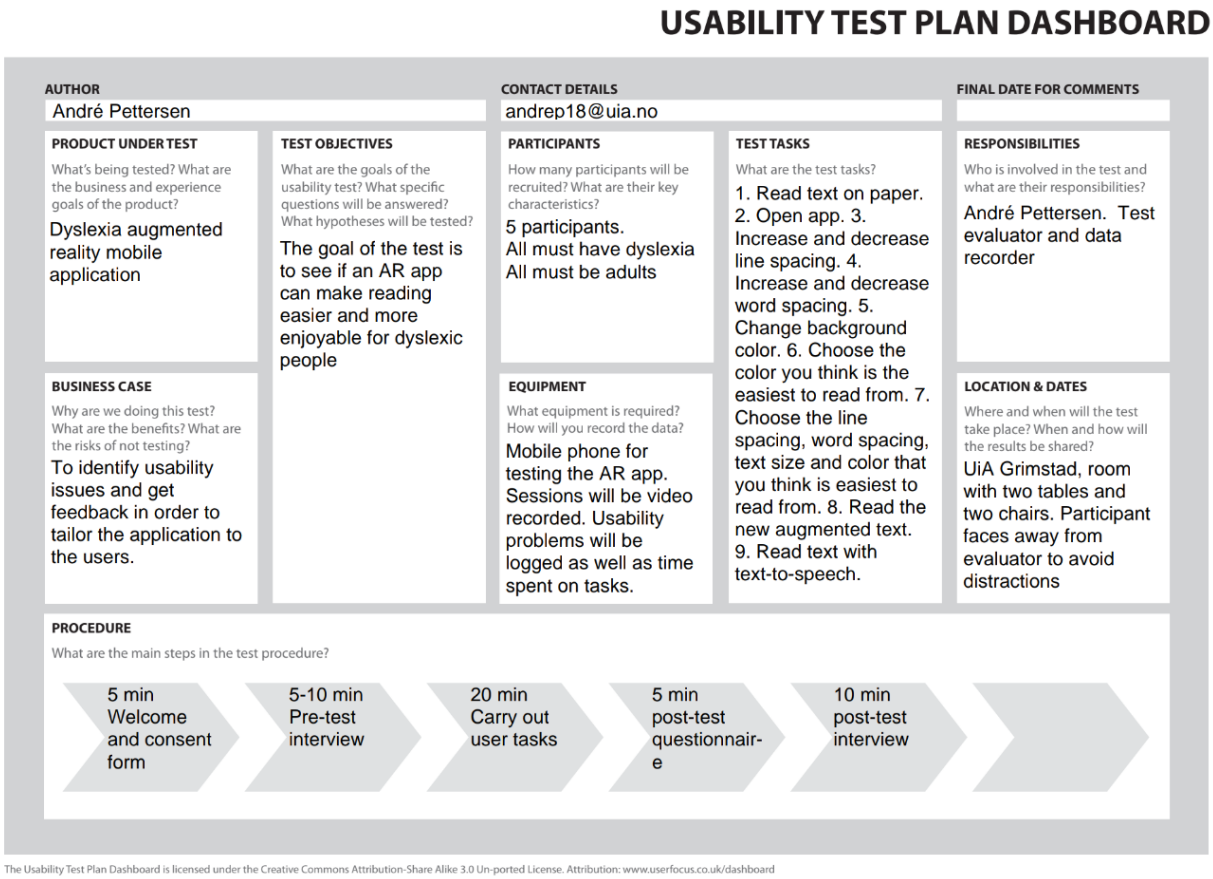

Figure 3.7: Usability test plan dashboard, from[36].

The full tests lasted roughly 45 minutes and include several steps. The first step lasted five minutes to welcome the participant and have them sign a consent form. The second step lasted five to ten minutes and consisted of a pre-test interview. The third step lasted 20 minutes and were dedicated to usability testing and observation in which the participant carried out a series of tasks while being observed. The tasks can be seen in the usability test plan dashboard in figure 3.7. The fourth step consisted of the participants filling out a post-test questionnaire which lasted for five minutes. The observer left the room while the participants filled out the questionnaire to reduce the risk of influencing the answers. Lastly a ten minute post-test interview was conducted with the participant.

Pre-test interviews

Before the participants tried the application a pre-test interview was conducted. The pre-test interview consists of some close-ended questions to gather data on their demographics, some open-ended questions regarding their experience with dyslexia, and also some questions utilizing a five-point Likert scale. A Likert scale is a scale that lets the participants rate the

degree to which they agree or disagree with a statement[37]. The Likert scale options can be either in the form of numbers such as a scale of one to five, or it can be in the form of words such as completely agree to completely disagree[37]. Figure 3.8 demonstrates three different ways a Likert scale can be used.

1	2	3	4	5
Never	Rarely	Sometimes	Often	Always
Completely disagree	Disagree	Neutral	Agree	Completely agree

Figure 3.8: Typical Likert scales, from[37].

Usability testing and observation

Usability testing refers to evaluating a product by testing it with representative users performing representative tasks[38]. The testing and observation mainly consists of the participant testing the application to find usability problems in the application, but in this test the usability testing was also used to see what kind of preferences the participants had to text augmentation, such as what color they prefer or what text size they prefer. To test the application the participants had to complete a series of tasks. Most of the tasks are meant to test the usability of the application, but a few of the tasks are meant to gauge the effectiveness of the app by having the participants read a text. The reading was timed in order to gauge how effective the app is at reducing reading time. The participants actions were also filmed during the testing to better observe how they completed tasks and how many buttons they pressed to complete the tasks. The recording of the session is very useful as it makes it possible to review the session to find details that would otherwise be missed.

The usability testing environment consisted of a table and a chair for both the participant and the interviewer. The participant was faced away from the observer/interviewer during the usability test to avoid being influenced by the interviewer. The environment was in a closed room to avoid external interference which could affect the usability testing and in turn the data and results. The testing environment can be seen in figure 3.9.

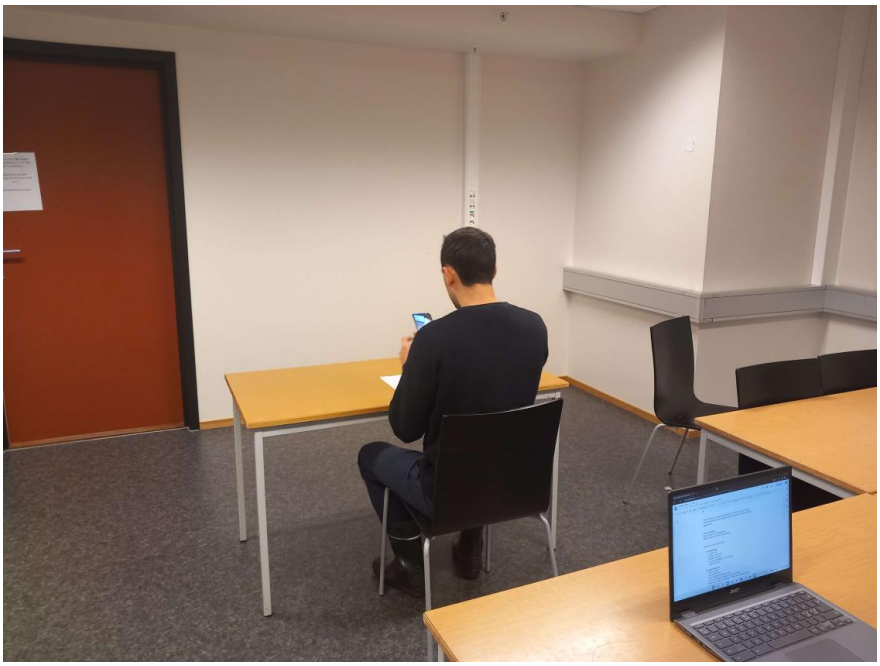

Figure 3.9: Usability testing environment with actor

Questionnaire

After the participants had finished testing the application they were asked to fill out a questionnaire on how they felt about the app. While the participant filled out the questionnaire, the interviewer left the room so that the participants answers would be less likely to be influenced. Questionnaires yield responses that are usually easy to tabulate or score, and the resulting data are easy to analyze, especially if the questionnaires mainly contain items with choices to be checked[39]. A questionnaire is used as the participants are more likely to answer truthfully without prompting from an interviewer[40]. The questionnaire consisted of two parts, one page containing questions the from the system usability scale[41] which utilize the Likert scale where the options range from strongly disagree to strongly agree. The second part which was on the second page consisted of ten questions taken from the user experience questionnaire[42] where each question consists of two antonyms and the participants have to choose a number from one to seven closest to how they feel about the app.

Post-test interview

After the participant finished testing the application and the questionnaire, a semi-structured qualitative interview was conducted. The objective of the post-test interview was to gather qualitative data on each participants personal opinions regarding the application. The interview consisted of a set of open-ended questions such as what the participant liked and didn't like about the app as well as what could be done to improve on the design. The participants were also asked what features they thought was the least and most useful and what changes they would like to see in the future. The interview guide can be seen in the appendix.

3.3 Research population and sample participators

3.3.1 Sampling Method

Individuals who have the relevant characteristics to a study is called the research population[43]. When conducting research it is nearly impossible to collect data from the whole population that exhibits the characteristic. Instead of collecting data on the whole population, the researcher can identify a representative subgroup, which is called a sample. The representative sample can be found in many different ways and the process of selecting this sample is called sampling method[43]. There are two different categories of sampling methods, one being a probability sampling method and the other being a non-probability sampling method. A probability sampling method uses a random selection so that every part of the population has an equal chance of being selected[43]. A non-probability sampling method on the other hand is not random and the sample is often chosen based on the researcher's own judgment[43]. A qualitative study typically uses non-probability sampling methods, as they often want the opinions of a sample that exhibits a particular characteristic and if the method used were random, then the probability of the participants having said characteristic could be very low.
As this study is a qualitative study which requires the participants to have dyslexia, a non-probability sampling method was used. There are different types of non-probability sampling methods and choosing the correct method requires the researcher to consider multiple factors such as knowledge about the population of interest and the size of the population of interest[43]. It can be hard to identify people with dyslexia as it is not a trait that can be seen by looking at a person and recruitment can therefore be difficult. To combat this a linear-snowball sampling method was used to find participants. A snowball sampling method is a strategy in which existing participants recruit future participants from others they know[43]. This sampling method can be linear or exponential depending on how many people each participant recruits and can be very useful when it is hard to identify and recruit people that

exhibit a certain trait such as dyslexia. The snowball sampling method was used to gather participants with dyslexia in both the preliminary interviews that was done prior to the development of the app as well as the user testing that was done after the app had been developed. These two groups consisted of five participants each, totaling ten participants. Together with most non-probability sampling methods, the snowball sampling method can be prone to bias due to not being a random selection, which the researcher has to keep in mind in their research.

Target group and participants

The target audience to use the AR app are people with dyslexia. However to gather data on the subject, it was important that the participants fit a set of criteria. The criteria is there to make sure the participants are able to provide the most accurate feedback ,and they also represent the ideal study participant. The set of criteria are as follows:

- Must have dyslexia
- Must be an adult aged 18+
- Must have basic knowledge on how to use a smartphone
- Must be able to meet physically at the University campus in Grimstad
- Must read and speak Norwegian

The people that ended up participating were all Norwegian speaking adults with dyslexia aged 20-50. The participants that partook in the preliminary interviews that was done prior to the development of the app consisted of three men and two women. The participants that partook in the user testing consisted of four men and one woman. The participants had different proficiency with technology, but they all owned their own smartphones and had at least basic knowledge of how to use the device.

Before partaking in any interview or user testing the participants had to sign a consent form. The consent form includes important information on why they are asked to participate, how their personal information is being kept safe and that they will stay completely anonymous in the thesis. When signing the consent form, the participant also gives consent to being filmed, but is informed that all recordings will be deleted once this thesis is finished. The consent form is attached in appendix C.

3.3.2 Biases in research

When conducting research and collecting data from human beings there is a risk that the data collected can be affected by bias. It is critical for the researcher to have this in mind when collecting data as biases can alter responses and behaviour. Being aware of possible biases in advance can help reduce the possibility of it happening or negate the effect of the bias itself.

Sometimes research participants have a tendency to say what they think the researcher wants to hear as opposed to what they really mean, because in the participants mind this would be more socially acceptable and therefore make them look better to others. This is called the social desirability bias[44] and can affect research by a large margin. There are ways to cope with a social desirability bias, such as asking questions that are more neutral with regards to acceptability so that it is harder for the participant to gauge what they think is the most desirable answer[44].

Another bias a researcher needs to be aware of is the Hawthorne effect, which is a form of behaviour change in participants when they know that they are in an experiment and that they are being observed, compared to what they normally would have done if they didn't know they were observed[45]. This can happen consciously or subconsciously by the participant and the researcher has to be aware of this to avoid getting biased data.

Chapter 4

Design and Development

This chapter covers how the augmented reality application was designed and developed, which includes what software was used to develop the design solution as well as what hardware was used.

As part of the human-centered design process the context of use was found from interviews with the target group and the user requirements was specified using Volere snow-cards. Before starting the actual development of the app a conceptual model was made to make sure there was a clear view on how the application would work. From there, gathering information on what tools and software needed to realize the design solution was done and the development could start.

4.1 Software used

To develop the design solution, different types of software was used. Unity[46], Microsoft Visual studio[47] and Vuforia[48] was used together to create the augmented reality application for an Android device.

4.1.1 Unity

Unity is a Real-Time Development Platform, which can be used to create 3D, 2D, VR and AR projects such as games, videos and applications for free[46]. The Unity engine can also be used to create games and applications for many different platforms such as Windows, iPhone, android and more. To develop in Unity, the developer will typically use the programming language called C#. Unity has very in-depth documentation and guides on the internet which helps a lot when developing. One one the documentations available online is the Unity User manual[49] which explains many features in detail, like how to work in Unity, how to use scripting, how to incorporate packages, and how to develop for different platforms. Unity was used as the platform to develop the Augmented reality application and the application itself was made for an Android device.

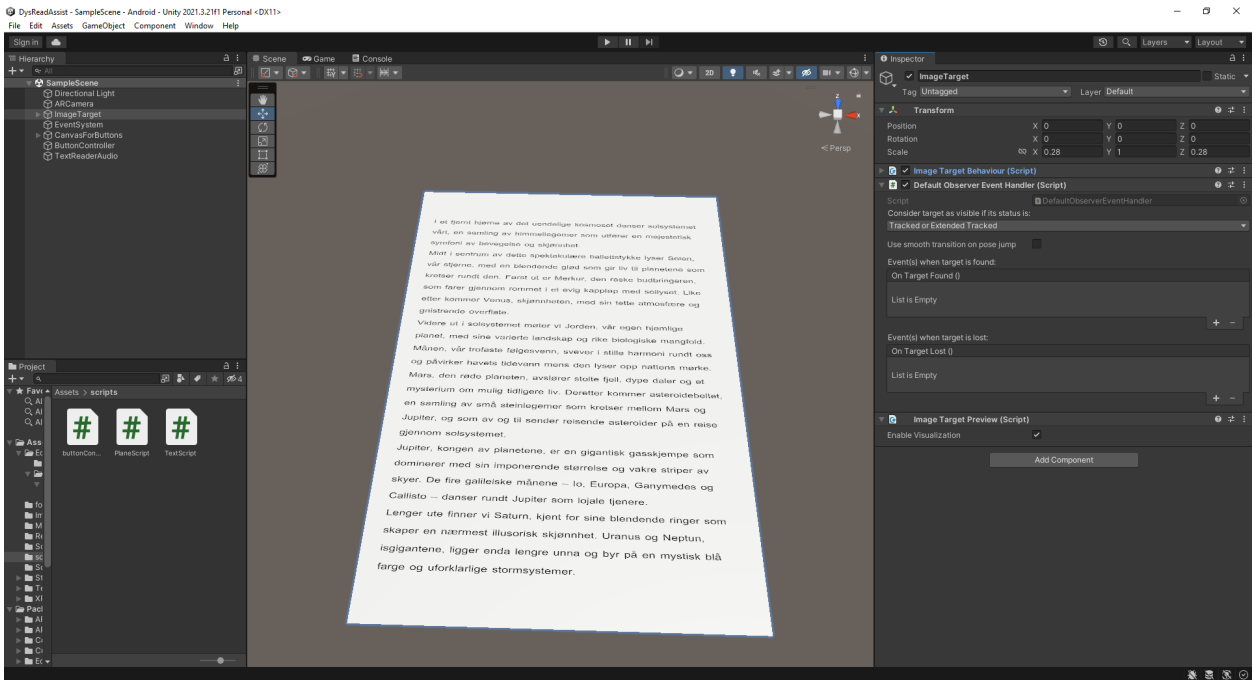

Figure 4.1: The application in the Unity environment

4.1.2 Vuforia

Vuforia is an augmented reality software development kit, which is a package that can be downloaded within the Unity engine. The Vuforia engine is used to assist in developing augmented reality applications for mobile phones. It allows for advanced computer vision functionality to an application, that allows it to recognize images and objects with options to configure the app to interact with the real world[48]. The Vuforia development kit lets the developer add pictures as tracking markers and helps trivialize the augmented reality tracking system. By uploading a picture such as a QR code to Unity, Vuforia is able to use the QR marker as a tracker which allows for precise placement of the digital object. Vuforia was used in the development of the application as it trivialized a lot of the tracking needed in the AR functionality of the app.

4.1.3 Microsoft visual studio

When developing an application in a game engine it is often required to write code. To have an easier time programming, developers often use a type of code editor which is often called an "IDE". "An IDE, or Integrated Development Environment, helps programmers join the different elements of coding together[50]." Having a code editor makes it easier to spot mistakes and the program can even give suggestions on how to write the code and makes certain keywords and phrases color-coded. There are many code editors available online and what editor is chosen is often based on preference. For this project Microsoft visual studio was used due to it both being free, and also due personal preference, and it helped speed up the programming process.

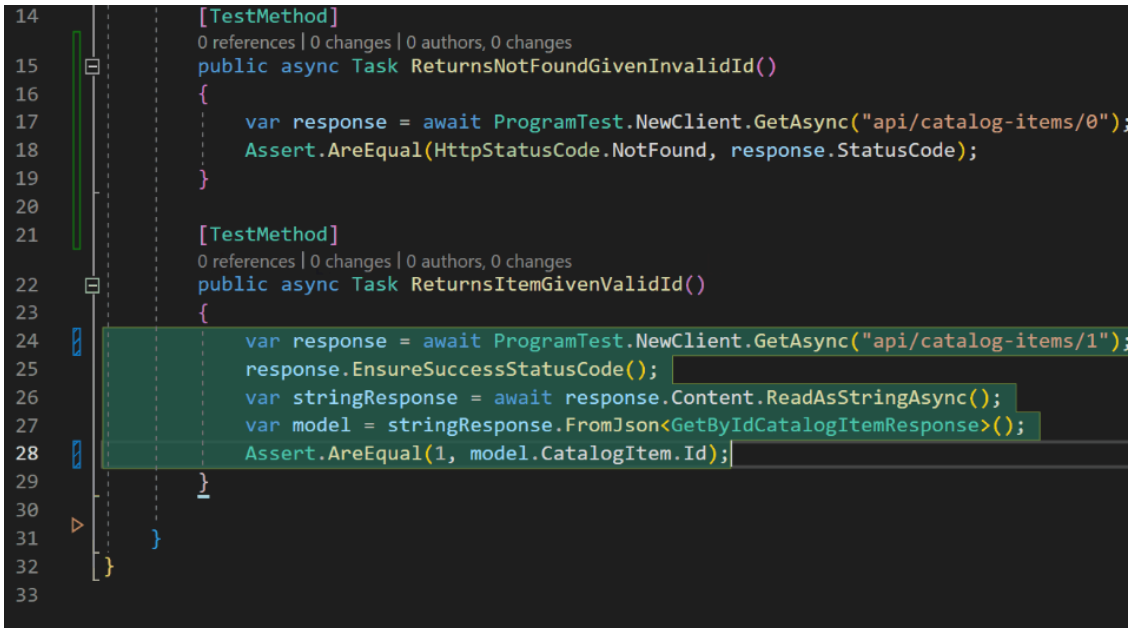

Figure 4.2: An example of the Microsoft visual studio code-editor, from [47].

4.2 Hardware used

There is not much hardware that was needed for the application, but the few pieces of hardware are essential to make the system usable such as a mobile phone.

4.2.1 Mobile phone

To be able to run and use the augmented reality application, a device is needed. As the intentions of this application was to run on a mobile phone, a mobile phone had to be used in the development as the platform to be run on. The phone used was a Samsung Galaxy S10e which is a smartphone that runs the Android operative system. This specific device is owned by the researcher and is used because it fits the criteria of being a smartphone that can run AR technology.

4.2.2 AR tracker

For the AR application to work, it needs a tracker or a marker. This marker is a physical piece of paper containing the example text as well as a QR code. The mobile phone detects the physical marker which then triggers the activation of a text plane with the sample text made available in the application. The usage of the marker allows for the text plane to be correctly oriented when a user is interacting with the application. Once the application is displaying the text, the user may allow to change the different options to their liking. The printed text and QR code can be seen in figure 4.3.

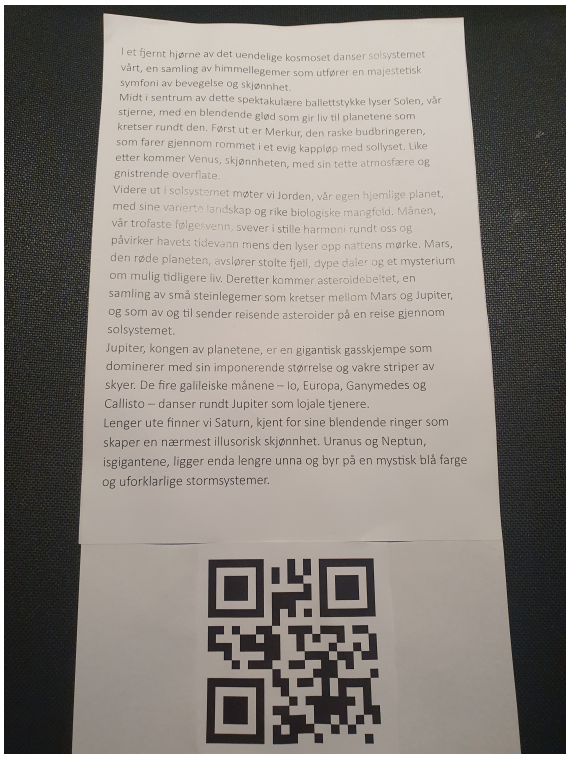

Figure 4.3: The printed text with the QR tracker

4.3 The augmented reality application

Since the main objective of this research is to test out the possibilities on the usage of augmented reality to support people with dyslexia, it was important to figure out what dyslexic people want from an assistive tool. Prior to developing the app, five interviews were conducted with people that have dyslexia in order to find out what their experiences with assistive tools was and what they would want from such tools. The participants had varying degrees of experience with dyslexic assistance tools, but everyone had at least tried a few. After looking at all the information gathered from the interviews the scope of the project was narrowed down. The scope narrowed down to a tool that would focus on making reading easier and more enjoyable for people with dyslexia. During the interviews it became apparent that there are many tools already available to make reading easier online, but most of them share the same problem, which is that they can only assist in digital text. An idea to use augmented reality to assist in reading printed/physical text came to be and the scope of the project was slightly narrowed down again. After going back to the interview data with this idea in mind, an augmented reality reading assistance tool was envisioned. The app would be a tool that can "film" real life printed text with a mobile phone, to then be able to "augment" the text in some way. The features of the app are listed as functional requirements in the Volere snow cards which can be found in appendix A. But to summarize, the user should be able to change the size of the letters, increase line spacing, increase word spacing, change the color of the font and background and also enable text-to-speech. All these options are there to let the user choose for themselves how they want to augment the text, as people all have different preferences.

4.3.1 How the application was developed

As mentioned earlier, the application was made using the Unity platform and programmed in the programming language C#. After setting up Vuforia in Unity, an image/tracker was added so that the application can tell where to place the digital text, this was done

by adding a simple QR code that was downloaded from a QR code generator website[51]. Vuforia handles the tracking by itself, so no coding was needed for the image tracking to work, the only thing that was needed was the QR code to be added. A simple white blank text plane is added as an overlay on top of the real life printed text when looking through the phone screen. This is so that the new text created will be readable, as putting new digital text over the old printed text will make the words be on top of each other and very hard to read. After the digital blank plane is overlaid correctly over the printed text, the new text is placed on top of the blank plane to make it look like a piece of paper with text on. The new text is in the font type Arial, as it is one of the better font types to read for people with dyslexia[7]. For this project it was deemed unnecessary to spend time on developing actual text recognition, and instead a demo text created beforehand is used. This is because part the objective of this research is to test if AR is useful and enjoyable to use, and real text recognition is not needed to test this. The example text used in this project was created in ChatGPT[52] with the prompt: "Write a short story about our solar system." The text created is in the Norwegian language as the test participants are native Norwegian speakers. The full text used can be found in appendix D.

The next step in the process is to add the possibility of changing color of the text and background. Four options in the form of buttons are available to the user. Two of the colors are based on research done by Rello[9] which suggests that the orange and peach colors are good background colors for people with dyslexia when using black text. The third color option is the standard black text on white background and the last color is a high contrast option that has yellow text on a blue background.

The following step in the process was to make it possible to change the size of the letters. Once the user presses a plus or minus button, the letter size increases and decreases respectively. Once the size of the text becomes bigger, the plane that the text is overlaid on also needs to increase so that the text does not go beyond the plane and becomes hard to read. The other options for text augmentation the user should have available are line spacing and word spacing. If the user increases the line spacing or word spacing the words of the text moves further apart from each other, which means that the digital plane also needs to increase at the same rate and also in combination with each other.

After all the text augmentation options were in place, the last thing to add was the text-to-speech option, which lets the user have the application read the text out loud. There are many text-to-speech options available, but as the application was being tested on Norwegian users and had Norwegian text it was important to get a Norwegian text-to-speech voice. Several different text-to-speech providers was tried and tested and Narakeet[53] text-to-speech with the voice of "Aslak" was chosen due to it having the most natural sound, although none of the Norwegian text-to-speech options was perfect and some parts of the text still sounds a bit robotic.

4.3.2 Scripts

There are a few scripts that controls the functionality of the application and all of the code produced for this project was made step by step for this project specifically. The programming language preferred by Unity is C# and is the language that have been used for the development of this application. The scripts themselves are organized with comments so that it is easier for readers to understand the code. Figure 4.4 shows some of the code used in the application for calculating the size of the canvas as well as comments.

```
6 references
public void changeThePlane()
{
    //line spacing
    mainTextInput.lineSpacing = lineSpacingNumber + (lineSpacingDenominator * 50);

    //word spacing
    mainTextInput.wordSpacing = wordSpacingNumber + (wordSpacingDenominator * 25);


    // calculation of text container
    textRectWidth = (sizeOfFont * 30f) + (wordSpacingDenominator * 20f) + ((wordSpacingDenominator * sizeOfFont)*1.5f);
    textRectHeight = (sizeOfFont * 60) + (lineSpacingDenominator * 200);

    //calculation for canvas size
    planeSizeX = (float)((sizeOfFont * 30f) / 3000f) + (wordSpacingDenominator * 0.01f) + ((wordSpacingDenominator * sizeOfFont) / 3000);
    planeSizeZ = (float)((sizeOfFont * 60f) / 4500f) + (lineSpacingDenominator * 0.01f) + ((lineSpacingDenominator * sizeOfFont)/500);


    //changes size of canvas in plancescript
    planeScript.xScale = planeSizeX;
    planeScript.zScale = planeSizeZ;


    //changes the size of the rectangle that contains the text
    TextPanel = GameObject.Find("mainText");
    textPanel_rt = TextPanel.GetComponent<RectTransform>();
    textPanel_rt.sizeDelta = new Vector2(textRectWidth, textRectHeight);
}
```

Figure 4.4: Code snippet from the scipts

4.3.3 UI

All the visuals in the app which include all the buttons and options the user have available are made within Unity. There are no downloaded assets except for the Arial font type which does not come with Unity by default. The buttons are designed with simplicity in mind as more complexity can very easily confuse the user. Steps taken to simplify the experience are to make sure known symbols are used, such as plus and minus, as well as the play and stop button. Tasks that the user performs should be done with minimal amount of cognitive effort[54]. All the buttons that control the colors as well as the play and stop button also have a black border around them. This is so that it is easier to spot them when changing the color of the digital background as changing the color of the background can make the corresponding button hard to see if not outlined. The plus and minus buttons are black with an orange color variant that is not used elsewhere in the application, so that they are easy to spot. They also contain a number between them which represents the size of the augmentation. The number is simply a level that the user can choose to have an easier time personalizing and remembering their choices. Lastly, the buttons are all located on the bottom half of the screen so that users have an easier time accessing them if they only use one hand as they can reach all the buttons with their thumb.

The four color options available to the user, as well as some different levels of augmentation can be seen below in figure 4.5, 4.6, 4.7 and 4.8.

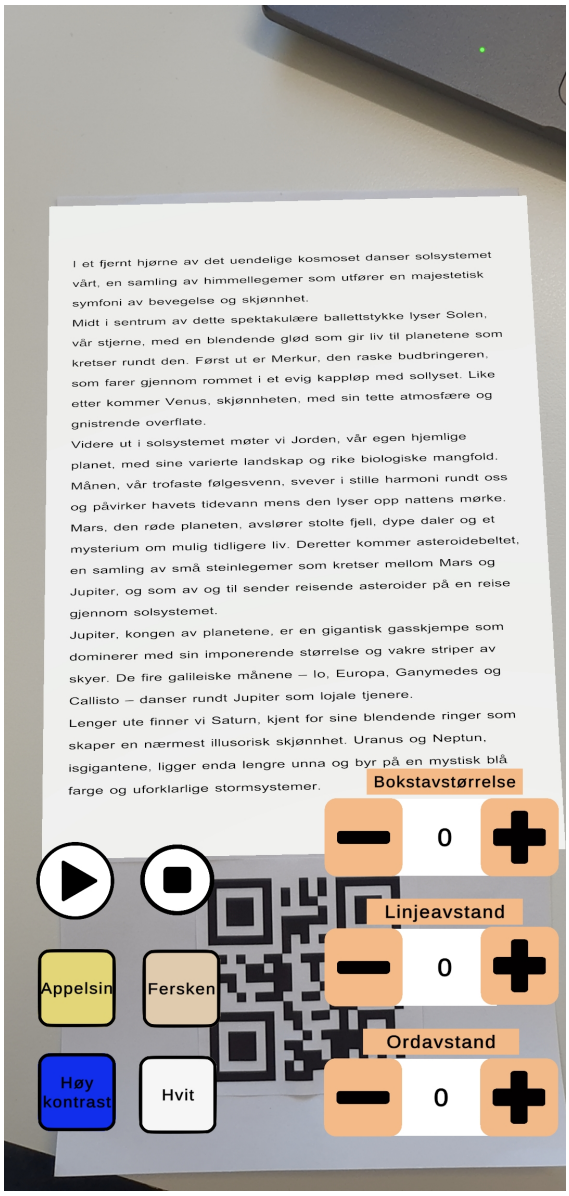

Figure 4.5: The app with white background and no text augmentation

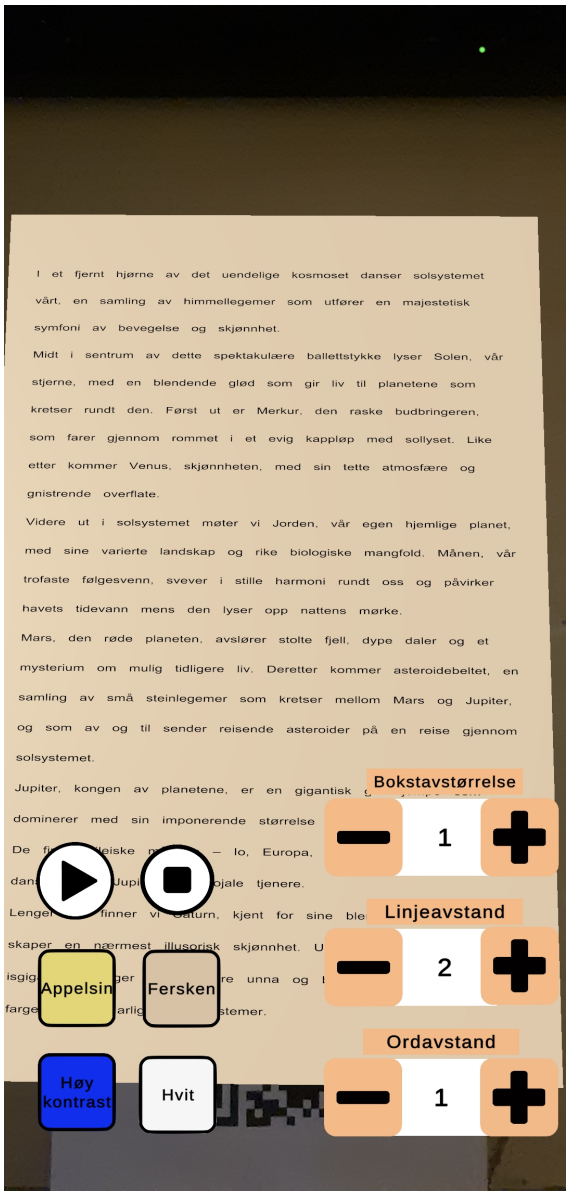

Figure 4.6: The app with peach color and some text augmentation

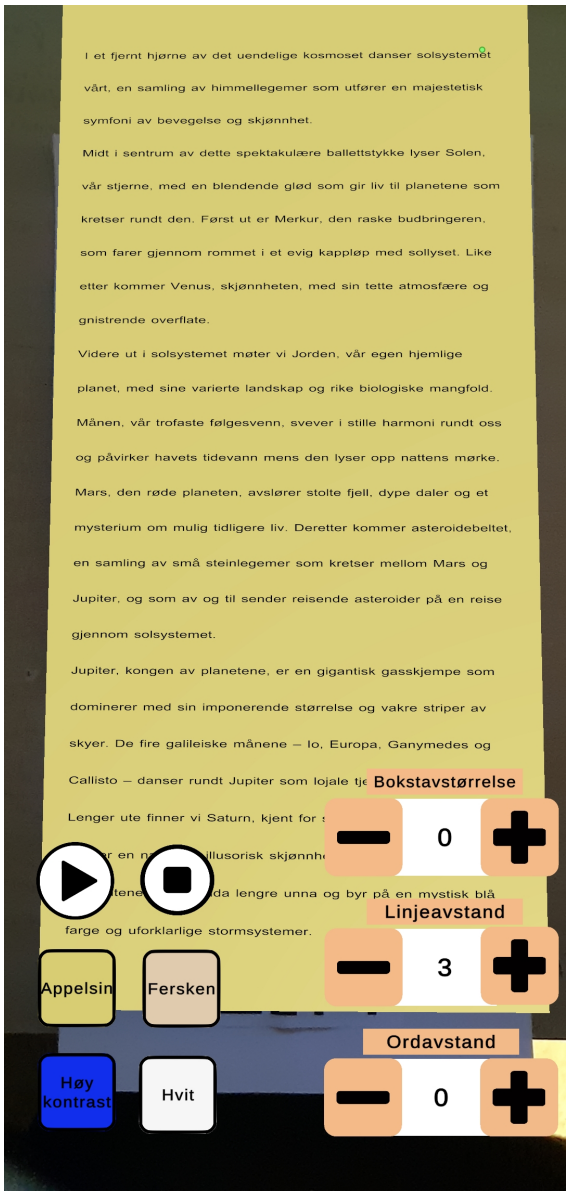

Figure 4.7: The app with orange background and increased line spacing

Figure 4.8: The app with high contrast colors and increased word spacing

Chapter 5

Findings and Discussion

This chapter presents the data and findings gathered from the interviews and user testings, in addition to the analysis and discussion of the results to answer the research questions.

5.1 Findings and Results

This section presents the summary of the preliminary interviews that was done prior to the development of the app, the summary of the interviews from the user testing, and the data collected during the user testings.

5.1.1 Preliminary interviews

To define the user requirements for the AR app, five preliminary semi-structured interviews were conducted with the target group consisting of three men and two women aged 20-50. The people that participated in the interviews were asked about their personal experiences regarding dyslexia and dyslexia assistive tools to better understand what people with dyslexia would want from an assistive tool. Understanding what the potential users of an interactive system wants from the system can be incredibly valuable and is a key part of the human-centered design process. Involving users in the design process provides valuable knowledge about how the system should work and the involvement should be active, such as acting as a source of relevant data[31]. The topic of augmented reality was not mentioned as this could affect the participants with social desirability bias and alter their responses to what they think the interviewer wants to hear[44]. The answers provided from all the interviews formed the basis for what user requirements the AR app would have.
The following section contains a translated summary of the answers for each topic from the interviews.

Topic 1 - What are the symptoms of your dyslexia and when did you discover that you had dyslexia? How does it affect you when it comes to learning in school or in a job? Most people were diagnosed around the age of eight to twelve. All the participants mentioned that reading takes a long time which is a hindrance in school as you often have to read a lot of material. Most participants also mentioned that writing also takes a long time and makes things like written exams very difficult.

Topic 2 - What kinds of methods or technology do you currently use to help you cope with dyslexia? One person said they did not use any technology to assist them at the moment. The other four used either text-to-speech or sound books from time to time. Two people used a form of browser tool that makes websites more dyslexia friendly. Two people mentioned spelling programs and word suggestion technology. One person said that ChatGPT[52] was a very useful tool.

Topic 3 - What other kinds of tools have you used in the past and how do they work? Everyone had used spell check programs such as Microsoft Word and similar programs. Most people had also tried sound books or text-to-speech.

Topic 4 - What are the main issues with the methods or tools you have used in the past and why did you stop using them? What works well for you and what does not work? Most of the programs they had used were tedious to use as the technology such as text-to-speech was very bad. Most people felt like the programs they had tried took longer to use than to just read and write on their own. Some people also had issues with licensing as it would not work properly and could not be used until they had contacted the customer support for that product.

Topic 5 - If you had to learn something from a book or text, would you rather have an assistive tool that helps you read the text, or would you prefer not reading altogether? Two people said they would want to avoid reading as much as possible as it is very time consuming and takes a lot of effort. Two people said they prefer reading themselves and would like a tool that makes reading easier. The last person said it depends on the material they have to read.

Topic 6 - If you had the possibility of using your mobile phone to assist you in reading, what kind of functionality would you like it to have? What are the most important things or tasks you want to do? Everyone had different wishes for what the mobile phone could do to assist them. The most prominent options include: Having the phone read text for them(text-to-speech), change the size of the text to make it visually easier to read, use the phone to scan a smart book that has various options built in, use the camera to scan the text and then have the phone read the text back to you.

Topic 7 - Do you have any recommendations when it comes to assistive technology for people with dyslexia The participants did not have too much to say when it came to recommendations, but one person said that a lot of individual dyslexia assistive tools already exist in some form, but a tool that combines the individual tools into one would be very useful. Another person also spoke very highly of having text read back to them as it makes it easier to follow the text and not get distracted, this was a feature they see available in some digital books.

5.1.2 pre-test interview

After the app was designed and developed it had to be tested to see if the design solution meets the requirements. Before the participants tried out the AR app, pre-test interviews were done gain some understanding on how the participants are affected by dyslexia, as well as making sure the participants fits the target group criteria. The following section contains a summary of the answers translated into English:

Q1 - What is your age and gender? Four men and one woman, aged 23-30.

Q2 - How old were you when you realized that you had dyslexia? The participants found out or got diagnosed with dyslexia between the ages five to twelve.

Q3 - What kind of challenges do you face for the most part with dyslexia? Most of the participants had the biggest challenges in school at younger ages due to there being a lot of reading and not much availability of good text-to-speech programs. All the participants had issues reading and writing and struggled with grammar.

Q4 - From a scale of 1-5 where 1 is very little and 5 is very much, how much is your daily life affected by dyslexia? Two participants answered 3 and three participants answered 4

Q5 - How much time do you spend on your phone each day? The participants spent 1.5 hours to 3 hours per day on their phones with an average of 2.2 hours per day.

Q6 From a scale of 1-5 where 1 is very little and 5 is very much, how experienced are you at using mobile phones? Most of the participants felt confident with using mobile phones, one answered 3, one answered 5 and the rest answered 4.

Q7 From a scale of 1-5 where 1 is very little and 5 is very much, how good do you feel your phone is at assisting you with reading difficulties? Most of the participants felt like their phone do not help them much, four participants answered 2 and one participant answered 3.

Q8 Have you tried dyslexia assistive tools before, if so what kinds? The participants had some varying experience with assistive tools but they have all tried text-to-speech and spell check tools such as Microsoft Word. Two of the participants had tried programs that suggest words when writing to make writing easier. Three participants had used browser add ons that are meant to make websites easier for people with dyslexia. One participant mentioned that chatGPT is used a lot as an assistive tool.

Q9 What kinds of tools worked for you and what tools did not work? Four out of the five participants really like to use text-to-speech when reading and all five participants feel like spell check programs work well when writing. Two participant spoke very highly of chatGPT and one participant liked having word suggestion programs. The people who had tried dyslexia browser extentions said it helped sometimes on some websites, but that it is nice to have different colors on background and text available. One participant did not not like to have word suggestion programs as it was very confusing at times. One participant did not like text-to-speech as they preferred reading at their own pace even if the pace is slower.

5.1.3 User testing and observation

After the pre-test interviews were done the user testing could start. The user testing consisted of nine total tasks, three of which included reading a short text that was timed. The entire user testing was filmed in order to analyse for usability issues in the app.

Task 1 - Read the text on the printed paper The time spent reading the printed text took from 1 minute and 58 seconds to 2 minutes and 42 seconds. The average time spent reading the printed text was 2 minutes and 24 seconds.

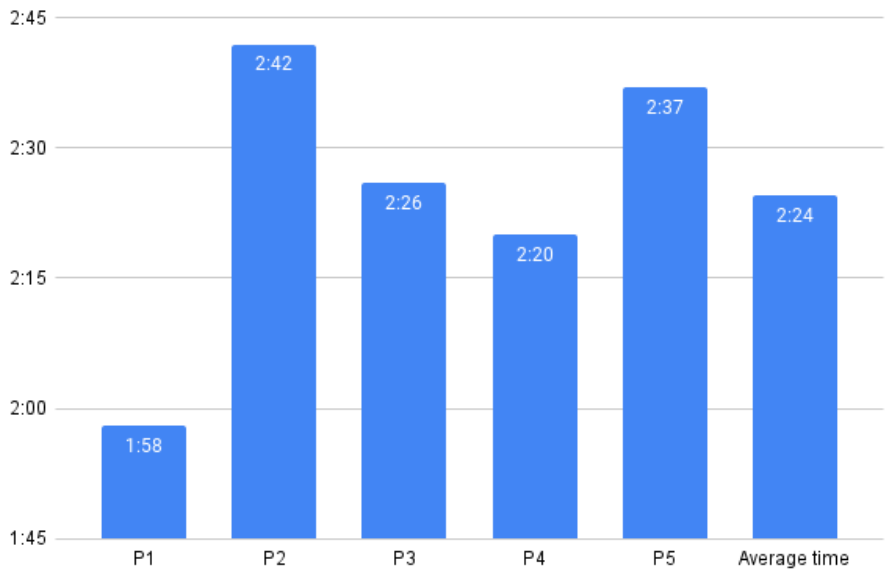

Figure 5.1: Time spent on reading the printed text

Task 2 - Using the mobile phone app, film the QR code until you can see the digital paper version This went smoothly for most participants as the QR code is very easy to see. Some participants however had some issues finding the correct distance as the app does not register the QR code if you are too close.

Task 3 - First increase the line spacing and thereafter decrease the line spacing This task was very easy for all the participants and only took a few seconds to find the correct buttons.

Task 4 - First increase the word spacing and then decrease the word spacing This went flawlessly for all the participants.

Task 5 - Change the color of the background Four out of five of the participants had no issues with this task. One participant however did not understand what buttons was for changing color right away and seemed scared to press the wrong buttons. The participant found the button right away after the observer said that it is fine to press different buttons to test.

Task 6 - Choose the color you feel like is the easiest to read from The participants have four color options available. One participant chose standard white background, two participants chose the peach color, one participant chose the high contrast option and the last participant chose the peach background at first, but then later changed to white background.

Task 7 - Choose the line spacing, word spacing and letter size that you feel like is the easiest to read from The options chosen were varied, four of the participant all kept word spacing at 0 and one participant increased the word spacing by one point. For the line spacing two participants kept line spacing at 0, while the other three participants increase the line spacing by one or two points. All the participants increased the letter size, some increased only by one point, while others increased the letter size with as much ass five points.

Task 8 - Read the text with the changes you have made Some participants had a large increase in reading speed with the changes made, while others only had a small increase in reading speed. One participant took longer to read the text through the app, but the participant had some issues with finding the text on the app at some point. The same participant also decided to change color of the background halfway through the text from peach color to white color.

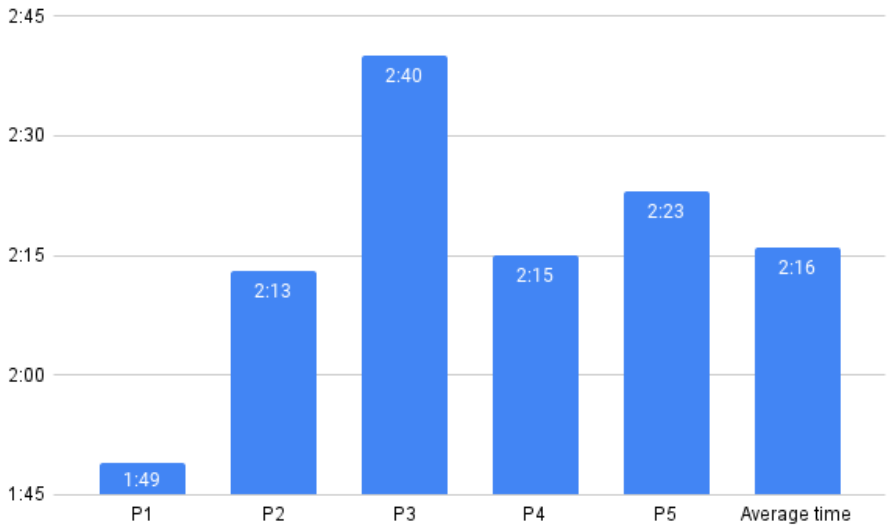

Figure 5.2: Time spent on reading the text through the app

Task 9 - Enable text-to-speech and read the text again Four out of five participants had no issues activating the text-to-speech. One participant had activated it by mistake and did not realize that it was possible to reset the text-to-speech and therefore started reading from the second sentence instead.

5.1.4 Post-test questionnaire

Following the user test the interviewer/observer gave the participants a post-test questionnaire and then left the room to allow the participant to fill out the form which consisted of two parts.

The first part of the questionnaire consisted of Likert scale questions of which some was taken from the System usability scale[41]. The results from the questionnaires can be seen in the figures below:

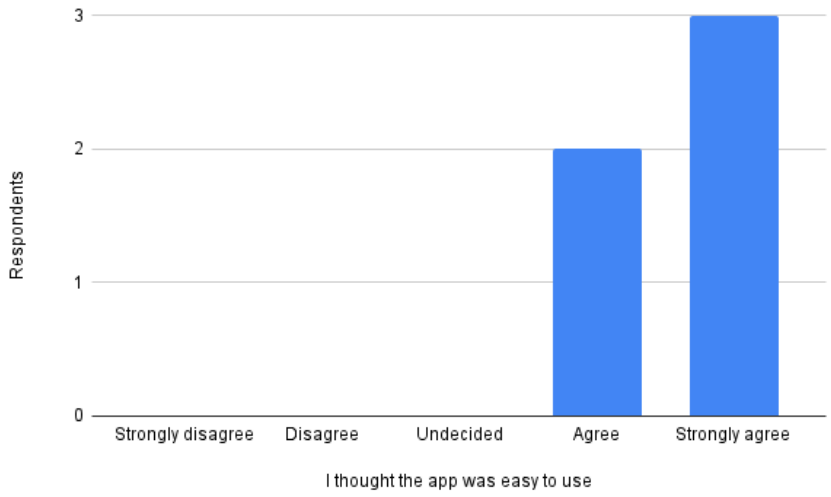

Figure 5.3: Questionnaire question 1

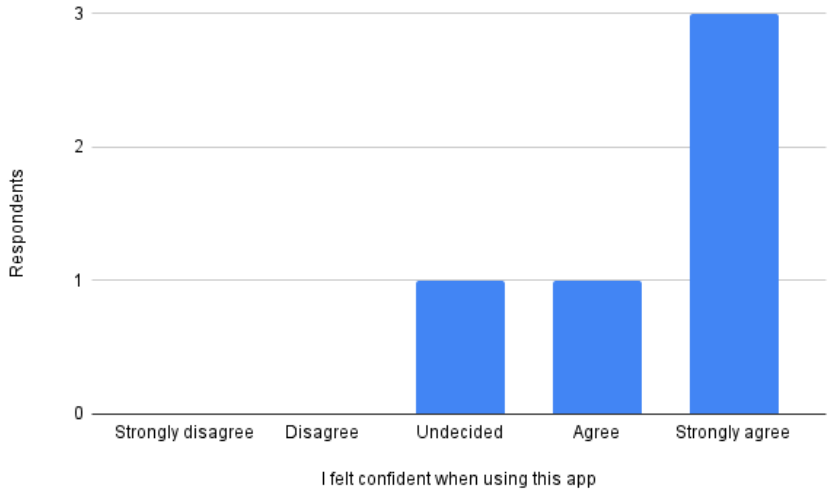

Figure 5.4: Questionnaire question 2

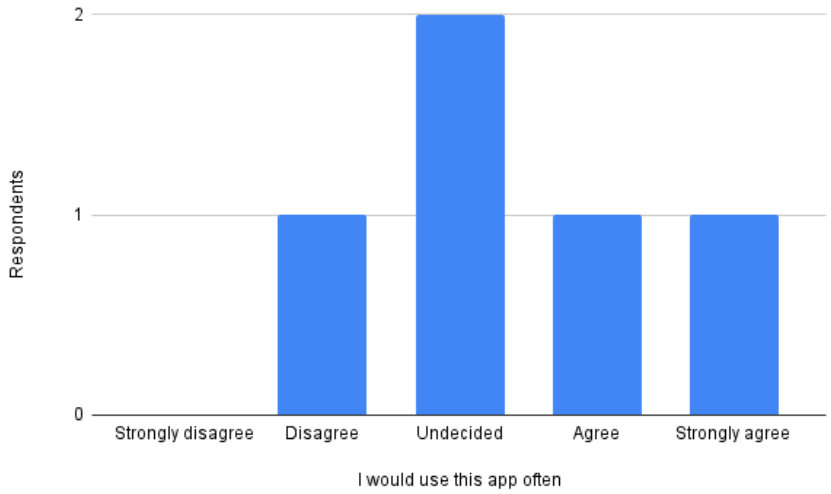

Figure 5.5: Questionnaire question 3

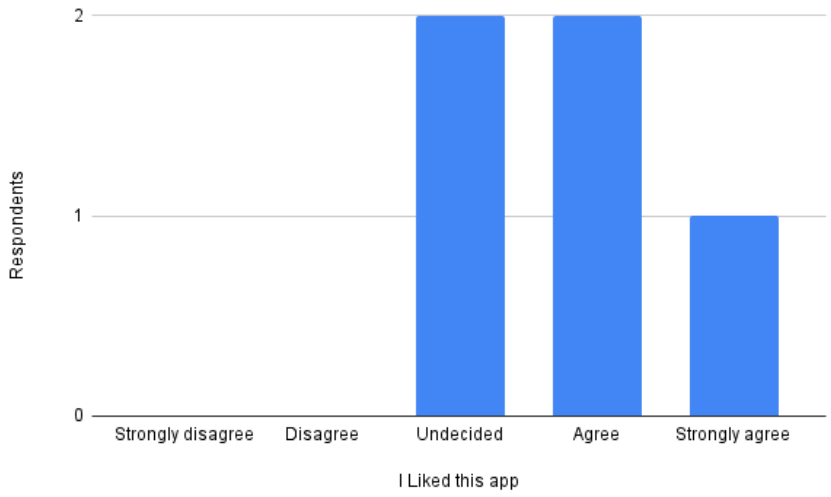

Figure 5.6: Questionnaire question 4

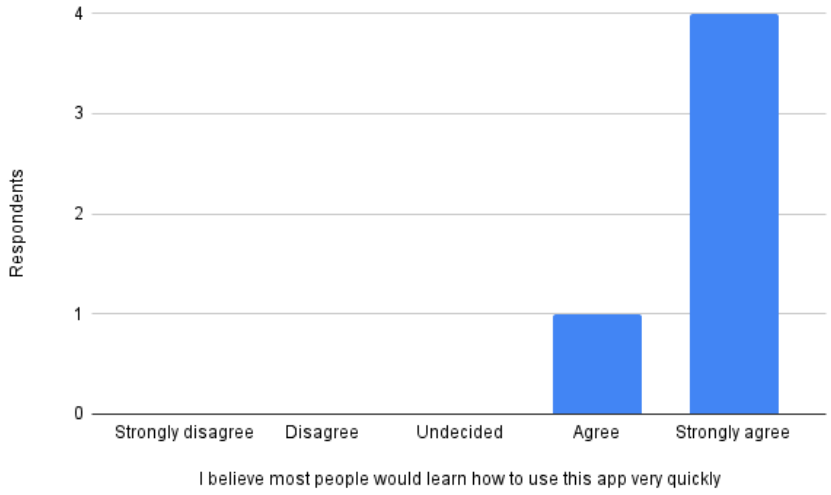

Figure 5.7: Questionnaire question 5

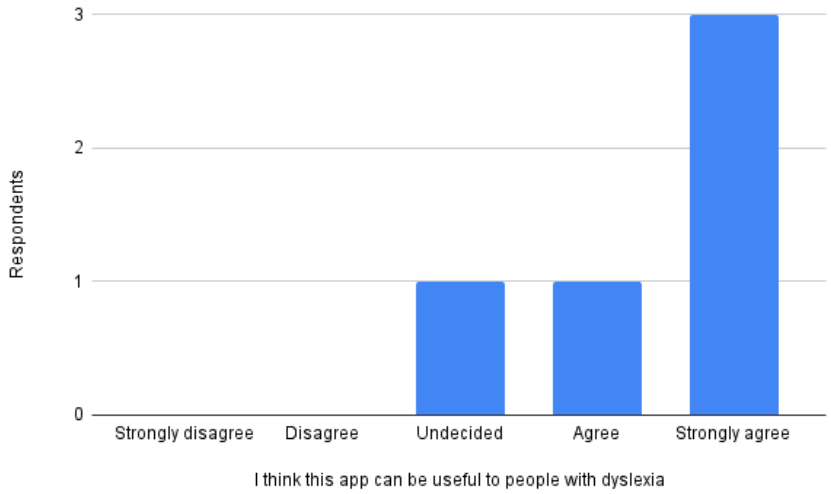

Figure 5.8: Questionnaire question 6

The second part of the form consisted of ten questions taken from the User experience questionnaire[42]. In the UEQ participants can give each question a score from one to seven and a score is then calculated based on the results. If the participant choose the most positive option, the overall score will get +3, while the most negative option gives a -3, and a score of four which is in the middle gives an overall score of 0[42]. This makes it easy to both calculate and visualize the overall mean score, as well as understanding where the app can be improved upon. A table of how many participants scored what number can be seen in figure 5.9. The overall mean score was then calculated using these numbers and can be seen as graphs in figure 5.10.

User Experience Questionnaire	1	2	3	4	5	6	7	
Not understandable	0	0	0	0	2	0	3	Understandable
Easy to learn	3	2	0	0	0	0	0	Difficult to learn
Boring	0	0	0	1	3	1	0	Exciting
Not interesting	0	0	0	0	3	2	0	Interesting
Obstructive	0	0	0	0	1	2	2	Supportive
Motivating	1	1	2	1	0	0	0	Demotivating
Clear	3	2	0	0	0	0	0	Confusing
Unpractical	0	0	0	1	1	2	1	Practical
Meets expectations	1	1	2	1	0	0	0	Does not meet expectations
Valuable	2	2	1	0	0	0	0	Inferior

Figure 5.9: UEQ table

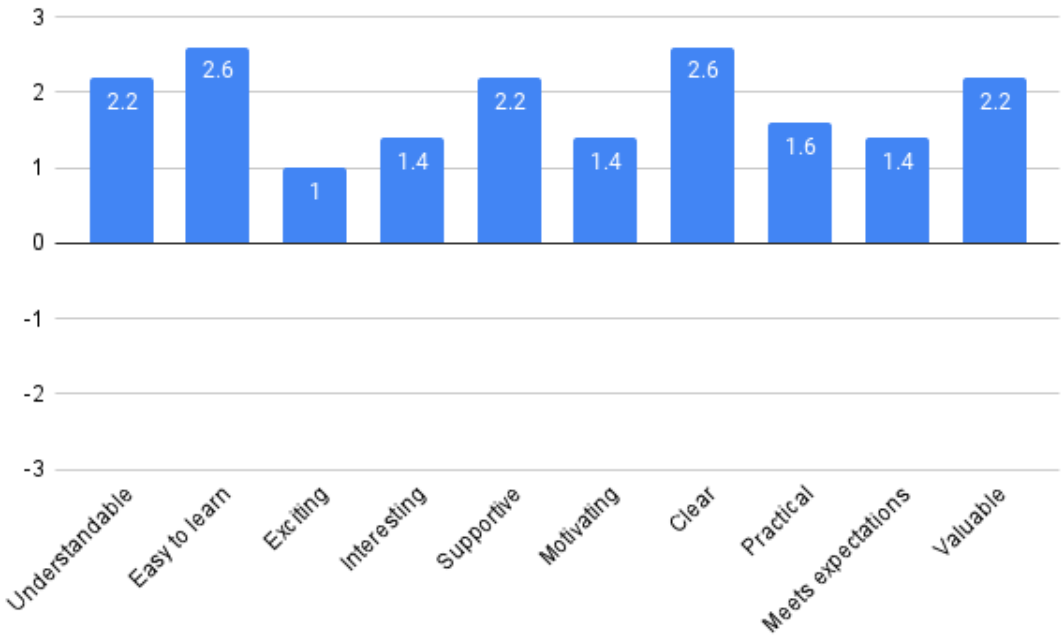

Figure 5.10: UEQ score

As can be seen in figure 5.10 every single topic got a positive score and the overall score is very positive.

5.1.5 Post-test interview

The last part of the user testing consisted of a post-test qualitative interview. Most of the questions are open ended to allow the participants to express their personal opinions on the app. The answers are summarized and translated to English in the following section:

Q1 - You read the text three times, which method was the easiest and which was the hardest?
All five participants said that reading with text-to-speech was the easiest, but most participants mentioned that the text-to-speech was weird or robotic at times. Three out of five participants said that reading the printed text was the hardest while two participants said that reading the text through the app was hardest. The people who said that the text was harder through the app also mentioned that the difficulty came from having to constantly aim at the QR code instead of lifting the phone up at their preferred height.

Q2 - How did it feel to be able to make changes to text through the app?
Most of the participants were positive about being able to change the size and really liked to make the text bigger. Some participants also mentioned that being able to change color was very nice and useful. It was also mentioned by some participants that the app was fun or interesting and that the app seem very helpful. One participant also mentioned that the phone screen should have been bigger so that it is possible to see more text at once.

Q3 - Is there anything you felt like was missing to make the experience better or more fun?
Most participants did not feel like the app was missing anything, but some participants wanted the possibility to change font type as well as adding more color options. A few participants also mentioned that maybe something could be done about the angle or distance of the phone and QR code to make the tracking or reading easier.

Q4 - Were there any buttons that were hard to find or understand?
None of the participants said they had any issues with finding the buttons. One participant however mentioned that the buttons for changing color was a bit unclear at first glance.

Q5 - What did you like the most about the app?
Some participants really liked that you could change the colors and most participants liked the fact that it is possible to customize to their own preference.

Q6 - What did you like the least about the app?
Two participants did not like that you constantly have to point the camera towards the QR code and wants to move the phone. One participant said that it was hard to read the names of the color buttons as the text was very cramped. One participant said that the least liked feature of the app was the high-contrast color itself.

Q7 - Did you feel like the alternatives available made it easier to read? If so, what alternatives was the most helpful? All the participants said that the alternatives available made it easier to read. Two participants said that text-to-speech was the most helpful and the rest of the participants said that increasing the size of the letters or text was the most helpful. Some also mentioned that changing of color was also very helpful.

Q8 - Was there any alternatives that you felt was not useful? If so, what alternatives was the least useful? Most participants said that there was nothing that was not useful, but some said that if they had to chose something it would be either word spacing or some of the colors options.

Q9 - Is there anything you would have changed, added or removed from the app?
None of the participants would remove any features. All of the participants liked the feature to change color but some would like more color options. One participant specifically mentioned that a dark theme would be nice. Three of the participants wanted it to be a bit easier to have the text displayed on the app, one of the participants even suggested that this could be done by having an option to take a screenshot of the text and then have it saved in the app, so that you do not need the printed text. The same participant also mentioned that this could be a nice feature as you could even read the text later if you did not have time

right away. Four out of the five participants also wanted an addition to the text-to-speech feature where the words that are being read out are highlighted so that it is easier to follow along with the speech.

5.2 Discussion

This section discusses the results and design decisions that were made.

5.2.1 Design Decisions

Using augmented reality to support people with dyslexia is not an entirely new concept, but there are not many options available on the market for people to use. As mentioned in Chapter 2 , there has only been a few studies done on the topic and some of the studies are old. Augmented reality technology however is always advancing, meaning there are new possibilities to innovate.

In the preliminary interviews that were conducted in advance of the design of the app, there were some topics that seemed very important. In topic 5 the participants were asked if they would prefer to have an assistive tool that helps them read text or if they prefer to avoid reading altogether. Half of the participants preferred to avoid reading while the other half preferred to read for themselves. If the design of the app was to accommodate both of these wishes, the app would need to be customizable so that both groups would be satisfied. Topic 6 is also an important one as it asks the participants what functionality they would want an assistive mobile app to have. Almost all the participants had different wishes for functionality, which also pointed towards the app needing to be customizable for the user. After the interviews it seemed clear that personalization would have play a big role in the app for it to be desirable to the target group.

In the study by L. Kasa[26] that was mentioned in chapter 2, a few individual ideas for AR were tested with dyslexic people. The first idea included the options of customizing font style, font size, and font color, all of which the participants enjoyed using and felt increased the readability of the text. The second idea was to scan text with a device and have the device read the text out loud via text-to-speech. This idea is very similar to a text scanner pen but instead of using a pen to scan, a mobile phone is used. The participants liked this feature as well and felt it made reading easier. The third idea was to change the color of the background and text to see if different color options could be beneficial. The test included both dynamic backgrounds and static backgrounds. The participants did not like the dynamic backgrounds as they felt like the text was moving too much and became harder to read. The participants did however like the option of changing a static background color.

In a similar study mentioned in chapter 2 done by Gupta et al[24]. It was tested if augmented reality could be used to increase reading speeds of people with dyslexia. The augmentation options available in that study includes: Real time text detection, customizable font styles, and reader mode which includes the option of having text read aloud. The results from the study showed that the average reading speed was reduced by 21%, meaning the options probably are beneficial to people with dyslexia. The study did however not test if the participants enjoyed using the system and there was no mention of usability issues.

The research done in the study by Gupta et al. and the research done in the study by L. Kasa show a lot of promise in both the effectiveness and enjoyment of the augmentation options available. Based on both of those studies as well as the research done through the interviews in this thesis, a set of requirements were made for the AR app prototype. The

requirements served as the basis of what functionality the app should have to effectively assist people with dyslexia in reading written content, and just like one of the participants in the interviews mentioned, the app includes several different tools into one and adds augmented reality to make the experience interactive. The functionality of the app includes: Scanning of printed text to get a digital version, being able to augment both size and color of the text to the user's preference, as well as enabling text-to-speech.

The human-centered design process includes several principles, one of them being that the design is driven and refined by user-centered evaluation[31]. This is why the last activity in the process of evaluating the design is so important. This is the activity that lets the designer truly know if the design solution meets the requirements, and to do this the target group has to be involved. By conducting usability testing and interviews with the target group it is possible to gather data and compare the results with the user requirements. For this thesis a set of Volere snow cards were used to define the user requirements, and if the functional requirements are not met then the design solution does not meet the necessary requirements yet and needs to be iterated on until they do. A total of seven Volere snow cards containing functional requirements were made, which are:

1. The app must be able to track a marker/QR code.
2. The app will add an overlay containing a digital piece of paper with text on top of the physical/printed text.
3. User must be able to change the spacing of words on the digital text.
4. User must be able to change the line spacing on the digital text.
5. User must be able to change the font size of the digital text.
6. User must be able to change the color of the font and background of the digital text.
7. User should have the option of enabling text-to-speech.

By testing the design solution with the target group it was possible to confirm what requirements were met. All five users that participated in the user testing were able to use all the functions of the app. Some users however had some issues with the tracking of the QR code, which means that this could be a point of improvement if the design were to be iterated on. None of the participants had any other issues with the functionality of the app, which means that the functional requirements were met.

5.2.2 RQ1 - How to design an effective Augmented Reality application that can assist people with dyslexia in reading written materials?

The AR app was designed and developed using the human-centered design process. The human-centered design ISO[31] states: "The human-centered design is an approach to interactive systems that aims to make systems usable and useful by focusing on the users, their needs and requirements, and by applying human factors/ergonomics, and usability knowledge and techniques. This approach enhances effectiveness and efficiency, improves human well-being, user satisfaction, accessibility and sustainability; and counteracts possible adverse effects of use on human health, safety and performance."

By following the HCD principles the app should be an effective app, but to answer the research question it is important to understand what it means to be an effective app. There are multiple things that can go into the effectiveness of the app.

One of these is the actual difference in reading speed when using the app compared to reading the text on the paper. Comparing the time it took to read the text is very measurable and is part of the quantitative data that is used in this thesis and is why a mixed method was used. Looking at figure 5.1 and figure 5.2 which shows the time spent reading the printed text and the time spent reading through the app respectively, it can be observed that there is a difference in reading speeds. Some participants had a significant reduction in reading time while others only had a slight reduction and one participant actually took longer when reading through the app. It should be noted that the participants read the exact same text both times, meaning a slight decrease in reading time is to be expected. One participant however spent 29 seconds less when reading the text through the app and stated that the text was much easier to read the second time. The participant who spent longer when reading through the app stated that there were some issues with the AR-tracking when reading and that a readjustment had to be made while reading, this could explain why it took longer the second time. On average the participants had a 5,5% decrease in reading time, while the one with the most reduction in reading time had a reduction of 17,9%. If the participant that had issues with the AR-tracking is removed from the calculations the average goes up to a 9,5% reduction in reading speed. This percentage is still less than half of the reading speed reduction of 21% that was found in the study by Gupta et al[24], meaning there could be room for improvement when it comes to reducing reading speeds.

Reading speed is not the only thing that goes into the effectiveness of an app however. According to the HCD[31] "Using the human-centered design approach enhances effectiveness." And in this context the word effectiveness means: "accuracy and completeness with which users achieve specified goals[31]." By going with this meaning of the word "effective", you have to test the application with the target group to see how well they achieve the specified goals. The specified goals of the app is to see if using augmented reality can assist people with dyslexia in reading written contents. According to the Oxford English Dictionary[55], one of the definitions of the word effective is "producing a striking or pleasing impression in a work of art or design". Both of these meanings of the word effective takes the users impression of the app into account and only the participants themselves can really tell if the app is effective or not. This leads to the second research question which is: "How do people with dyslexia experience using Augmented Reality to assist them in reading?" By getting an understanding of how the participants experience the app, it might be possible to tell how effective the app is.

5.2.3 RQ2 - How do people with dyslexia experience using Augmented Reality to assist them in reading?

By conducting user testing, the participants were able to experience using an AR app to assist them in reading. Following this, qualitative interviews where conducted to gauge how the participants experienced using the app. The following section details the participants opinions and attitudes towards using AR to assist in reading.

Personalization of the app

A preference is personal and subjective, and it can therefore be difficult to make a "one size fits all" product. It is however possible to give the user options for customization so that there is an increased likelihood of them enjoying the experience. By looking at observations of the user testing, it can be seen that the participants had very different preferences. Some participants used different colors than others and some used different text sizes and all of the participants chose different settings when asked to pick a color and text size. This is reflected in the thematic analysis of the post-test interview, where some of the participants' favorite feature was changing color, while for others it was changing text size. When asking

the participants what feature they thought was the most useful for increasing the readability of the text they also had different answers. As dyslexia is a continuum and not a distinct category, people with dyslexia will have different severity of reading difficulties[3]. They will therefore also most likely have different preferences in how much assistance or what type of assistance they want.

When the participants were asked if they think the app can be useful to people with dyslexia, most of the answers pointed towards them agreeing that it could be useful, as can be seen in figure 5.8. This might be because they think that the customization options of the app allows it to be useful to most dyslexic people. Most of the participants also had an interest in adding additional features to the app to further enhance the customizability of the app.

Usefulness of the app

For people to want to use a product, it has to be useful to them in some way. To make a system usable and useful to humans, the users needs and requirements should be in focus[31]. When the participants were asked in the post-test questionnaire if they would use this app often, there was only one person who strongly agreed, while the others averaged on undecided as can be seen in figure 5.5. However when asked if they think the app can be useful to people with dyslexia there was three people who strongly agreed as can be seen in figure 5.8. At the same time, when asked if they like the app, the average answer leaned towards agreement as can be seen in figure 5.6. This could be interpreted as the participants thinking that the app and idea is good in general, but that it might be lacking something for them to personally take use of it. One of the recurring themes found in the thematic analysis is the participants being unsatisfied with the tracking or aiming feature. It seems like it was difficult at times for the participants to keep the mobile phone in the correct position to get the best view of the AR-text.

When the participants were asked if there were any alternatives they felt were not useful, they all said that all the features were useful in some way. Since all the participants said they liked the features available, it could be interpreted as the AR-tracking being the culprit for not everyone wanting to use the app for themselves, but still thinking that the app is useful to other people with dyslexia.

Positivity of the app

A theme from the thematic analysis that appeared often was a general positivity towards the app. The participants were positive towards most of the features of the app when asked about them in the interviews and the same answers are reflected in the user experience questionnaire. Looking at figure 5.10 there is not a single topic that had a negative mean score and some of the topics had close to a perfect score. Despite the fact that some of the participants had a little trouble with the AR-tracking, they were still positive towards the app. This could mean that the participants think that the app shows promise and that the general idea behind it is good. During the interviews the participants praised the apps ability to be customized multiple times, and was mentioned by one participant as being their favourite feature.

5.2.4 More features

A common theme from the post test interviews was a desire for more features. All five participants wanted more features in the app and they made it very clear that they did not want to replace any features, but add to them. Some participants even stated that more

options for customizability would make it more likely that they would use the app regularly. The main features that were requested are:

- More color options
- Text highlighter for text-to-speech
- Save the text for later use
- Be able to move the text to a different location so you can hold your phone in a preferred position

The feasibility of the options might vary, but as the HCD process is iterative, it is always possible to implement new features and conduct a new round of user tests.

Chapter 6

Conclusion and future work

6.1 Conclusion

An augmented reality application that assists dyslexic people in reading written content has been designed and developed. The application was designed with a human-centered design process and the feature set of the application was informed by interviews with the relevant stakeholders, in addition to prior attempts as highlighted in the state-of-the-art. Following the development of the AR application, the app was tested over five sessions with one participant at a time, totaling five participants while using a qualitative dominant mixed method approach. The user testing consisted of pre-test interviews, user tasks, observation, questionnaires and post-test interviews. The data collected from these user tests was then analyzed to evaluate what parts of the app the participants enjoyed or did not enjoy as well as assessing how the participants experienced using augmented reality technology.

Research question one: "How to design an effective Augmented Reality application that can assist people with dyslexia in reading written materials?" The app was effective at assisting people with dyslexia in reading written content. The participants themselves stated that they enjoyed using the app, that it was easy to learn and use, and that they thought the app would be useful to people with dyslexia.

The AR app was developed using a human-centered design approach[31] and uses known user experience design principles such as simplicity[54]. One way of simplifying the experience for the user is to design the system for a minimum amount of conscious and cognitive effort[54]. By incorporating proven iconography such as "play, pause, and stop" and "plus and minus" the user is less likely to be confused by the interface and is more likely to know what all the options do, meaning they can do the task they want more efficiently.

The augmentation options available to the users all have the purpose of assisting in reading in some way. Text-to-speech can help people with severe reading difficulties avoid reading altogether, while the text augmentation and color options available can make the text easier to read. According to the participants' answers in the questionnaires and qualitative interviews, the options that were available were all useful and made reading more enjoyable. This in turn seems to show that the app is effective in its purpose which is to assist people with dyslexia in reading written materials.

The time spent reading the text decreased by an average of 5,5%, which is less than similar tests mentioned in chapter 2. The observations showed that this could be because of issues with the AR tracking. If the participants had used the application more and gotten used to the AR feature, then the time spent reading could decrease further as one participant who did not have issues with the AR functionality had a decrease of 17,9%.

Research question two: "How do people with dyslexia experience using Augmented Reality to assist them in reading?" During the user testing after the user tasks were completed the participants filled out questionnaires and partook in qualitative interviews. The user experience questionnaire consisted of ten questions which are meant to measure how the users experience using the app. Looking at the results in figure 5.10 it can be seen that all ten categories had a positive score, which shows that the participants enjoyed the experience. This can be supported by the post-test interviews, such as when the participants were asked how it felt to be able to make changes to the text through the app. The participants said that they enjoyed being able to make the text bigger and change the background color and text color.

The participants also seemed to appreciate the ability to customize the text to their own preference, and they spoke highly of personalization options as they knew that dyslexia is a continuum where everyone has different challenges and preferences.

6.2 Future work

This project developed an augmented reality based assistive tool to support people with dyslexia in reading written content. By following the human-centered design approach which is an iterative process, the application can be innovated on. By testing with and taking input from the target group, it is possible to find room for improvements. During this work there were a few key points that were requested from the target group as well as new technology that has improved. A few of the key points are to allow for more color options such as a dark theme, make a feature to have word highlighting during text-to-speech for an easier time reading along, make it possible to scan the text once and then be able to move the phone to a preferred position, and lastly with the recent advances of artificial intelligence and computer learning, it could be possible to get a much better text-to-speech voice option that does not sound robotic.

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Appendix A

Volere requirement snow cards

Requirement #: 1 **Requirement Type:** 9 **Event:**

Description: The app must be able to track a marker/QR-code.

Rationale: The app needs to know when to activate its augmented reality functions as well as place the overlay in the correct position.

Originator: Software developer

Fit Criterion: When the user starts the application the camera will be activated, when aiming at the QR-code an overlay will appear on the screen.

Customer Satisfaction: 5 **Customer Dissatisfaction:** 5

Priority: 1 **Conflicts:**

Supporting Materials:

History: Created 25.03.2023

Requirement #: 2 **Requirement Type:** 9 **Event:**

Description: The app will add an overlay containing a digital piece of paper with text on top of the physical/printed text.

Rationale: It is required in order for the text to be manipulated by the user.

Originator: Software developer

Fit Criterion: When the user starts the application the camera will be activated, when aiming at the QR-code an overlay will appear on the screen.

Customer Satisfaction: 5 **Customer Dissatisfaction:** 5

Priority: 1 **Conflicts:**

Supporting Materials:

History: Created 25.03.2023

Requirement #: 3 **Requirement Type:** 9 **Event:**

Description: Being able to change the spacing of words on the digital text.

Rationale: In order for the user to change the text to their own preference.

Originator: Software developer

Fit Criterion: The user will get plus and minus buttons that lets them increase or decrease the word spacing.

Customer Satisfaction: 3 **Customer Dissatisfaction:** 2

Priority: 2 **Conflicts:**

Supporting Materials:

History: Created 25.03.2023

Requirement #: 4 **Requirement Type:** 9 **Event:**

Description: Being able to change the line spacing on the digital text.

Rationale: In order for the user to change the text to their own preference.

Originator: Software developer

Fit Criterion: The user will get plus and minus buttons that lets them increase or decrease the line spacing.

Customer Satisfaction: 3 **Customer Dissatisfaction:** 2

Priority: 3 **Conflicts:**

Supporting Materials:

History: Created 25.03.2023

Requirement #: 5 **Requirement Type:** 9 **Event:**

Description: Being able to change the size of the font on the digital text.

Rationale: In order for the user to change the text to their own preference.

Originator: Software developer

Fit Criterion: The user will get plus and minus buttons that lets them increase or decrease the font size.

Customer Satisfaction: 3 **Customer Dissatisfaction:** 2

Priority: 2 **Conflicts:**

Supporting Materials:

History: Created 25.03.2023

Requirement #: 6 **Requirement Type:** 9 **Event:**

Description: Being able to change the color of the font and background of the digital text.

Rationale: In order for the user to change the appearance to their own preference.

Originator: Software developer

Fit Criterion: The user will get buttons with different colors which change the text or background color.

Customer Satisfaction: 4 **Customer Dissatisfaction:** 2

Priority: 2 **Conflicts:**

Supporting Materials:

History: Created 25.03.2023

Requirement #: 7 **Requirement Type:** 11 **Event:**

Description: The digital text in the app should be in the Arial font type.

Rationale: The arial font is a font type that is easier to read for people with dyslexia.

Originator: Software developer

Fit Criterion: User can see that the font has been changed compared to the physical/printed text.

Customer Satisfaction: 3 **Customer Dissatisfaction:** 3

Priority: 3 **Conflicts:**

Supporting Materials:

History: Created 25.03.2023

Requirement #: 8 **Requirement Type:** 9 **Event:**

Description: The user should have the option of enabling text-to-speech

Rationale: Text-to-speech is widely used by people with dyslexia and is a very useful tool when having to read text.

Originator: Software developer

Fit Criterion: The user can press a play button to start the text-to-speech as well as a pause and stop button to stop the sound.

Customer Satisfaction: 4 **Customer Dissatisfaction:** 4

Priority: 2 **Conflicts:**

Supporting Materials:

History: Created 25.03.2023

Appendix B

Thematic analysis

You read the text three times, which method was the easiest and which was the hardest?

Participant no.	Notes and codes	Themes
1	With tts was easiest, the first time was hardest. - I wish it was possible to hold the phone at my preferred distance, a bit tiresome if not.	Tracking - Unsatisfied
2	With tts was easiest, the first time was hardest.	TTS - Satisfied
3	With tts was easiest, Second time was hardest.	TTS - Satisfied
4	With tts was easiest, Second time was hardest. - The text itself was fine, but the TTS was a bit weird and robotic. It was also a bit difficult to track the text at times.	Tracking - Unsatisfied
5	With tts was easiest, the first time was hardest.	TTS - Satisfied

How did it feel to be able to make changes to text through the app?

Participant no.	Notes and codes	Themes
1	I think the app was good, i think it would be really useful to be able to film all text you find	Useful - Positivity
2	Was nice and fast, Was a bit small, wish the screen was bigger	Positivity, Desire for more features
3	Interesting, helpful	Useful - Positivity
4	Was fine, wish it had more options for color	Satisfied, Desire for more features
5	I liked the idea	Positivity

Is there anything you felt like was missing to make the experience better or more fun?

Participant no.	Notes and codes	Themes
1	Not really	Satisfied
2	More colors	Desire for more features
3	No	Satisfied
4	The angle/distance was not optimal, it would have been nice to also be able to change Font.	Unsatisfied, Desire for more features
5	Not that i can think of	Satisfied

Were there any buttons that were hard to find or understand?

Participant no.	Notes and codes	Themes
1	Didn't understand what buttons controlled the colors at first glance, everything else was clear	Usability issue
2	No	Satisfied
3	No	Satisfied
4	Was very clear	Positivity
5	Everything was clear	Positivity

What did you like the most about the app?

Participant no.	Notes and codes	Themes
1	That you can change the color of the text	Positivity - Personalized
2	That it was easy to change the text to my preference	Positivity - Personalized
3	The idea itself, AR was cool.	Positivity
4	That you can change the text to your own preference	Positivity - Personalized
5	Changing color	Positivity - Personalized

What did you like the least about the app?

Participant no.	Notes and codes	Themes
1	Was hard to keep focus on the text if i moved too much	Tracking - Usability
2	Didn't like the high contrast color	Negative towards alternative
3	Was a bit hard to read the text on some of the buttons, specifically the high contrast color button.	Usability issue
4	Angle of phone in regards to the text, was difficult at times. Wish it was possible to have text highlight for the TTS.	Unsatisfied, Desire for more features
5	The text-to-speech was a bit robotic and unnatural	Feature needs improvement

Did you feel like the alternatives available made it easier to read? If so, what alternatives were the most helpful?

Participant no.	Notes and codes	Themes
1	Yes, changing size of text was most useful	Positivity Useful
2	Yes, changing of letter size was the most useful	Positivity Useful
3	Yes, text size was most useful	Positivity Useful
4	Yes, TTS was the most useful	Positivity Useful
5	Yes, changing color was most useful	Positivity Useful

Were there any alternatives that you felt were not useful? If so, what alternatives were the least useful?

Participant no.	Notes and codes	Themes
1	Everything was useful, but if i had to pick one it would be word spacing.	Useful
2	I liked the alternatives but, word spacing wasn't useful to me	Useful - Personalized
3	Not really, but peach color was not useful to me	Useful - personalized
4	No, everything seemed useful	Useful
5	They all seemed useful.	Useful

Is there anything you would have changed, added or removed from the app?

Participant no.	Notes and codes	Themes
1	Would be nice to be able to to save the text you film in an archive for later reading, would also be nice with text highlighter in the TTS,	Desire for more features
2	More colors and possibility to take a picture of the text so you don't have to aim the whole time.	Desire for more customizability, Desire for more features
3	Color buttons should be a bit bigger	Usability issue
4	- Add more color options, - add text highlighter for TTS, - Make aiming of phone to the printed text easier	Desire for more customizability, Desire for more features, Tracking - unsatisfied
5	Want a dark theme for the colors	Desire for more customizability

Appendix C

Consent Form

Vil du delta i forskningsprosjektet

Effective use of Augmented Reality to Support Learning for People with Dyslexia

Dette er et spørsmål til deg om å delta i et forskningsprosjekt hvor formålet er å finne ut om det kan lages bedre teknologi som kan assistere folk med dysleksi. I dette skrivet gir vi deg informasjon om målene for prosjektet og hva deltakelse vil innebære for deg.

Formål
Formålet med dette prosjektet er å finne ut om augmented reality-teknologi kan bli brukt som et effektivt verktøy for å assistere folk med dysleksi. Forskningsprosjektet er en masteroppgave og vi prøver å finne ut hvordan læring kan bli gjort enklere for folk med dysleksi.

Hvem er ansvarlig for forskningsprosjektet?
Universitetet i Agder er ansvarlig for prosjektet.

Hvorfor får du spørsmål om å delta?
For å bedre forstå hvordan augmented reality kan hjelpe folk med dysleksi, så trenger vi hjelp av folk som faktisk har dysleksi. Ettersom du har dysleksi, så passer du inn i dette prosjektet.

Hva innebærer det for deg å delta?
Vi er interessert i at du tester vår applikasjon for å se om den er nyttig for å assistere folk med dyslexi. Vi kommer til å spørre deg spørsmål før og etter at du har testet applikasjonen og vi kommer til å filme deg under testingen av appen. Testing av applikasjonen kommer til å ta cirka 30 minutter.

Det er frivillig å delta
Det er frivillig å delta i prosjektet. Hvis du velger å delta, kan du når som helst trekke samtykket tilbake uten å oppgi noen grunn. Alle dine personopplysninger vil da bli slettet. Det vil ikke ha noen negative konsekvenser for deg hvis du ikke vil delta eller senere velger å trekke deg.

Ditt personvern – hvordan vi oppbevarer og bruker dine opplysninger
Vi vil bare bruke opplysningene om deg til formålene vi har fortalt om i dette skrivet. Vi behandler opplysningene konfidensielt og i samsvar med personvernregelverket.
De eneste som vil ha tilgang til din oppgitte informasjon er studenten som er ansvarlig for prosjektet og to veiledere som er ansatt på Universitetet.
Din informasjon blir kun lagret lokalt på studentens maskin og vil bli slettet når prosjektet er ferdig.
Alt av informasjon som du oppgir vil være anonym i den ferdige masteroppgaven.

Hva skjer med personopplysningene dine når forskningsprosjektet avsluttes?
Prosjektet vil etter planen avsluttes Desember 2023. Videoopptak vil ikke vises til noen og vil ikke vises i forskningsrapporten. Informasjonen du oppgir ellers vil være anonym.

Hva gir oss rett til å behandle personopplysninger om deg?
Vi behandler opplysninger om deg basert på ditt samtykke.

På oppdrag fra Universitetet i Agder har Sikt – Kunnskapssektorens tjenesteleverandør vurdert at behandlingen av personopplysninger i dette prosjektet er i samsvar med personvernregelverket.

Dine rettigheter
Så lenge du kan identifiseres i datamaterialet, har du rett til:

- innsyn i hvilke opplysninger vi behandler om deg, og å få utlevert en kopi av opplysningene
- å få rettet opplysninger om deg som er feil eller misvisende
- å få slettet personopplysninger om deg
- å sende klage til Datatilsynet om behandlingen av dine personopplysninger

Hvis du har spørsmål til studien, eller ønsker å vite mer om eller benytte deg av dine rettigheter, ta kontakt med: Universitetet i Agder ved masterstudent Andre Pettersen (andrep18@uia.no) eller veileder Ghislain Maurice Norbert Isabwe (maurice.isabwe@uia.no)

- Vårt personvernombud: Trond Hauso (Personvernombud@uia.no)

Hvis du har spørsmål knyttet til vurderingen som er gjort av personverntjenestene fra Sikt, kan du ta kontakt via:

- Epost: personverntjenester@sikt.no eller telefon: 73 98 40 40.

Med vennlig hilsen

Ghislain Maurice Norbert Isabwe *Andre Pettersen*
(Forsker/veileder)

Samtykkeerklæring

Jeg har mottatt og forstått informasjon om prosjektet **Effective use of Augmented Reality to Support Learning for People with Dyslexia**, og har fått anledning til å stille spørsmål. Jeg samtykker til:

- □ å delta i Intervju
- □ å delta i testing av applikasjon og bli filmet

Jeg samtykker til at mine opplysninger behandles frem til prosjektet er avsluttet

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(Signert av prosjektdeltaker, dato)

Appendix D

Text used in the app during user testing

I et fjernt hjørne av det uendelige kosmoset danser solsystemet vårt, en samling av himmellegemer som utfører en majestetisk symfoni av bevegelse og skjønnhet.

Midt i sentrum av dette spektakulære ballettstykke lyser Solen, vår stjerne, med en blendende glød som gir liv til planetene som kretser rundt den. Først ut er Merkur, den raske budbringeren, som farer gjennom rommet i et evig kappløp med sollyset. Like etter kommer Venus, skjønnheten, med sin tette atmosfære og gnistrende overflate.

Videre ut i solsystemet møter vi Jorden, vår egen hjemlige planet, med sine varierte landskap og rike biologiske mangfold. Månen, vår trofaste følgesvenn, svever i stille harmoni rundt oss og påvirker havets tidevann mens den lyser opp nattens mørke.

Mars, den røde planeten, avslører stolte fjell, dype daler og et mysterium om mulig tidligere liv. Deretter kommer asteroidebeltet, en samling av små steinlegemer som kretser mellom Mars og Jupiter, og som av og til sender reisende asteroider på en reise gjennom solsystemet.

Jupiter, kongen av planetene, er en gigantisk gasskjempe som dominerer med sin imponerende størrelse og vakre striper av skyer. De fire galileiske månene – Io, Europa, Ganymedes og Callisto – danser rundt Jupiter som lojale tjenere.

Lenger ute finner vi Saturn, kjent for sine blendende ringer som skaper en nærmest illusorisk skjønnhet. Uranus og Neptun, isgigantene, ligger enda lengre unna og byr på en mystisk blå farge og uforklarlige stormsystemer.

Appendix E

Interview guides, user tasks, and questionnaires, original Norwegian

1. Har du noen form for dysleksi?(hva er symptomene?) Når fant du ut at du hadde det eller når fikk du det diagnostisert? Hvordan påvirker det deg når det kommer til læring i skole eller jobb?

2. Har du noen nåværende måter å takle dysleksi på som for eksempel bruke teknologi eller visse teknikker. (Gjelder dette i hverdagen eller bare når det kommer til å lære nye ting?)

3. Har du prøvd noen andre metoder eller verktøy før?(hvordan fungerer de?)

4. Hva var hovedproblemene med metodene du brukte før? Hvorfor stoppet du med å bruke dem? Hva funker bra for deg, og hva funker ikke for deg?

5. La oss si at du må lære noe som er skrevet i en tekstbok eller skrevet på nett. Vil du heller ha assisterende teknologi som hjelper deg med å lese teksten bedre, eller vil du heller ha en teknologi som lar deg unngå å lese i det hele tatt?

6. Hvis du hadde muligheten til å bruke mobilen din til å assistere deg med å lese, hva slags funksjoner vil du at mobilen eller appen skal ha? Hva er de viktigste oppgavene eller tingene du ønsker å kunne gjøre?

7. Har du noen anbefalinger eller innspill angående hjelpemidler for personer med dysleksi?

Figure E.1: Preliminary interview

Før test intervju:

- Hvor gammel er du?
- Hva er kjønnet ditt?
- Hvor lenge har du vist at du har dysleksi og hvordan påvirker det deg med tanke på lesing?
- Hva slags utfordringer er det du for det meste møter?
- Fra en skala fra 1-5 hvor mye føler du at din hverdag blir påvirket av dyslexi?
- Omtrent hvor mye tid bruker du på mobilen hver dag?
- Fra en skala fra 1-5 hvor erfaren er du på å bruke mobil?
- I en skala fra 1-5, i hvor stor grad føler du at mobilen hjelper deg med lesevansker?
- Har du prøvd dysleksi-assisterende verktøy før? Hvis ja, hvor mange?
- Hvordan fungerte verktøyene du har prøvd, var det noe du følte fungerte og noe du følte ikke fungerte?

Figure E.2: Pre-test interview

- Les teksten på papiret, du trenger ikke lese høyt
- Film QR koden med mobilen slik at du får et digitalt papir på mobilen.
- Øk linjeavstanden og deretter senk linjeavstanden.
- Øk ordavstand og deretter senk ord avstanden.
- Endre farge på bakgrunnen.
- Velg den fargen du føler gjør det lettest å lese
- Velg ordavstand, linjeavstand og tekststørrelse til det du føler er lettest å lese.
- Les hele teksten igjen med de nye endringene du har gjort.
- Slå på tekst-til-tale og les sammen med teksten.

Figure E.3: user tasks

- Du leste teksten 3 ganger, hvilken metode var enklest, og hvilken var vanskeligst?
- Hvordan føltes det å kunne gjøre endringer på teksten på mobilen?
- Er det noe du savnet for å kunne gjøre opplevelsen bedre eller gøyere?
- Var det noen knapper som var vanskelig å finne eller trykke på? Isåfall hvilke?
- Hva likte du mest med appen?
- Hva likte du minst med appen?
- Følte du at alternativene i appen gjorde det lettere å lese? Isåfall, hvilke alternativer hjalp mest?
- Var det noen alternativer du følte ikke var nyttige? Isåfall, hvilke alternativer var minst nyttige?
- Er det noe du ville ha endret, fjernet eller lagt til i appen?

Figure E.4: Post-test interview

Jeg likte denne appen

Helt uenig | Helt enig

1	2	3	4	5

Jeg tror jeg ville brukt denne appen ofte

Helt uenig | Helt enig

1	2	3	4	5

Jeg synes appen var lett å bruke

Helt uenig | Helt enig

1	2	3	4	5

Jeg følte meg selvsikker når jeg brukte appen

Helt uenig | Helt enig

1	2	3	4	5

Jeg tror at denne appen kan være nyttig for dysletikere

Helt uenig | Helt enig

1	2	3	4	5

Jeg kan tenke meg at de fleste ville lære å bruke denne appen veldig raskt

Helt uenig | Helt enig

1	2	3	4	5

Hvordan opplevde du det å bruke appen? Merk kun én rute på hver linje.

	1	2	3	4	5	6	7	
Uforståelig								Forståelig
Lett å lære								Vanskelig å lære
Kjedelig								Spennende
Uinteressant								Interessant
Hindrende								Støttende
Motiverende								Demotiverende
Tydelig								Forvirrende
Upraktisk								Praktisk
Oppfyller forventningene								Oppfyller ikke forventningene
Verdifull								Verdiløst