User Centred Design for adolescents with Cerebral Palsy

Designing an eye controlled software to enhance mathematical activities

ANVÄNDARCENTRERAD DESIGN FÖR UNGDOMAR MED CEREBRAL PARES

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Abstract

This study aims to find an answer to what prerequisites that needs to be taken into consideration when designing an eye controlled software for mathematical activities carried out by children that suffers from cerebral palsy. A user centred study was conducted at three habilitation centres around Stockholm. This resulted in a high-fi prototype for columnar calculation, in which findings from the study were incorporated.

These findings included the need to be able to adjust colour, size and shape of interface elements, as the target group suffered from visual impairments. The interface should have a simple and clean design, as too appealing elements may draw the attention away from the task. Furthermore, it shouldn’t be too childish, despite the fact that the software covers basic mathematics.

The tasks should have various kinds of representation, such as read-out instructions and visualizations. It is also theorized that by designing the interface to have non-selectable elements, the user doesn’t need worry about clicking on buttons that affects the interface. Thus, the focus can be on solving the task. The user should be encourage to solve tasks by getting feedback when a task is solved. This feedback should only be given once per task, and should be customizable and optional.
Referat

Användarcentrerad design för ungdomar med Cerebral Pares

Den här studien syftar till att svara på frågan hur fysiska och kognitiva förutsättningar ska beaktas när ett ögonstyrt matematikhjälpmedel för barn och ungdomar med cerebral pares designas. En användarcentrerad designprocess vid tre habiliteringscenter genomfördes. Detta resulterade i en high-fi prototyp för matematiska uppställningar, i vilken aspekter från studiens resultat var integrerade.

Dessa resultat innefattade ett behov att kunna ändra färger, former och storlek på grafiska element i gränssnittet. Detta eftersom många av användarna har cerebra synnedsättningar (cv1) och är exempelvis känsliga för vissa kontraster. Gränssnittet ska även ha en enkel och ren design, eftersom för tilltalande element kan leda till att de riktar sin uppmärksamhet på dessa, istället för att intressera sig för uppgiften.

Programmet ska också stödja olika typer av representationer av uppgiften, så som visualiseringar och uppläsning. Detta förenklar processen att förstå vad som förväntas utföras. Det argumenteras också för fördelarna med ett gränssnitt där stora delar av vyn inte är klickbar. I och med detta så kan användaren vila blicken och få en uppfattning om var denne befinner sig, utan att behöva oroa sig för att räka klicka på en knapp och därigenom göra förändringar i gränssnittet.

Användaren ska uppmuntras till att lösa uppgiften genom att få feedback. Denna återkoppling ska bara ske en gång per uppgift och vara anpassningsbar och valbar.
Preface

One of the key ideas with user centred design is the iterative process. The same is true when writing the report for master thesis. I would therefore like to thank my supervisor at KTH, Åke Walldius, for his guidance and continuous feedback on the report.

I also had the privilege to have Magnus Magnusson from SU as supervisor. Magnus has years of experience in the field of AAC, and have pointed me to relevant literature and given valuable input when needed.

There are several people at Tobii Technology who have made this work possible, especially Uli Ehlert (supervisor) and Markus Cederlund (administrative supervisor). A special thank is directed to Pawel Wesolowski and Ole Alexander Mæhle at Tobii Norway, for their hospitality and competence.

Oskar Wyke, my co-worker on this project, has been an asset throughout the entire thesis work. We have bounced ideas, created prototypes and collected feedback. Together we formed a creative process that I believe is difficult to recreate alone.

Lastly, I would like to extend my sincere gratitude to the children and teenagers who made the effort to be involved in the design process. They, together with teachers, families and speech therapists have formed an invaluable source of information.
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Glossary and Abbreviations

**AAC Augmentative and Alternative Communication**, a field of research, clinical and educational practice that aim to study and compensate for temporary or permanent impairments for people with severe disorders of speech-language production and/or comprehension.

**AAC aid** A device, either electronic or non-electronic, that is used to transmit or receive messages.

**Acquired disability** is an ongoing or permanent condition a person has received as a result of illness or accident.

**CP Cerebral Palsy** is a developmental disability that affects posture and movements.

**CVI Cerebral Visual Impairment**, a condition where some of the special ’vision’ parts of the brain and its connections are damaged. This causes visual impairment even though the eyes are normal.

**Developmental disability** is a lifelong disabilities attributable to mental and/or physical impairments.

**Eye control** The technique to interact with an interface by using the gaze.

**HCI Human-Computer Interaction** is the study of how people interact with computers and to what extent computers are or are not developed for successful interaction with human beings.

**Hjälpmedelscentralen** A national institute in Sweden that facilitates people with disabilities.

**Skolverket** The Swedish education administration.

**Vetenskapsrådet** The Swedish Research Council is a governmental agency that supports scientific research.
Chapter 1

Introduction

It has been estimated that approximately 1.3% of all individuals have such severe communication disabilities that they are not able to rely on their natural speech to meet their daily need for communications (Beukelman and Mirenda, 2005, p.3). There is a wide range of Augmentative and Alternative Communication (AAC) resources to aid this group of people.

Tobii Technology produces a series of AAC aids with a multi-modal interface, including eye tracking, touch screen and stand alone switch button. They are designed for two different target groups; people who are suffering from either developmental or acquired disabilities. Developmental disabilities are life long impairments that are present from birth, such as cerebral palsy (CP), autism and Rett Syndrome. Acquired disabilities are either a permanent or ongoing condition that affects the health condition, such as amyotrophic lateral sclerosis (ALS) and stroke.

These two groups of people have fundamentally different prerequisites for AAC aided communication, as well as different experiences in terms of perception of the real world. For example, a child with severe developmental disorders, who has used a AAC aid all his life, has very limited experience in conducting unaided communication. On the other hand, someone with an acquired disease could live a normal life for decades before falling ill.

It is a delicate matter to develop software for either of these target groups, as there are many aspects to consider.

1.1 The Problem

Up until now, there has been very limited support in Tobii AAC aids for communicating mathematics and creating mental models of mathematical concepts. The goal with this thesis is to present a strong foundation, based on scientific research and empirical studies, for a math tool that meets some of the needs in today’s AAC aided education. A prototype was based upon the findings.

Why is there a need to develop a specific application for mathematics? First off, the interaction that takes place when working with mathematics can be considered
a special case of communication. The extensive use of symbols for representing quantities, operations and complex relationships creates an entire subset of communication conventions. It has been argued that “[mathematics] has its unique culture that is distinctively different from ‘everyday ways’ of doing things” (Kinard and Kozulin, 2008, p. 2). The work flow and order in which mathematics is written – usually different from the sequential left-to-right writing – makes the situation even more complex.

Since there are no sufficient tools for this type of activities, the user is limited to keep a lot of information in the memory while working with a mathematical task. This can be compared with solving a quadratic equation \((ax^2 + bx + c = 0)\) without jotting anything down in a notepad.

The mathematical symbols are used to conduct what could be considered an internal dialogue to manipulate (solve) mathematical problems. In an educational situation, the teacher needs to see how well the student performs in order to give formative feedback and assess mathematical skills. This argues for the need of information transfer in the classroom.

A user centred methodology was applied, in order to (i) understand the need for a mathematics tool and (ii) validate the usefulness of the prototype.

### 1.1.1 Scope and limitation

The research will focus on children and teenagers that suffer from CP and use Tobii eye trackers as an AAC tool. This limits the literature study on disabilities to only include cognitive and physical aspects of this specific impairment.

The focus of the research is on understanding the user situation and how to enhance it. There is no demand that the prototype will be a totally bug free “final product”.

### 1.1.2 Research question

It is not a straightforward task to develop a math software for adolescents with CP. Thus, the following research question was investigated:

**What prerequisites must be considered when designing mathematical software for adolescents with cerebral palsy who rely on Tobii assistive eye tracking as a communication device?**

The cognitive abilities puts restraints on the mathematical scope, as well as how it is presented. Therefore, the study will also briefly discuss design aspects of the software as well as content.

### 1.1.3 Frame of reference

This thesis is built up on three pillars, namely
CHAPTER 1. INTRODUCTION

- HCI methodology and theory
- the framework provided by AAC
- research on physical and cognitive limitation in children with cerebral palsy

In addition to this, mathematical concept formation will be presented.

1.2 Related research

This thesis is a result of a study carried out by the author and Oskar Wyke. Many of the activities were planned and conducted together by the researchers, such as usability evaluation at the habilitation centres and development of prototypes.

1.2.1 Research questions

The aim of Oskar Wyke’s report is to find answers to the following research questions

**What particular design choices are to be considered when creating a learning tool for the specific user group, young people with Cerebral Palsy?**

**What methods of user inclusion and iterative testing are available and useful in the process of evaluating usability and accessibility of the tool, used by the specific user group?**

1.3 Thesis disposition

The thesis has elements of theoretical as well as empirical research, as described below.

**Background**  In this chapter, the reader gets introduced to AAC and its history, as well as a overview of CP and the fundamental ideas with HCI and user centred design. Basic facts about eye trackers, eye control and the company Tobii Technology is also presented here.

**Theory**  This chapter covers previous research on consequential impairments in children with CP and in what ways this effects development processes. Furthermore, limitations for eye trackers as an AAC device and design guidelines for eye controlled interfaces are discussed.

**Empirical study**  In this chapter, the methods and finding from the user centred empirical study is presented. For each iteration, the method is presented followed by how it was implemented and the outcome from it. There are sections that address difficulties with the approach, ethical reflections and critical analysis of methods used.
CHAPTER 1. INTRODUCTION

**Result**  The results from the empirical study is presented here. It answers the research question by comparing previous research with the empirical study.

**Discussion**  The discussion summarizes the thoughts of the study and its’ outcome.

**Recommendations**  The study opened up for further topics to be investigated. They are presented in this section.
Chapter 2

Background

2.1 What is AAC?

The American Speech-Language-Hearing Association (ASHA) defined AAC as:

 [...] an area of research, clinical, and educational practice. AAC involves attempts to study and when necessary compensate for temporary or permanent impairments, activity limitations, and participation restrictions of individuals with severe disorders of speech-language production and/or comprehension, including spoken and written modes of communication. (American Speech-Language-Hearing Association, 2005, p. 1)

Taking a closer look at the quotation above, it becomes evident that this field covers several aspects of communication. It is important to stress that AAC is not solely a field in which people with communication impairments gets facilitated. On the contrary, almost everybody uses some sort of support to their spoken language. Unaided AAC (sometimes called natural AAC or non-verbal AAC), includes body language, gestures, facial expressions and gaze (Heister Trygg, 1998, p. 25). The symbols can either be used to emphasize the message, replace spoken communication or show emotional state (Beukelman and Mirenda, 2005, p. 39ff).

Aided AAC uses some form of external device to receive or transmit the message (Beukelman and Mirenda, 2005, p. 4). Strictly speaking, a pencil can be considered an AAC aid. However, it is more common to refer to technologies – either high-tech or low-tech – that enhance communication for people with some sort of impairment.

ASHA has also defined four primary components of AAC: symbols, aids, strategies and techniques. Below follows an interpretation of these components, as described by Beukelman and Mirenda (2005, p. 4):

Symbol is an alternative representation for a message. A traffic light beaming red is a symbol for stopping the car.
CHAPTER 2. BACKGROUND

Aid refers to any device that may be used to transmit the message (or symbol). Tobii’s eye tracker is an example of an AAC aid.

Technique is how the message is selected from the aid. In the example of eye tracking, it typically is by directing the gaze toward a desired symbol/message.

Strategy is the overall ability to conduct efficient communication. If the AAC user is able to both spell words to create sentences, and also to adequately use symbols and thereby express the same sentence, the latter is a more efficient strategy. Of course in different situations, different strategies are more efficient.

Heister Trygg (1998) presented another system for describing AAC; the BRO model (Swedish acronym, Brukare-Redskap-Omgivning). In this model, the user, the aid and the surrounding world are seen as separate entities. For the purpose of this thesis, the BRO framework is discarded in favour for ASHA’s.

2.2 A historical overview of AAC

There are evidences that suggest that deaf individuals in the Roman empire used an early form of sign language to communicate (Zangari, 1994, p. 29). This is one of the earliest AAC finding. As modern society evolved, so did the medical advances. More children with developmental disabilities survived infancy, and at the same time people in general lived longer. This resulted in a larger population with developmental and acquired disabilities.

2.2.1 The 70s

Different political factors influenced the field of AAC in the 70s. UN issued the Declaration of General and Special Rights of the Mentally Handicapped, ”emphasizing the universal rights of these individuals to educational services that would allow them to develop to their fullest potential” (Zangari, 1994, p. 32).

Different symbol systems was developed, including the very important Bliss system, that is still used today (see figure 2.1). Numerous studies have shown that Bliss is the least transparent and most difficult system to use. Nevertheless, it is widely used because

• the symbols can be combined in a way that allows the user to express thought not present on the communication board. For example, the word for galaxy can be created by symbols for many stars and planets.

• the system can be introduced in a simple way, and then expanded as the user gains experience.

• Bliss can be combined with other symbols, including written language.
CHAPTER 2. BACKGROUND

(Beukelman and Mirenda, 2005, p. 59)

Figure 2.1: "I will come to your house". An example of Bliss Symbols (www.blissymbolics.us)

At the same time, AAC aids based on microcomputers were introduced to the market (Zangari, 1994, p. 34). These aids grew more complex as the technological area advanced. Worth noting about the 1970s is that the first gaze boards were developed at this time. A gaze board is a low-tech, transparent board that the communication partner holds in front of the disabled person. The communication partner then follows the gaze of the user, as it looks in one of the nine cardinal directions. A symbol is typically selected in two steps; first by indicating a color, then to select a cluster of symbols. In all the clusters, there are uniquely color coded symbols that correspond to the color selected in the first step (Beukelman and Mirenda, 2005, p. 74). In some ways, this can be considered the predecessor to the AAC aid eye tracker.

In the late 70s, technological advances in eye tracking recording systems made the gaze data more accurate and easy to obtain (Rayner, 1978).

2.2.2 The 80s

The International Society for Augmentative and Alternative Communication (IS AAC) was founded in 1983. With over 2500 members in 50 different countries, the organisation is a major force in AAC (ISAAC, 2011).

Further advances in the technology during the 80s made high-tech AAC aids more sophisticated. The enhanced speech synthesis and improved graphic capabilities opened up for further development. Thus, all the pieces to construct a device based on remote eye tracking were at place.

2.3 Tobii Technology and Eye tracking

Tobii Technology (here on called Tobii) is a Swedish company, established 2001 by three former students from KTH (Tobii, 2011). The business idea was originally to sell eye tracking systems that monitored and recorded the users gaze point. Tobii is today a widely recognized eye tracker provider with two major business areas; Analytic Application and Assistive Technology.
2.3.1 Tobii Analytic Applications

In Analytic Applications, eye trackers are designed to record the gaze of the participant. This technique is useful in several different applications, such as assessing patients in eye hospitals, conducting usability tests for commercial products and researching cognitive developments in infants.

2.3.2 Tobii Assistive Technology

Assistive Technology is the department that work with AAC aids. The ambition is to facilitate a broad spectrum of people with communication impairments. Up to date, all the high-tech AAC aids have support for different input methods. The model P10, as well as the newer C-Series, has touch screen and USB ports that allow external input method like mouse, keyboard, joystick and switch. All but one high-tech device has support to mount an eye tracker to it. This is an optional extension to the AAC aid. Tobii does also produce low-tech AAC aids like S32, a playback device that is activated by pressing symbols on its board.

Figure 2.2: C15, a Tobii AAC aid. The eye tracking unit sits under the screen. Courtesy of Tobii Technology.

2.3.3 Existing communication software

There are different software that can be used with Tobii AAC eye trackers. Below is a list of the most common ones.

Mind Express Mind express is a software developed by RehabCenter AB. It has grammatical functions and support for several different symbols, including Bliss. Symbols can be structured in sub-sets. These subset can be arrange to make it easier for the user to find the right words.

Tobii Communicator Tobii Communicator (here on called Communicator) is a platform that allows several types of communication. In addition to be able to form and read sentences, it also allows the user to send emails, make phone calls, using instant messengers such as MSN and even access the community Facebook. It can
be extended by symbol systems for a wide range of users with different cognitive and developmental impairments.

There are also games available, that can be used for leisure or to help the user get familiar with the AAC device. Some of the games challenge the users’ intelligence and help to develop analytic processes.

The user interacts with the software by pressing on buttons. Here, ”buttons”, is used in a wide sense and include message windows, components of the games and normal buttons.

Conceptually speaking, there are two different modes in the software; the Run view and the Edit view. In Edit view, pages can be created and manipulated. The size, shape, background- and text colour can be change to fit the user’s need. This view is typically used by parents, speech therapists or other persons that work in the team surrounding a disabled person. The pages can be clustered into page sets, which is a collection of pages.

In run view, the user can interact with the software. The user manipulates the interface by pushing buttons, which either executes an navigation to another page, or updates the graphical components on the current page.

**Tobii Windows Control** Tobii Windows Control is, strictly speaking, not a communication software. It allows the user to navigate in Microsoft Windows environment.

Moving the cursor and execute different types of clicks is a cognitive exhaustive task, why it’s not suitable for all AAC users.

### 2.3.4 Eye tracking and eye control

Eye tracking is a common term for a broad section of techniques to record gaze data (Duchowski, 2007, p. 53). Tobii eye trackers are Video-OculoGraphy systems, meaning that video cameras are used to record gaze movements. Three of the important components in the system are

- Near Infra Red illuminators, positioned under the screen and directed at the eyes. Human eyes does not detect high frequencies electro magnetic waves, why the participant does not notice the illuminating of the eyes.

- Video cameras, that record the eye’s position.

- A main board, where the calculations are made. The calculations are based on the position of the pupil as well as a reflected reference glint on the eye (the Purkinje reflection).

There are several ways to describe the performance of an eye tracker system. Sample frequency is a measure on how many images that are taken every second, the accuracy is a measuring on the offset between recorded gaze target and actual gaze target and the precision is a quantification of the variance of the gaze data.
CHAPTER 2. BACKGROUND

The term "eye tracking" is used for the technique that records the gaze of the user. "Eye control" refers to the method of using gaze as to interact with the system. This technology is used as primary input for many of the AAC users, but also as a complementary access method to the normal input devices, such as keyboard and mouse.

2.4 Cerebral Palsy – An overview

Cerebral Palsy (CP) is an umbrella term for neurodevelopmental condition (Bax et al., 2005, p. 572). It is considered to be one of the most common causes of physical impairments for children (Shevell, 2009, p. 872). A usual approximation is that 0.1% – 0.3% of all children are diagnosed with CP (Morris, 2007; Woods, 1969).

Over the years, the definition of the condition has varied. Morris (2007) summarized the almost 170 year long development of the term, starting at the early 1840’s when William Little gave a series of lectures on joint contraction and spasm. He clearly indicated that the observed spastic behaviour and paralysis were caused by damage in the brain, usually from pre term birth. Little also stated that the behavioural disorders and epilepsy observed in these people was not central to the diagnosis, instead this should be seen as occasional complications. Though several people were involved in this research area, CP was for many years known as Little’s Disease.

In the 1920s, Winthrop Phelps proposed a classification system for CP, based on both physical and mental abilities. The system had five subcategories; spasticity (non-volunteer tightness in the muscles), athetosis (continuous stream of slow writhing movements), synkinesia (non-volunteer movements coincided with volunteer movements), ataxia (lack of coordination) and tremor (non-volunteer muscle contractions). The overall aim with the classification system was to be able to suggest treatments to improve the locomotion, posture, self-help and general appearance of the patient (Morris, 2007, p. 4).

The group for the Surveillance of Cerebral Palsy in Europe (SCPE) based their definition on clinical features. The three subgroups are spastic-, ataxic- and dyskinetic CP. The two former similar to what Phelps proposed, the latter one defined as "involuntary, uncontrolled, recurring, occasionally stereotyped movements of affected body parts" (SCPE, 2011). SCPE has also proposed that a person must be at least four years old to be diagnosed with CP.

There is still no universal definition of CP. This can be exemplified by looking at articles from present time. In a recent paper, Shevell (2009) argued for an assessment of CP based on The Gross Motor Function Classification System. Rosenbaum et al. (2010) opposed this, and replied "We are most concerned if, as is suggested, type of cerebral palsy (CP) and limb distribution are going to be used by professionals as a basis for counseling individual families on the functional prognosis of their child with CP" (Rosenbaum et al., 2010, p. 1).

An easy-to-grasp, broad and widely cited definition of CP is the one of Bax:
CHAPTER 2. BACKGROUND

Cerebral palsy (cp) describes a group of disorders of the development of movement and posture, causing activity limitation, that are attributed to non-progressive disturbances that occurred in the developing fetal or infant brain. The motor disorders of cerebral palsy are often accompanied by disturbances of sensation, cognition, communication, perception, and/or behaviour, and/or by a seizure disorder. (Bax et al., 2005, p. 572)

2.5 Human-Computer Interaction

Human-Computer Interaction (HCI) is a discipline that is concerned with designing, evaluating and implementing interactive systems (ACM, 1992, p. 5). It includes all the important aspects for interaction between human and computer (Gullielsen and Göransson, 2002, p. 39), and should therefore always be considered when designing a system for humans.

2.5.1 User Centred Design

The most important aspect when working with HCI is the user(s). To give extensive attention to the user’s needs, wants and limitations in a design process is called User Centred Design. It has been stated that in order to achieve usability, a user centred approach is a necessity (Benyon, 2010, p. 84). Rubin and Chisnell (2008) summarized the basic ideas of this design philosophy as

- Early focus on users and their tasks
- Evaluation and measurement of product usage
- Iterative design

(Rubin and Chisnell, 2008, p. 13)

The last step – iterative design – is in itself user centred and consists of four steps:

Analysis of the end user, tasks and actions related to the activity that is aimed to be improved, and the context in which the activity is carried out.

Design proposal with prototyping. Developing a prototype is in itself a iterative process that describes the creative nature of the work.

Evaluation of the prototype. Usually, the prototype is tested against pre-defined usability goals.

Feedback with suggestions on how to improve the system. This is the final step before starting a new iteration.

(Gullielsen and Göransson, 2002, p. 109)
CHAPTER 2. BACKGROUND

2.5.2 Usability and Accessibility

There is no way to summarize good design in a simply way. However, “friction free” interaction and easy-to-learn/easy-to-use are indicators of a usefulness that is associated with carefully planed design. These aspects are part of the product’s usability, which is the quality of interaction in terms of parameters such as time required to perform task, error rate during interaction and learnability (Benyon, 2010, p. 80). ISO 9241–1 is a standards that describes usability as “the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use” (Gulliksen and Göransson, 2002, s. 55). Hence, usability depends on several factors, including where the product is to be used, who the intended end user is and what task that should be carried out.

In order to reach usability for a certain target group, they need to be able to interact with the system. This aspect, called accessibility, has been legislated to make sure that everyone can access information that is a spread via software technologies (Benyon, 2010, p. 80).

2.5.3 Methods

There are several different ways to collect user feedback. It can either be related to a prototype evaluation or getting an overview about the users, their context and activities. The literature on methods available is overwhelming. Gulliksen and Göransson (2002) points out that it is important to focus on the entire process when deciding on what methods to use. That is, to have an idea of what is important in a certain state in the development process and then find a suiting method that fits the purposes, needs and budget as well as the user group. Evaluation methods does either have direct or indirect user participation (Benyon, 2010; Gulliksen and Göransson, 2002).

**Direct user participation**  This group of methods involves the intended end users in a direct way. It can be some sort of contextual study, such as contextual inquiry, were the user is observed in the context of which the intended task is carried out. Focus groups, where several participants discuss the task at hand, is a way to create an climate of creative thinking and synergy effects.

There are also evaluation methods that is non-contextual, for example lab tests. The greatest disadvantage with the latter type is that the users’ behaviour may be affected as the tasks are not performed in the “real” environment. It is, furthermore, a time consuming and usually expensive process which may involve special equipment (Gulliksen and Göransson, 2002, p. 261).

One well-known evaluation method, think aloud, is a widely used qualitative method where the participant expresses thoughts while performing pre-defined tasks. There are also quantitative methods, where data is collected in order to assess how it affects the usability (Gulliksen and Göransson, 2002, p 256).
CHAPTER 2. BACKGROUND

**Indirect user participation** Many of the indirect user participation methods has in common that they are faster to conduct and less expensive than involving users directly. The trade-off is that they do not give information about all the usability problems (Gulliksen and Göransson, 2002, p 259).

*Personas*, which can be explained as a fictive user of the system with specific characteristics, is a way to work with participants in mind, even though no real user is involved (Benyon, 2010, p. 57). Other methods that can be classified as indirect are the use of documents, like style sheets, guidelines and check lists that is created to make the interface easier to grasp.

Usability experts are persons with long experience of working in the field of HCI. They can conduct inspection-based evaluation, were they look at a product/prototype and assess it based on their knowledge about the users and usability (Gulliksen and Göransson, 2002, p. 257). Usually, a set of *heuristics* can be used as guidelines. In an ideal scenario, several experts should review the system individual and then combine their results (Benyon, 2010, p. 229). Jakob Nielsen pioneered in this field, and created together with his colleagues a list of the ten original heuristics (Preece et al., 2002, p. 686). They are

- **Visibility of the system.** The user should always get information about what is going on.
- **In accordance with the real world.** The system should present information in a way that is familiar to the user.
- **User freedom.** The user should be able to navigate and redo choices.
- **Consistency and standards.** The product should have a consistency in its’ behaviour as well as language. It is therefore important that one function or item does not has different names. If the product is a part of a bigger platform, the platform’s conversions should also be taken into consideration.
- **Error prevention.** Design the system in a way that errors occurs as seldom as possible.
- **Recognize rather than recall.** To minimize the cognitive load, the user should have all valuable information present at all time so that there is no need to remember certain information from other parts of the product.
- **Flexibility.** Allow the user to navigate in the software in different ways. An expert user of the system should be able to take short cuts.
- **Minimalistic design.** The product should not contain information that is unnecessary for the user.
- **Help user upon error.** Error messages should be polite and explain in plain language what the problem is, and if possible also suggest solutions.
CHAPTER 2. BACKGROUND

- *Help and documentation.* It is desirable if the product can be used without an manual. Documentation is however often necessary. The information should then be easy to access and list concrete steps to aid the user.

(Preece et al., 2002, p. 687)

It is always useful to have these aspects in mind when designing a system.

### 2.5.4 Using prototypes

A prototype can be thought of as a concrete, but partial representation or implementation of a system design (Benyon, 2010, p 184). It is used to communicate design decisions made within the design team or during a user evaluation. By their very nature, prototypes have compromises. This is an intentional decision from the designer, in order to make the tester focus on the right things. Prototypes can be arranged and categorized in different ways.

**Low-fi/high-fi** Early prototypes do usually not look like the final product. A computer screen can for example be imitated on paper or cardboard. These *low-fi prototypes* can be modified easily, which makes it easy to explore alternative designs and ideas (Preece et al., 2002, p. 531). Users who, for example, evaluate a homepage on a hand-made paper prototype, will likely not comment on the exact shape and size of things. This approach is thus good when evaluating work flows.

High-fi prototypes is on the other hand made in the same material as the final product would be expected to be built in. This type of prototypes should be used when the designer has enough information from the users to do so. Reviewers tends to comment on superficial aspects, instead on the content (Preece et al., 2002, p. 535), which of course is fine if the content and its’ work flow has been evaluated in previous iterations.

There are other things to take into consideration before developing a high-fi prototype, namely

- It is a time consuming process.
- One bug in the system may halt the entire testing.
- Software developers are reluctant to change things that they have spent hours to create.

(Preece et al., 2002, p. 535)

**Prototypes according to RUP** Rational Unified Process (RUP) is a system development process that is widely used for commercial products. In RUP, prototypes are classified according to what purpose they serve:

- *Behavioural prototypes:* used to test a certain type of system behaviour.
CHAPTER 2. BACKGROUND

- *Structural prototypes*: used to explore an entire system architecture.
- *Exploratory prototypes*: used to evaluate in order to save or dismiss ideas.
- *Evolutionary prototypes*: used to build the final product by incremental design.

(Gulliksen and Göransson, 2002, p. 189)
Chapter 3

Theory

3.1 Consequential impairments in children with Cerebral Palsy

3.1.1 Visual, hearing and language related impairments

As discussed previously, CP is a brain disorder that affects posture and movements. However, it is very common that a person suffering from CP has other related diseases and should be considered multi handicapped (Woods, 1969, p. 28). Depending on the location of brain damage and the severity of it, the disorders can express themselves in various ways. It is not uncommon that hearing, speech or language comprehension is affected. Typically, the hearing impairment affects the perception of high frequent sounds, making it hard to distinguish high frequency consonant sounds (Woods, 1969, p. 28).

It is also common to people with CP suffer from Cerebral Visual Impairments (CVI), a condition where the perception of vision is compromised due to impairments in the cerebrum (Boot et al., 2010). This condition can affect different perceptual functions, including visual acuity, colour vision and contrast sensitivity, the perception of movement, visual memory and visual imagination (Dutton, 2002, p. 114). To fully grasp this situation, Woods (1969) is quoted:

Some cerebral palsied children do not find it easy to appreciate space or distance. When coming into a room the child may not sense immediately that one piece of furniture is nearer than another. He may not understand pictures and find it difficult to translate the three dimensions of ordinary life into the two dimensions of pictures.

(Woods, 1969, p. 30)

3.1.2 Implications for the development processes

These impairments have other implications on the development in the early years. Haskell (2000) noted that "[m]any children with cerebral palsy are deprived of op-
opportunities to physically explore their environment and several suffer an abnormal reduction of crucial preschool experiences” (Haskell, 2000, p. 81).

There are also external aspects to consider. People interacting with children that suffer from speech impairments, tends to ask yes or no questions, as well as give rewards in form of verbal feedback despite performance. According to the theory of learned helplessness, these free rewards steams from low expectations on the impaired person to ask or make comments on anything. Instead, the people tend to satisfy all needs without regards to the activity from the child. This may lead to depression and inability to initiate communication, which may also hamper the linguistic development (Basil, 1992, p. 189).

3.2 Mathematical concept formation

3.2.1 Cognitive technologies

What is intelligence and what role does it play when creating mathematical concept formations? Schoenfeld (1987) has given the following answer to the first part of that question;

I take as axiomatic that intelligence is not a quality of the mind alone, but a product of the relation between mental structures and the tools of the intellect provided by the culture. Let us call these tools cognitive technologies.

(Schoenfeld, 1987, p. 91)

This position is in harmony with the ideas of a sociocultural theories. It can be argued that the culture of a society consists of material and immaterial tools – artefacts – that closely interplay with each other (Säljö, 2005, p. 29). These tools work as cultural amplifiers, a mean for empowering the human cognitive capacity (Schoenfeld, 1987, p. 92).

In the history of mathematics, several cognitive technologies have been refined throughout the years. For example, the notion of numbers used today – with its position system that allows decimals – is the result of a cultural evolving from the old Egypt. Looking at more concrete concepts, it becomes obvious that a paper, where calculations can be stored and revisited, has qualities that chalks and boards lack.

A common feature with cognitive technologies is that they externalize the intermediate products of thinking, like writing down all the steps when solving an equation (Schoenfeld, 1987, p. 91). This aspect also makes it easier for teacher to understand the chain of thought, as it reveals part of the thinking process.

There are several cognitive technologies for mastering mathematical concepts. However, many of these, such as a calculator, require precise hand movements and high cognitive abilities.
3.2.2 Mathematical difficulties in children with cerebral palsy

**Arithmetical problems**  As discussed previously, a person with CP usually suffers from additional disorders. Several studies have shown that it is very common to experience arithmetical problems in children with CP (Arp et al., 2006; Haskell, 2000; Jenks et al., 2009). These problems include simple addition and subtraction (Arp et al., 2006, p. 406), and is usually related to visual or hearing impairments, epilepsy and intellectual disabilities (Jenks et al., 2009, p. 529).

**Working memory deficiency**  It has been reported that children with CP have deficits in working memory (Jenks et al., 2007, p. 864). The working memory plays an important role when accessing the long term memory when conducting arithmetical calculations.

In a recent study, it was shown that person with CP performed below average when testing the following aspects of working memory

- *Visual spatial sketch pad*, the part of the working memory that handles visual-spatial information
- *Phonological loop*, the part of the working memory that handles temporary storage of phonological information.
- *Central executive*, the controlling unit in working memory.

(Jenks et al., 2007, p. 872)

**Absence of physical counting**  Small children are known to use their fingers to point on each element when counting them. It is argued to be an important phase before they internalize that knowledge, and thus are able to use only visual counting (Arp et al., 2006, p. 406). It was shown that this form of active manipulation may not be essential for concept formation, but it may be important in order to avoid delays in quantity conservation formation (Lister and Juniper, 1995, p. 9).

There is also a correlation between eye-hand coordination and *subitizing* (Arp et al., 2006, p. 405). Subitizing is the ability to accurately assess a smaller quantity without counting. In the study conducted by Arp et al. (2006), it was shown that children with CP performed worse in subitizing tasks, compared to the control group.

Thus, a person who is unable to coordinate arm-hand movements, or is suffering from CVI, are likely to have problems with mathematics.

3.3 Limitations for Eye trackers as AAC aid

3.3.1 Calibration related limitations

The most important variable for successful eye controlling is a precise calibration, covering the extents of the viewing area (Duchowski, 2007, p. 134). Tobii eye trackers can be calibrated with two-, five- or nine calibration points; in general more
CHAPTER 3. THEORY

calibration points gives a more accurate eye controlling experience. During the calibration procedure, a circle with a small, black circle in the center, is presented at the first calibration positions. When gaze data is collected at one position, the circles makes a smooth movement to the next calibration point.

**Problems getting sufficient gaze data** Persons with CP sometimes have short attention span, problem with vision (CVI) and suffers from involuntary movements. This can complicate the calibration procedure, as not enough gaze data may be obtained.

Even if the system has enough data to adjust the calibration for the particular person, the data can be of shifting quality, making eye control difficult or cumbersome, as the user might for example needs to compensate a calibrated offset.

**Calibration drifts over time** The eyes are continuously changing as a person gets older. Therefore, it is important be observant if the accuracy of eye controlling drops. It is also stated the some eye trackers lose the calibration over time (Zhang et al., 2004, p. 86).

**Calibration deviation** It is common that eye tracking equipment has a deviation in accuracy at the edges of the screen (Zhang et al., 2004, p. 86). Thus, targets (buttons) may be more difficult to press if they are positioned at the fringes of the screen.

### 3.3.2 External limitations

**Limited mobility** Eye trackers do typically have a limited region where the gaze can be registered. This is a potential problem for persons with spasms, as they may make involuntary movements while eye controlling. It can also be a cumbersome process to find a suitable position for the eye tracker with respect to where the user is positioned.

**Disturbing light** Eye trackers that rely on infra red illumination of the cornea are sensitive to external light. If the eye tracker is used in an environment with near infra red light, it can compromise the user experience, and sometime even make the device unusable.

### 3.4 Interface guidelines for eye control

#### 3.4.1 Avoiding ”Midas Touch”

King Midas was, in the Greek mythologies, granted one wish. In his greed, he asked that everything he touched would turn into gold. As he accidentally touch his daughter, she too was transformed into a golden statue. His gift turned out to be a curse.
King Midas has given name to one of the most common problems in eye control, the *Midas touch*. At first, it may seem perfect to just look at a desired graphic element on the screen, and have it selected, without involving cursor or keyboard. Soon enough, though, the situation will be similar to King Midas’ – everywhere you look there is another command activated. Midas touch usually occurs when the user is fixating on some item solely to get information, but the program interprets it as an input (Majaranta and Räihä, 2002, p. 15).

One way to prevent Midas touch is by letting selection of interface items be done in two steps. It has been proven to work well in previous studies (Tien and Atkins, 2008).

**Figure 3.1:** A screen shot of Tobii Communicator. The letter ‘G’ is typed, which generates word suggestions to the left. This design would be problematic with a too short dwell time. Courtesy of Tobii Technology

### 3.4.2 Dwell time – accuracy correlation

Dwell time refers to the time that a user needs to fixate on a button in order to perform a click. This is one of the selection strategies that is widely used when eye control is the only input device. Depending on task and user’s experience, the optimal dwell time can vary from a couple of hundred milliseconds to one second (Majaranta and Räihä, 2002, p. 16).

It has been shown that dwell time has a strong correlation with accuracy as described in the graph below (Tien and Atkins, 2008). Even though the dwell time in the study was shorter than for many of the eye control systems, it clearly indicates a trend on how dwell time affects accuracy.
CHAPTER 3. THEORY

3.4.3 Visual feedback

When typing on a keyboard, the user gets tactile feedback as well as notices the letters on the screen as they appear (Majaranta and Räihä, 2002, p. 17). This can be compared with eye controlling to generate input, where the user usually focuses on the button pressed. Switching focus to see that the system registered the input and to verify that the input is correct is time consuming and affects the user experience in a negative way.

In a recent study (Majaranta et al., 2004), three different feedback models was evaluated;

- Speech feedback, the symbol on the item is spoken upon selection, no visual feedback.
- 1-Level visual feedback, were the selected item briefly turns red when selected
- 2-Level visual feedback, were the item gets a frame upon focus and turns red when selected

It was shown that the 1-Level visual feedback gave best accuracy when the dwell time was short (450 ms). The 2-Level visual feedback got good results, even though the users stated that it was confusing (Majaranta et al., 2004, p. 144).

![Figure 3.2: The accuracy increases as dwell time gets longer (Tien and Atkins, 2008)](image)
CHAPTER 3. THEORY

It is, nevertheless, important to remember fundamental design principles. It is encouraged to be consistent in the design, both from a micro and macro perspective. Thus, feedback conventions in similar systems needs to be taken into consideration in order to secure the user experience (Benyon, 2010, p. 90).

3.5 User centred design for children with cp

There are several things that need to be considered when applying a user centred approach together with people who has cp. For example, methods that rely on the users expressing their thoughts have to be altered or discarded, as the users may have a very limited way to communicate (Hornof, 2009, p. 2177).

Hornof (2009) pointed out that one of the most important parts when working with persons with disability is to make them feel part of the design team. This is a time consuming process, as a way of communication needs to be established before continuing with the work (Hornof, 2008, p. 72).

When working from a HCI approach, it is common to develop a low-fi prototype before going into specific design. When the users have limited communicational and motor skills, this process is compromised (Hornof, 2009, p. 2177).

Nevertheless, it is advised to involve a person with impairments in an early stage of the development (Gauffin, 2003, p. 25). The situation is different for every individual, why persons with impairments should be included as reference cases. Hornof (2009) described guidelines for designing activities with children that suffers from severe motor disorders, including

1. *Accept the awkwardness*. If the designer has not worked with persons that are impaired, it is likely to feel a bit awkward in the beginning. This is a feeling that passes over time.

2. *Listen to the children*. It is important to show an interest to what the child has to say. The goal is to make the child feel like a "design partner" in the process.

3. *Interact with several caregivers*. People that work close to someone with severe motor disorders have learnt how to interpret communication, and can be of assistance when communicating.

4. *Work with several children in parallel*. By introducing a prototype to several children at the same time, a synergy effect can be expected.

The team that works with a person that suffers from severe motor disorders is usually a good source of knowledge. It is common that they collaborate and share thoughts from their unique perspective, as this gives a differentiated picture of the overall situation, which is beneficial for the AAC user’s future development (Beukelman and Mirenda, 2005, p. 112). Typically team members are parents, siblings,
teachers, caregivers, nurses, augmentative communication specialist, speech therapists and technology developers (Hornof, 2008, p. 71).

What is the impaired persons’ impressions from participating in design processes? It is stated in the report from Hjälpmedelscentralen, that they are positive to participate in evaluating new solutions. The most important thing to remember is to see the individual as a person and not a representative for a group of people (Gauffin, 2003, p. 29).
Chapter 4

Empirical study

4.1 Users

4.1.1 Recruitments

Subjects were recruited from habilitation center in the Stockholm area. They were approached by first presenting the project for involved speech therapists and math educators. Three habilitation centers were asked to participate, all of which accepted.

This approach has several advantages. From an ethical point of view, there is another agency involved to make sure that appropriate protocols and procedures are followed (Brodin and Björck-Åkesson, 1994, p.102). This does of course not mean that the researchers should delegate this important aspect of the study – it does however create a security net.

Also, as stated above, the team that works with impaired people has "expert knowledge" when it comes to the particular person.

4.1.2 The user base

The user base consisted of one primary and one secondary group of users. The first group was defined by the following criteria

- Aged 12-18 years old
- Suffering from cerebral palsy
- Using Tobii AAC aid for communication
- Attending math classes, or involved in other math related activities

In total, six persons from the primary target group was engaged in the project. Of these persons, one dropped out due to medical reasons and one dropped out due to other circumstances.

The secondary user group consisted of members in the team that works with the primary user, and fulfilled at least one of the following criteria
CHAPTER 4. EMPIRICAL STUDY

- Being involved in and carrying out math activities (e.g. math teachers)
- Being experts in assessing communicative skills (e.g. speech therapists)
- Being an expert on the particular users’ preferences, skills and behaviour (e.g. care givers)

<table>
<thead>
<tr>
<th>Age</th>
<th>Mathematical Level</th>
<th>Eye tracking experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>Equal to 5th grade</td>
<td>3 1/2 years</td>
</tr>
<tr>
<td>13</td>
<td>Equal to 1st grade</td>
<td>4 years</td>
</tr>
<tr>
<td>15</td>
<td>Equal to 3rd grade</td>
<td>3 years</td>
</tr>
<tr>
<td>15</td>
<td>Equal to 7th grade</td>
<td>3 years</td>
</tr>
</tbody>
</table>

Table 4.1: List over users in the primary user group. The mathematical level is an estimation from the teachers.

By involving speech therapists, a broader perspective on communication abilities is taken. Their continuous contact with the primary user together with expert knowledge in the field of AAC gives an unique understanding of limitations for the specific user.

Math teachers working with the primary user have good understanding of the limitations and problems related to the math activities. They are also likely to be exposed to the math software in their teaching. Thus, their input is important for the mathematical scope and for the software’s work flow.

When including people with disabilities in user centred design, their assistants can participate in the evaluation process, as they usually work close with the person originally intended to participate (Rubin and Chisnell, 2008, p. 295).

In this section, ”primary user” and ”person with impairments” will be used interchangeably, as well as ”secondary users” and ”team”.

4.1.3 Specific features of the users

The severity of the conditions that the end users had varied from person to person. There were however some features that they all shared.

- All of them sat in wheelchairs. One of the tester controlled his wheelchair by a joystick, others got help from their caregivers.
- They had limited verbal abilities. One of the testers were able to make utterances that was interpreted by his caregiver. All of them were able to answer to yes and no questions by either looking at the communication partner or look away.
- Their limbs did non-volunteer movements. This made it close to impossible for them to use pen and paper.
4.2 Research aspects

4.2.1 Verifying the quality of empirical data

*Triangulation* is an approach to achieve academic validation and verification by applying different methodologies and empirical informers to the study. By doing this, the research is less vulnerable to any specific method’s shortcomings. It should also be noted that each method reveals different aspects of the empirical reality (Patton, 1999, p. 1192). There are four types of triangulation:

- **Method triangulation**, e.g. using different methods in one study. This is used for verification on the consistency in findings generated by different data collecting methods.

- **Triangulation of source**, e.g. using the same method on different participants. This is used for verification on the consistency of findings within the same method.

- **Analyst triangulation**, e.g. using multiple analysts to exam the data. This is used to verify that the interpretation of the empirical data is consistent between researchers.

- **Theory triangulation**, e.g. using different analysis tools to exam the data. This is used for expanding the interpretation of the gathered data.

(Patton, 1999)

Method triangulation was obtained by using different methodologies during the user evaluations. Every method was used in three different user groups, which leads to validation of source triangulation.

Even though this study is conducted by two researchers, the common interest is too large and the framework of analysis is too similar to be able to say that there is an analyst or theory triangulation.

It can, however, be argued that by including speech therapists, math teachers and care givers, the study reflects different theoretical standpoints.

4.2.2 Ethical reflections

One should always be cautious when handling information about other people. When conducting this study, the research ethics proposed by Vetenskapsrådet has been followed.

One dilemma when designing for AAC aid is that the researcher is encouraged to, on the one hand, have continuous contact with the team and end user in order to form a atmosphere were feedback is easily obtained (Hornof, 2009). On the other hand, the researcher should not raise false expectations on friendship or long-term links. This can be very problematic as the research interest usually has to do with
human communication, which in some sense is inseparable from human contact (Brodin and Björck-Åkesson, 1994, p. 100).

Consent forms were distributed to all subject who participated in the research. The primary user group, from which all were adolescents, had their parents signing the consent form, see appendix A.

4.3 Pre-study: Getting a grip of the prerequisites

4.3.1 Method: Contextual inquiry

According to Bailey’s Human Performance Model, three factors are dominant to the usability of a product, namely Somebody (the user), Something (the activity) and Some place (the context). The model shows that these factors are equally important, and needs to be considered in any type of product development. However, product developers usually put the main focus on the system (Rubin and Chisnell, 2008, p. 7).

Contextual inquiry is a methodology that helps to consider these factors. The cornerstone of the method is to meet users in the context where the activities are carried out. The typical goals of using this particular approach is to understand, extend and transform user work (Wixon et al., 1990, p. 332). Raven and Flanders (1996) described the basic principles of the method as

1. Data gathering must take place in the context of the users’ work.
2. The data-gatherer and the user form a partnership to explore issues together.
3. The inquiry is based on a focus; that is, the inquiry is based on a clearly defined set of concerns, rather than on a list of specific questions (as in a survey).

Several users ought to be included in the study, as this adds more dimensions to the different aspects of the activity. The researcher should be observant to how much effort different sub-tasks requires, and have a continuous dialogue to maintain a shared understanding of the activities.

Wixon et al. (1990) also stated that one advantage with this method is that the researcher build the understanding at the same time as data is collected. Thus, there is no need to wait until the study is terminated to be able to draw initial conclusions.

There are a few known shortcomings to contextual inquiry. Most of them concern research in larger teams, were it is argued that a fourth basic principle should be added, namely establishing a shared focus within the team of developers (Simpson, 1996, p. 26). Another issue that is raised is that contextual inquiry can be time consuming and is tying up several people for an amount of time. There has also been critique that ”focus” is an ambiguous term to use, and may refer to the focus of the contextual inquiry or the focus of the subject of investigation (they do not need to be the same) (Simpson, 1996, p. 27).
4.3.2 Implementation

In this study, the primary end users as well as members of their team (speech therapists, math teachers and caregivers), were gathered in their classroom. The focus of the study was (i) to get an understanding of how the users worked with mathematics in school and (ii) getting an idea of what mathematical scope that would suit the users.

Questions were continuously asked on what was difficult, interesting and fun. They were answered in different ways, depending on the communication strategies mastered for each student. Most of the users got help from their caregiver, working with Bliss signs or interpreting utterances.

The team also got the opportunity to give their view of the math situations, and express what difficulties they had observed. These observations differed largely depending on the primary users specific impairments.

Prior to the first meeting, an agenda was composed. It was used as an support to make sure that all important topics got covered. It also helped all participants to get a common idea that the focus was on the users and how they work, not of the final product. The questions formulated was intentionally wide and open, in order to be allowed to be able to explore all the different aspects presented during the observation. This is usually called an unstructured approach, and is often used in exploratorial observations. A key idea is to approach the situation open minded, pay attention and try to observe “everything”, even though that is impossible even for the most skilled researcher (Patel and Davidson, 2003, p. 94).

Notes were taken by the researchers, and later compared and discussed.

4.3.3 Outcome

The data from all contextual inquiries were reviewed. This process led to a number of important findings of various nature; from interface design, to central ideas for improving the mathematical situation, mathematical scope and even to core values for the habilitation centres.

Teaching material and methods  One of the most important observations was how the habilitation centres work with mathematics today. Usually they use textbooks, where the caregiver helped to write down the results of the tasks. One of the end users, who could use Tobii Windows Control, had a Microsoft Word document with a coloured template, that was used for addition.

For the most novice students, the text books only included addition with positive integers up to twenty. Every task had a visualization, as shown in figure 4.1, to further help the student.

Appealing design with few distractions  One problem with other math related software that was brought up, was the presence of cognitive distractions. At one habilitation center, they showed examples of software where the user was guided
CHAPTER 4. EMPIRICAL STUDY

Figure 4.1: Example from the textbook MatteDirekt (Falck et al., 2008), used at one of the habilitation centres. Courtesy of Bonnier Utbildning.

through different mathematical tasks by an animated character. When the user hovered on a button in the interface, the character explained the task in a narrative way. This might be compelling to other students, but did not suit students with limited cognitive functions. The problem was that the design was too unclear – the user usually did not understand what to do. Secondly, the audible feedback produced was so compelling that the user just hovered over different buttons, instead of doing the mathematical activity.

Simple, but not childish  It was pointed out that even though the students worked with basic mathematics, they were not childish. Other software that dealt with basic mathematical concepts was usually designed for younger children.

Support independence  One of the core values at habilitation centres was to let the students become as independent as possible. This has proven to be difficult in mathematics, due to the lack of suiting software. Usually, the caregiver is the one writing down the correct answers. This can be problematic since the disabled children sometimes has learnt to interpret the caregivers subtle signals (body language, tone of voice etc.), and thus get a hint what the correct answer might be.

Improve wording  When using the speech synthesis in mathematical discussions, the software needs to interpret mathematical symbols and read it aloud according to conventions. For example, the symbol for multiplication, $\times$, needs to be read out as "multiplied by" (five multiplied by two equals ten), and not as "asterisk" (five asterisk two equals ten). This has been a problem when using standard communication software.

Giving the user feedback  Some of the users are motivated by getting a reward when completing a task. In order to prevent a behaviour where the user is more interested in the award than the math, the reward should only be given once for each task.
Visualization to support mathematical thinking  Mathematics is difficult for people with CP. Many textbooks have visualization to the tasks in order to aid simple addition and subtraction. One of the children used the textbook Matematik-safari, which only used addition of numbers between one and ten. All tasks used different type of pictures, as the one shown in figure 4.1.

Spatial problems  Many mathematical problems involves some sort of assessment, like which number is biggest. Prepositions, colours and shapes are difficult for people with CP. It was hypothesized that this might be an effect of CVI and the fact that the children most of the day sit in their wheelchairs and therefore have a weaker sense of space.

4.4 Iteration 1: Defining mathematical scope

4.4.1 Conceptual model

A conceptual model can be thought of as ”a description of the proposed system in terms of a set of integrated ideas and concepts about what it should do, behave and look like, that will be understandable by the users in the manner intended” (Preece et al., 2002, p. 40). The main goal with this iteration was to create and verify conceptual models based on the finding from the prior iteration.

The design space were diverged – in accordance to Löwgren and Stolterman (2005) – by discussing several ideas for the conceptual model. This approach can be though of as an expansion of the design to cover broader issues, finding alternative options and exploring more opportunities (Löwgren and Stolterman, 2005, p. 29). Several ideas were discussed before the convergence process – the narrowing down part – of the design process started. Two ideas was nominated for user evaluation. At this stage, the prototypes consisted of a sheet of paper, with a high-level description of what mathematical difficulty that the software were to be designed to deal with, together with some intended main features.

Geometrical concept  The geometrical concept springs from the criteria in the curriculum for special schools in Sweden. It states that the pupil should be able to recognize some main features in geometrical shapes (year five), and to be able to depict and describe geometrical features (year nine).

The idea was to present the user with various shapes and give instructions like ”select the biggest triangle”. When the right shape is selected, new shapes appear together with a new task. The tasks can be changed to also include colour and positions.

This concept could be used to introduce more complex mathematical phenomena such as area. A more detailed overview can be found in appendix A.
Chapter 4. Empirical Study

Columnar Calculation It is stated in the curriculum for special schools in Sweden that the pupils should be able to count with natural number as well as be familiar with addition, subtraction, multiplication and division (year five). This knowledge is also the foundation for several other mathematical ideas.

It is difficult to use normal text editors for columnar calculations, as the input work flow is from left to right and from up to down (if carry digits are needed).

The idea was to build a framework which supported this. Additional features included the use of voice synthesis to read the calculation out loud, thus enabling communication in the classroom. For children with basic algebraic problems, visualization for the tasks should be available to support the learning.

When pupils were introduced to the columnar calculation algorithm, they could use "auto selection". This option selected the proper position to enter a number. When the number was entered, it automatically selected the next position to enter a number into.

A "practice mode" was proposed, were tasks were automatically generated. In this mode, different levels of difficulty could be chosen.

4.4.2 Method: Focus group evaluation

A focus group is a group of individuals who are brought together to for a open-ended discussion about an issue. It is a qualitative research tool that gives an understanding about a larger group’s impressions of the issue. The method generates subjective data, but lacks any statistical validation. This type of exploitative evaluation methods are typically used early in an design process to make a proof of concept (Rubin and Chisnell, 2008, p. 17).

It has been shown that the number of ideas generated does not double as the group grows from four to eight participants (Morgan, 1984, p. 225). Furthermore, there are no evidence that points to the fact that the quality of the ideas are higher in comparison to individual interviews.

There are, however, some important advantages with this approach. By gathering users to discuss the design, synergy effects can be anticipated (Hilliges et al., 2007, p. 138). These effect may include ideas to be taken further by discussions in the group. It also brings representatives from different stakeholders together, and thus making it possible to exchange knowledge and perspectives. Furthermore, focus groups has an air of consensus for the members of the group (Preece et al., 2002, p. 213).

A focus group session should take no longer than one and a half hour. A typical agenda for the focus group is to get an introduction to the problem by the researcher, followed by a discussion. During this discussion, the group is encouraged to talk to each other and not include the researchers. This makes it easier for the researcher to collect notes and, if necessary, moderate the discussion (Morgan, 1984, p. 256).

Stewart and Shamdasani (1990) noted that there are a few limitations with using focus groups. First of, the responses from group members are not independent, since they may have been influenced by other members. This can be very negative if there
CHAPTER 4. EMPIRICAL STUDY

is one person in the group that is dominant.

Secondly, the moderator can have an effect on the results by knowingly or unknowingly provide cues to the type of answers desired.

Lastly, answers given in focus groups tend to be open-ended, which makes it difficult to analyse the data.

4.4.3 Implementation

The conceptual prototype was evaluated with a series of focus groups, one for each habilitation center. This ensured that the opinions from a broad spectrum of the community was heard. The groups consisted of the same people that participated in the previously discussed contextual inquiry. This has both the advantage that they are familiar with the ambition of the study, as well as gives the user a feeling of being a part of the design process.

In order to make the users feel even more involved in the design, the session started by giving a brief presentation that made it clear to them that the conceptual model was a direct result from the previous meeting with them and other habilitation centers.

Data was gathered by both researchers, taking notes while alternating the role of moderator.

4.4.4 Outcome

Stimulus for visualization It is important that the software is interesting for the user, as it otherwise could make them uninterested in the tasks. The tasks in the textbooks had different kinds of visualizations, of which not all was suiting. Money, for example, is something that the end users do not have any relationship to, therefore it does not make sense to them to sum coins. More suiting objects would be taxi cars and other vehicles which they ride in daily. It would of course be best if the user could choose images for the visualization.

When the children were asked what visualizations they would like to have, they answered emblems for their favourite teams.

Visualize numbers between one and twenty There were no need to make visualization available for bigger numbers than twenty. The pupils who did calculations with greater numbers did not need the support that visualization gives.

A ”mathematical” keyboard Small buttons are difficult to select on the eye tracker and space is the confining factor. The software should have a ”mathematical” keyboard, with only the necessary buttons visible.

Geometry to develop language competence One of the things that especially the speech therapists liked with the geometrical concept was that it helped
to develop the language competence. It is a good way to learn prepositions, colour and size – all of which children with CP have problems with.

**Geometry to exercise working memory** By making more complex tasks in the geometrical concept, like "select the top most, red circle", the pupils also got a chance to practice their working memory by keep the instructions in mind.

### 4.5 Iteration 2: Designing the work flow

#### 4.5.1 Wire-frame prototype

Both the conceptual models addressed interesting aspects of concept formation and mathematical understanding. However, the scope and resources in this study only allowed to explore and develop one of the models. After addressing this with the product manager for Communicator, the Columnar Calculation concept was nominated for further development. The decision was based on the following two arguments:

- It is a mathematical concept that is used in a broader section of mathematical activities.
- The concept had more potential to aid the primary end user to actively participate in the mathematical activities.

A wire-frame prototype was developed, based on the feedback and input from the focus groups. It was made in Pidoco, a free, on-line based prototyping tool, that allows the designer to create and link screen shots to a functional wire-frame prototype. The limitation with this kind of prototypes, is that there is only certain pre-determined "interaction paths" that takes the user forward.

#### 4.5.2 Method: Think aloud

The main idea with *thinking aloud* evaluations is to let the user provide a running comment on her thoughts while performing the task of the test, thus making the user experience easier to observe and understand. It is one of the most common methods used in field of HCI (Nielsen et al., 2002; Ramey et al., 2006).

There are several ways to extend and enhance the thinking aloud method. If the user becomes quiet, it usually is an indication that there is something with the design that is worth looking into. It is recommended that, instead of prompting the user to explain in detail what is difficult, note the situation down. That way the user does not get thrown off from the mind set of solving the task (Rubin and Chisnell, 2008, p. 206). These situations can later be revisited, which gives the user a chance to elaborate what was problematic.

It is important to let the user know that it is the prototype that is being tested, not the skills or abilities of the test person. This helps the participant to become more comfortable in the situation.
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This type of validation has the benefit of capturing both the preference (how the user would like the program to work) and the performance (how they interact with the prototype) (Rubin and Chisnell, 2008, p. 204).

4.5.3 Implementation

The goals with this iteration was to

- Assess how natural the work flow felt.
- Validate that the design was intuitive.
- Validate that size, colour and location of the graphical objects did not hinder the end users to access them.

Two particular issues was raised when deciding on what evaluation method that should be used. The first one was of a technical nature; in order to interact with the prototype, the user needs to be able to navigate in Microsoft Windows environment. The majority of the primary users, who’s only access to the computer is through eye tracking, did not have the required skills to do this.

The other issue was related to whether or not there was an efficient evaluation method that could include the primary end user without compromising the validity of the study. One could for example suggest that a variation of think aloud, where the care giver helped with the interaction while verbalize the thought of the end user, could be used. This approach does however have a few problematic aspects.

Firstly, thinking aloud should be based on the instant, unaltered impression of the interface. Everything that is perceived has at some point gone through the short term memory. This is the information that is valuable for the usability tester. If there is a longer period of time between action and verbalization, there is a risk that the user has constructed descriptions or explanations by using the long term memory (Nielsen et al., 2002, p. 105).

Secondly, verbalizing thought while performing tasks puts an cognitive load on the user (Nielsen et al., 2002, p. 104). While this might lead to a slightly biased data from normal users, it will most likely have a greater impact on users that suffers from cognitive impairments.

Other possible methods that involved the end user were discarded, since the extracted feedback based on their assumptions on how they would be able to interact with the system would also be a cumbersome and somewhat unreliable process, since different end users posses different levels of the ability to do meta-reflections.

Instead, the team members did individual usability testing. This opened up for an evaluation of a more academic and practical nature. The user was asked to conduct two tasks while thinking aloud. Notes were taken during this process. When the tasks were solved, a retrospective walk through of the work flow was performed. Questions were asked about the passages were the user had hesitated or stalled. This dialogue led to both verification/clarification of the issue, as well as suggested behaviour and features.
CHAPTER 4. EMPIRICAL STUDY

**Pilot study**  Pilot studies are conducted prior to the real usability test, in order to secure its quality. Ideally, a "real" user in the lower end of the expertise scale should participate to give the most valuable feedback on the pilot test (Rubin and Chisnell, 2008, p. 215). The small number of primary end users in this study made it difficult to allow this. The pilot study user base was instead recruited from Tobii’s staff working with Assistive Technology.

It can indeed be argued that if "normal-abled" persons find the pilot test easy to conduct and the prototype to work well, this does not say much about how the actual end user will perceive the system. But in the case that a non-disabled person finds the system difficult to use, this can be an indication that there are problems in the system that needs to be attended to before evaluating it with persons that has additional physical and cognitive impairments (Brodin and Björck-Åkesson, 1994, p. 99).

**Primary user evaluating the prototype**  One of the primary end users was able to use the computer in Microsoft Windows environment. He was also able to give verbal responses, which were clarified by his care giver when necessary. This qualified him to do a smaller version of retrospective think aloud. During this session, he was asked to perform the tasks without commenting on his thoughts. When the task was completed, he was asked to comment on the prototype.

This session was valuable, as it verified that at least this particular user in the primary target group was able to use the software.

4.5.4 Outcome

The gathered data from all the participants were analysed in order to find patterns in the interaction. Critical events, usually when the user turns silent or looks puzzled, were compared over the subjects to see if there were any coherence in the different users’ behaviour.

**The work flow was intuitive**  The majority of test persons understood the work flow of the prototype. The most common mistake was that they, when performing the calculation, tried to input a number before selecting a position to enter the number into. This was a mistake that was only made once for every test person, which suggests that it was easy to learn and relative intuitive.

**Different correction options**  The proposed correction option was too undifferentiated. It would be an advantage that, instead of indicating whether the entire task was correct or not, only the incorrect digits would be marked in red. The math teachers also said that some of the pupils did not use carry digits, and that it would be beneficial if it was optional whether or not they were taken in consideration when correcting the task.
Different options for practice mode  Practice mode was originally thought of as a way to generate tasks within four predefined intervals. Some of the children still had problems with addition where carry digits were used. It was pointed out that a useful feature would be to generate tasks without carry digits.

The design was clean enough  One of the important aspects of the software was that the design would have few distractions. One of the caregivers stated that it was positive that the calculation page was "clean" in a sense that unnecessary input positions was removed. That is, if two numbers between one and nine was to be added, there were no input positions for hundreds, thousands and ten thousands.

Addition with more terms  There were only two term addition in the prototype. Both caregivers and math teachers wondered if it would be possible to have addition with more terms.

Ambiguous symbols  Symbols were used instead of text to describe the behaviour that the button invoked. This was motivated by the fact that the majority of the end users were still struggling with reading, and that schematic symbols deems a lower cognitive load on the user. It was evident, however, that some of the symbols were ambiguous for the evaluators. These symbols were

- The arrow to go down to start input to the second term. It pointed to the right, and was interpret as "go to next page", or change view. It was not clear that it would put focus on the term that was below the first term.

- The menu had a button for closing it and get back to the task. The symbol used was a arrow pointing backwards. This was interpret by many of the test persons as "go to previous task".

The users were familiar with symbols in Communicator, why it was proposed that those should be used.

Export calculations  Teachers were particularly interested in being able to save the calculations done in the software. This way, they could keep track of how well the pupils did. It was also suggested that they might want to save their work to revisit it at later occasion.

Inconsistency in interface  Many of the persons evaluating the prototype felt that there were a too big “gap” between the design for setting up the task and the view for calculating. Objects like the number panel, which are used in both states, had different appearance.

The visualization is to cluttered  In the prototype, motorcycles were used to visualize a task. This concerned both speech therapist and teachers, as they were to cluttered. It was suggested that visualizations should be clean and simple.
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4.6 Iteration 3: Constructing the release candidate

4.6.1 High-fidelity prototype

Based on the feedback from the wire-frame prototype, a high-fidelity prototype was developed. This prototype was implemented as a plug-in to Communicator. This platform supports eye tracking interaction, and thus allowing the primary end users to interact with the developed software in a natural way. As Rubin and Chisnell (2008) pointed out, researchers may be able to imitate a set-up that reflects the one that the users are custom to, but it won’t be exactly the same as their own set-up. By just adding the extra functionality to their normal communication platform, several problematic aspects of validation on the gathered data was avoided.

4.6.2 Method: Enhanced beta test

The first version of a software that is available for external users are often called a beta release. The beta release can be tested in a beta program. The purposes with beta testing are:

- External validation of the product with almost its full functionality with real customers and real customer environment.
- Provide the company with positive quotes and testimonials. These can be used to promote further development on the prototype.

(Lawley, 2007)

Users that participate in beta program are given a copy of the software and get to try it out under a period of time. This extended use of the software helps reveal aspects of the prototype that otherwise would not come up in shorter evaluation tests.

Enhanced beta testing refers to additional steps in test period, such as interviews and data logging, see below.

4.6.3 Implementation

Outline of the iteration  Both quantitative and qualitative data was gathered in the last iteration. The main outline of the evaluation was

- Introduction. Gather qualitative data in conjunction with the introduction of the software.
- Usage. During 1-2 weeks of usage, gather quantitative and qualitative data.
- Feedback. Gather qualitative data after the evaluation period.
CHAPTER 4. EMPIRICAL STUDY

Preparations: meeting the team  Before the software was introduced to the primary users, their teams were gathered for a walk-through of the software. They were introduced to the relevant settings for the interface, and also asked to pay attention to (i) situations when the user do not know how to proceed, and (ii) when they need help to proceed and times when incorrect clicks occur. They were also informed about the logging functionality.

Introducing the software to the primary user  A detailed test plan for the introduction session was written. It described in detail how the introduction of features were presented and what tasks the user was asked to perform. In addition to the test plan, a observation scheme was created. It described specific situations that were likely to occur when the user interacted with the prototype, as well as possible ways that the user may act in the particular situation. With the observation scheme, the scope for the observation was narrowed down, thus making it easier to observe the interesting events. Additional notes were taken, in the case something interesting happen that was not covered in the observation scheme.

The entire introduction session was recorded with a video camera, and later analysed.

Data logging  Quantitative data was gathered by logging particularly interesting events. One advantage with data logging is that it is a non-obtrusive way of getting knowledge about the usage of the prototype. Once again, the integrity aspects needed to be considered. Should the users be informed about the data logging, despite the fact that the knowledge of data logging may change their behaviour? Preece et al. (2002) argued that the transparency about this type of issue depends on several variables; how much of the personal information is collected? How will the information be used?

After addressing this issue with the product manager and software development team at Tobii, as well as with supervisors at KTH and SU, a decision was reached that the data logging should be accepted by key persons in the teams, but not by the user until the data was collected. The user could decide after the evaluation period whether or not the data should be removed or used in the study.

Different types of metrics was designed to assess interesting aspects. The learn-ability was measured by clocking when the user solved the same task at two different occasions (during introduction and during debrief).

The Midas’ Touch aspect of the interface was assessed by measuring the amount of clicks that was done within the period $2 \times \text{dwelltime}$ for every system, where the last click did not generate any input.

By measuring the ratio of removed digits / inserted digits for each session, an overall measurement of the prototype was obtained. These result indicates different aspects such as:

- general understanding of the input method (decreased/increased need to correct input).
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- how comfortable the user is with the interface (decreased ratio suggests that buttons are easy to click).

The result may also be bias to a small amount of mathematical learning, even though the short test period makes this unlikely.

| 1304931356062,50 | INSERTDIGIT | result | three | AUTOSELECT OFF | NO MIDAS |
| 130493135762,50 | INSERTDIGIT | invalide | three | AUTOSELECT OFF | MIDAS |
| 1304931364687,50 | INSERTDIGIT | result | five | AUTOSELECT OFF | NO MIDAS |

Figure 4.2: Snippet from the data logging. The columns represents (from left to right): time, action, position, digit, auto select and the evaluation whether or not the input was considered a Midas’ Touch.

Debriefing  A debriefing session was planned one to two weeks after the introduction, depending on when the teams and users were available. This session consisted of interviews with the team only, as well as the team and the end user. In the first interview, a wider perspective of the software was discussed. Questions like ”what are the advantages/disadvantages with the software for general users with cp?” The second interview was focused on the particular user who evaluated the system. The log files were extracted from the eye tracker, and the logging functionality removed.

4.6.4 Outcome

Smart and time efficient  When demonstrating the prototype, one teacher was very excited over the fact that the software would make calculations more time efficient than before. This was mostly due to the fact that the interface presented all the necessary buttons at all times. Thus, the end user would not need to switch between the prototype and other input software. The teacher anticipated that calculation would take shorter time, which would open up for more mathematical activities.

In accordance with previous feedback  The refined design was based on feedback from previous iteration. All the teams were happy to see that their feedback had been taken into consideration when creating the high-fi prototype.

Unfamiliarity to edit pages  One assumption when creating the high-fi prototype was that some people in the team had experience in manipulating the user interface in the built-in ”edit mode” of Communicator. It was discovered that both speech therapists and teachers were not used to do this.

The settings of the program were therefore adjusted to fit the particular user prior to the introduction session.
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**Limited accessibility at lower part of screen** There is a pause feature on Tobii’s eye trackers, that allows the user to toggle the eye control on/off. The option to toggle the pause mode is presented when the user looks slightly under the screen.

Some of the buttons were placed at the bottom part of the screen. During the introduction session, some users accidental triggered the pause mode dialogue, when their original intent was to press one of the buttons on the interface.

**Insufficient data from logging** When extracting the data generated from the logging, it became evident that the test period was too short to draw any general conclusions about the prototype. As it is the end of the school year for the student, they had put a lot of effort on final exams and other activities. The time restrains on the study did not allow an extension of the test period.

**Reading the task out loud not only for communication** The original idea to have a button that reads the task out aloud was that the children could participate in classroom activities. While many of the users thought this was a good idea, one of the users expressed another use for this function. When calculating larger tasks, he found it a valuable support to hear the task out loud before calculating. The speech therapist agreed that this could be helpful for other students with decreased cognitive abilities.

**Saving tasks essential** All habilitation centres had different ways to store calculations made in the classroom. Some saved it in binders, other stored digital copies of the work on the hard-drive. The prototype had no support for this, which was one of the thing that both teachers and students saw as the biggest disadvantage.

**4.7 Data from external informers**

In addition to the refined user evaluation, other persons with deep knowledge in the fields that this study rests upon has been a source of “informal” information. These persons were senior staff at Tobii with years of experience in the AAC area and supervisors at KTH and SU.

**Allowing to change settings in run view** The product manager of Communicator pointed out that many of people who work with persons with disabilities are not used to complex interfaces, such as the edit view. In previous software releases, they had therefore added a simple settings view in run time. With this design, it was more likely that the software was adjusted to fit the end user.

An additional benefit would be that the settings could be made with eye control, enabling the primary end user to manipulate the behaviour of the program.
CHAPTER 4. EMPIRICAL STUDY

Using Tobii SymbolStix  Tobii SymbolStix is a package of symbols based on stick figures. The product manager for Communicator had a list of testimonials from speech therapists using SymbolStix in their work, for example

In our speech and occupational therapy practice we use SymbolStix each week with all of our 130 patients. We love the look of the symbols: cool, relevant and comprehensive! SymbolStix give us recognizable symbols for current popular people and topics that are exciting for our patients.

SymbolStix is a good complement to the basic package of symbols used in Communicator.

![SymbolStix symbol for mathematics](image)

Figure 4.3: A SymbolStix symbol for mathematics. Courtesy of Tobii Technology

Learn the students to wait  Persons with impairments are sometimes ”spoiled” with perfect communication. The communication partners usually stays put and give instant feedback on activities carried out. It is valuable to get the experience of waiting. Hence, the software should enable the student to start working on other things until the teacher is present to give feedback. When this happens, it is important that previous tasks can be accessed.

4.8 Critical analysis of methods

Involving persons with disabilities in a design process is not as straight forward as having normal-abled users. Some of the most critical aspects are described below.

Recording feedback  During the pre-study and the first iteration, data was only gathered by taking notes. The main reason for this is that recording devices would not capture the entire communication. For example, an audio device would not include the gestures that the students used for communication. A video recorder would allow this, however several apparatuses would be needed, as several children were involved at the same time. Due to logistic, economical and analysing aspects video cameras was discarded as recording device.
CHAPTER 4. EMPIRICAL STUDY

User base and drop-outs Ideally, more users would be involved in the study to gain an even broader testing of the prototypes. However, the numbers of users that fulfil the inclusion criteria are very limited. Furthermore, they are more likely to drop-out due to medical reasons; either surgery or the fact that if they catch a cold, they might be home for a longer period of time.

In order to correct for this, speech therapists were asked to assess the usability of the prototypes for other persons with impairments.

Time aspects and restrains It is important to remember that these children are attending school, with all the responsibilities that comes with this. In addition to this, they are also involved in activities such as physical therapy. All the evaluations took time from these activities, and could only do so to some extent.

To complicate the situation, there are other factors to take into consideration. Setting up the equipment is time consuming and sometimes lead to technical issues. Once everything is in place, the communication is much slower compared to normal verbal interviews.

Difficult to elaborate There were various levels of communication difficulties when talking with the users. In most cases, they were able to give answers themselves, or aided by their caregiver. However, one of the end users had problems in reflecting over the design of the software. The questions prepared for the debriefing session in the last iteration was dismissed, as the user at this time was only able to answer to yes or no questions.
Chapter 5

Result

By combining findings from the empirical study and previous research the following results gives answer to the research question;

What prerequisites must be considered when designing mathematical software for adolescents with cerebral palsy who rely on Tobii assistive eye tracking as a communication device?

Notice that some of the results is true for other communication devices than Tobii eye trackers.

5.1 Visual impairments

5.1.1 Colours and contrasts

Previous studies (Dutton, 2002; Woods, 1969) as well as results from this study indicate that many persons with CP suffers from visual impairments (CVI). This makes the persons sensitive to contrasts. The condition is different for different persons, why it should be possible to adjust colour in the settings of the software.

In the developed prototype, there were options to change background and font color on several different elements:

1. Selected input position.
2. Unselected input position (when the correction option is not toggled).
3. Feedback on correct input (when the correction option is toggled).
4. Feedback on incorrect input (when the correction option is toggled).

5.1.2 Size and shape

The visual impairment may also affect the ability to distinguish different objects on the screen. A software should allow the user (or member of the team) to resize and
move the items in the interface of the screen to suit the specific user.

As discussed previously, the end users in this study showed examples of the need to customize the interface. One of the testers needed very big buttons, and no carry digits to distract him. Another tester was perfectly fine with even the smallest targets.

![Figure 5.1: Colour settings in the software](image)

### 5.2 Accessibility for eye trackers

#### 5.2.1 Avoiding the edges on the screen

Another finding in this study was that some of the buttons at the edge of the screen were difficult to access. As noted by Zhang et al. (2004), it is probably due to deviation in calibration.

In the particular case of Tobii eye tracking, where the pause feature is triggered by looking below the screen, the buttons should preferably be placed some centimetres from the lower edge of the screen since the two features may interfere with each other.
CHAPTER 5. RESULT

5.2.2 Consider disturbance in signal

Tobii eye trackers rely on image processing of the user’s gaze. In all systems with this technique, there will be an amount of disturbance in the signal. This can either lead to decreased accuracy or precision, which is the cause of decreased preciseness when eye controlling. Thus, despite of target group, buttons or other interactive interface component that is designed for eye control should be bigger than for normal input methods.

5.3 Mathematical aspects

5.3.1 Substitute cognitive tools

One of the theorised reasons for the late development of mathematical concept formation is the lack of cognitive tools available for severely impaired children. Research (Arp et al., 2006; Haskell, 2000) as well as empirical studies suggested that this was due to lack of experiencing normal developmental activities.

I was also found in a previous study (Lister and Juniper, 1995) that persons with cp are able to internalize mathematical concepts. This is a solid argument for developing cognitive tools that supports the development.

Thus, children with severe disabilities should have access to substitutional cognitive tools.

5.3.2 Supporting different representations

There are several examples of representations of mathematical tasks. The instructions can be written, read aloud, displayed in graphs and figures etc. This helps the user to get a grasp of the task at hand.

For children with cognitive impairments (including cvi), this support is even more important. Software that is designed to be used in mathematical education should therefore have support for this.

In the prototype that was developed in this study, this was done by having support for visualisation (see figure D.11) as well as functionality to read the task read out loud.

5.4 Design aspects

5.4.1 Designing for different users

This study showed that persons with cp are able carry out different activities on their eye tracker. The limiting factors include non-volunteer physical movements and cognitive abilities. It can be argued that by designing a software that allow the user to manipulate the interface, the different users’ needs can be met.

It is true that Communicator is flexible when it comes to change shape, colour and size. It was noted in this study that despite of this, many people in the teams
around the user is unfamiliar with this. Looking at a larger picture, to change work flow or behaviour in the software is even more unthinkable for this target group.

In order to facilitate the user in the best way, there should be some standard designs for the software (one is usually not enough!). What should these designs look like? This question can only be answered by working with end users and their team all the way through the design process.

### 5.4.2 Reduce stress factors

It can be very stressful to use eye control when the interface is compact with a lot elements that executes commands. When observing the users’ behaviour during the navigation of other eye controlled application, including the summery page (see figure D.12), this became evident. It was common that the users moved their gaze rapidly over the screen, in order to get an overview of the information without clicking.

This phenomena, which springs from Midas’ Touch (Majaranta and Räihä, 2002; Tien and Atkins, 2008), can be prevented by designing for ”safe havens”/non-selectable elements in the interface. The software developed in this study had the central element (the first and second term) as non-selectable, static elements. This was an attempt to increase the user experience. The input strategy, to first select a position and then insert a number, also decreased the risk of accidentally inputs. The trade-off, however, is that it takes one extra click for each input.
Chapter 6

Discussion

One of the most important cognitive technologies when learning mathematics in school is pen and paper. This allows to externalize thought, and thus make it possible to focus on other processes. There are several other tools, like rulers and calculators to further facilitate mathematical activities. Despite this, mathematics is known to be one of the most difficult subjects in school.

In the light of this, the situation for students with CP that uses AAC eye trackers is uneven. Not only are they not able to use the most basic cognitive technologies, they do also have reported problems with simple arithmetical operations. The purpose of this study was to find theoretical and empirical evidence of these problems, in order to facilitate this target group in the most useful way.

Since there was no suiting software for independent mathematical activities, the student was dependent on the caregiver to take notes or making entries in the textbook. The process is time consuming, and does not support individual commitments. This is an important aspect, as persons with severe developmental handicap are in the risk zone for learned helplessness.

The main goal with the mathematical prototype was to “level the playing field” for students with CP. More precise, they should be able to verbalize mathematics in order to be able to independently participate in communication in the classroom. They should also be able to do calculations in an efficient way, with a basic interface that was customizable to their needs.

The overall results of the software was positive. This is mostly a result of a thorough user centred process, from which ideas was formed and extensively validated before implementing the high-fi prototype. Examples of this is the support for tackling problems related to CVI as well as the simple overall work flow. There are however, things to look further into in order to develop the prototype to a final product. The natural expansion to include all four basic mathematical operations is the most obvious.
Chapter 7

Recommendations

This study has contributed with valuable finding for developing mathematical related software for Tobii AAC eye trackers. Below follows a list of recommendations for future work in this area. The feedback is divided into sub-groups for the reader’s convenience.

7.1 Refining the prototype

7.1.1 Expanding mathematical scope

A natural extension for the software is to support all the basic mathematical operations (addition, subtraction, multiplication and division). This was something that one end user pointed out early on in the final iteration.

They were not included in this software due to two factors. Firstly, the time constraint on developing the high-fi prototype. The focus of this study was on usability, why the implementation time for the software was limited.

Secondly, the interaction design for multiplication and division is different in comparison to addition and subtraction. The multiplication algorithm consists of two steps, first a step with pairwise multiplication, that generates terms for a final addition. These two calculations allocate a large portion of the screen, why alternative interaction patterns should be considered and evaluated.

7.1.2 Refining the edit interface

In this report, the only usability aspects that were considered are the ones that concern the primary end user. When setting up the program (in terms of colours, shapes, sizes, feedback, correction options, work flow etc.), the edit interface is used. Since this interface is managed by mouse and keyboard input, it is common that a team member (parent, teacher, speech therapist) is the one customizing it. These people are differently accustomed to working in such environment. Hence, there is a need to review and improve the design on the edit mode.
CHAPTER 7. RECOMMENDATIONS

7.1.3 Evaluating learning aspects

The main goal with the developed software was to create a platform for basic mathematical operation concept formation and classroom participation. Even though several aspects were taken into consideration when evaluating the system, it did not assess educational goals. According to Squires and Preece (1996), there is an essential relationship between usability and educational issues, that needs to be taken into consideration in order to secure good educational software design (Squires and Preece, 1996, p. 15).

When doing this, the Jigsaw Model, as proposed by Squires and Preece (1996) can give some valuable input.

7.1.4 Comparing error rate

There were not enough data from the usage to draw quantitative conclusions on whether or not the interaction work flow decreased the number of erroneous inputs. The steps taken to prevent Midas Touch should however had the desired effect.

It would therefore be interesting to first and foremost conduct a more longitudinal study to validate the above mentioned assumption. At the same time, it would be interesting to log erroneous input on other interfaces such as the one in figure 3.1. This can generate interesting insight in the overall design aspects for Communicator applications.

7.2 Extend collaboration with habilitation centres

There are several reasons for Tobii to extend the co-operations with the habilitation centres. A user centred design approach will ensure that future software is designed in a way that suits the users.

It is also valuable to know more about the context in which the eye trackers are used in. This includes seeing what role the caregiver and other persons in the team work support the activities carried out.

Furthermore, the problem that many of the involved persons do not use the edit interface in Communicator needs to be addressed. The solution can range from changing the interface to be more user friendly, to have seminars in which the interface is explained. Either way it should include persons from the habilitation centres.

7.3 Explore the Geometry prototype

Even though the geometry prototype was discarded in this study, it still had potential to aid the eye tracker users in concept formation.
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REFERENCES


REFERENCES


Appendices
Appendix A

Pre-study

In this section, documents for the pre-study is presented.
APPENDIX A. PRE-STUDY

A.1 Interview Outline

Agenda för studiebesök 1

- Skapa intresse att medverka – berätta

- Lyhört lyssnande
  - Hur ser typisk lektion ut?
  - Kommunikation med AAC-elever kontra andra elever?
  - Kognitiva nivåer
  - Logopedens relation till eleverna

- Boka tid för en observation. Vara med i klassen

- Kolla in föräldrars godkännande, anonymt eller med namn/foto?

- Boka tid för nästa iteration.
A.2 Consent form - Adult

Medgivandeformulär

Bakgrund

Vi – Pär Dahlman och Oskar Wyke – utvecklar inom ramen för vårt examensarbete på KTH ett program till Tobis kommunikationshjälpmedel. Syftet med programmet är att tillgodose vissa av de behov av interaktion som uppstår i samband med matematikstudier.

En målsättning med projektet är att låta personer som använder Tobis kommunikationshjälpmedel testa programmet för att se hur det fungerar. Denna användbarhetsstudie kommer att ligga till grund för rekommendationer om hur vidare utveckling av matematikhjälpmedlet bör fortskriva.

Medgivande

Jag ger mitt medgivande att låta Pär Dahlman och Oskar Wyke använda data och synpunkter, som uppkommer under användarstudien, i utvecklingen av kommunikationshjälpmedlet.

Jag är också medveten om att den information som insamlas i samband med användbarhetsstudien kommer att anonymiseras. Eventuella foton och inspelningar från användbarhetsstudien kommer att enbart att ligga till grund för analys och raderas efter sex månader, om inte annan överenskommelse nås.

Namn (texta): ____________________________________

Signatur:  ____________________________________

Datum  ____________________________________
APPENDIX A. PRE-STUDY

A.3 Consent form - Under-age

Medgivandeformulär

Bakgrund

Vi – Pär Dahlman och Oskar Wyke – utvecklar inom ramen för vårt examensarbete på KTH ett program till Tobii kommunikationshjälpmedel. Syftet med programmet är att tillgodose vissa av de behov av interaktion som uppstår i samband med matematikstudier.

En målsättning med projektet är att låta personer som använder Tobii kommunikationshjälpmedel testa programmet för att se hur det fungerar. Denna användbarhetsstudie kommer att ligga till grund för rekommendationer om hur vidare utveckling av matematikhjälpmedlet bör fortskrida.

Medgivande

Jag ger mitt medgivande att låta Pär Dahlman och Oskar Wyke genomföra användbarhetsstudien tillsammans med mitt barn och personal på skolan.

Jag är också medveten om att den information som insamlas i samband med användbarhetsstudien kommer att anonymiseras. Eventuella foton och inspelningar från användbarhetsstudien kommer att enbart att ligga till grund för analys och raderas efter sex månader, om inte annan överenskommelse nås.

Barnets namn (texta): ____________________________

Förälderns namn (texta): _________________________

Förälderns signatur: ______________________________

Datum  ____________________________________

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Appendix B

Iteration 1

In this section, documents for the first iteration is presented.
B.1 Geometrical Concept

HUVUDIDÉ

Den grundläggande idén med detta verktyg är att eleven skall ge möjlighet att bekanta sig med de geometriska formerna. Utöver just själva formerna så är även färg och storlek parametrar som kommer att finnas med. Ett sista viktigt koncept som kommer att behandlas är position.

Upplägget är att eleven möts av yta, innehållande ett antal geometriska figurer av varierande typ, färg form och inbördes placering. Till denna samling figurer ges också en uppgift. En typisk uppgift kan t.ex. vara ”Välj den största triangeln.” som då fungerar som en uppmanning till eleven att välja ut den kvadrat, bland ett antal andra geometriska figurer, som har störst yta.

Exempel på geometriska figurer som visas för eleven

MÅLSÄTTNING

Under arbetet med verktyget är tanken att eleven skall få ökad kännedom och känsla för följande begrepp och koncept:

- Olika geometriska figurer
  - Cirkel
  - Kvadrat
  - Triangel
  - Rektangel

- Olika storlekar
  - Största
  - Minsta
  - Näst största
  - Näst minsta

- Positionering och inbördes ordning
  - Översta
  - Understa
  - Högra(?)
  - Vänstra(?)

- Olika färger
  - Röd
  - Grön
  - Svart
  - Osv.

Då olika individer ligger på olika nivå gällande förståelsen av ovan nämnda koncept så kommer fullständig anpassningsbarhet vara en del av upplägget. Är det t.ex. så att en individ endast har kunskap om kvadrater och cirklar kan endast dessa former väljas ut. Detsamma gäller för de olika positionsbestämningarna.
APPENDIX B. ITERATION 1

B.2 Columnar Calculation

Uppställning

Målsättning
Programmet ska underlätta för eleven att

- Utföra/kommunicera addition, (subtraktion, division och multiplikation)
- Öva på addition, subtraktion, (division och multiplikation)

Huvudidé

Alt 1.
Eleven väljer själv täljare, nämnare och räknesätt. Eleven kan sedan utföra uträkningen på sammas sätt som vanligtvis görs med penna och papper, det vill säga räkna "från höger till vänster" och använda sig av minnessiffror.

<table>
<thead>
<tr>
<th>1</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>3 4</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
</tr>
</tbody>
</table>

Det finns en knapp som aktiverar röstsyntesen att läsa upp det uträknande svaret. På så sätt underlättar programmet inte bara själva räknemomentet, utan även kommunikationen i klassrummet.

Alt 2.

Tillägg

Visualisering
Konkretisera talen genom att också representera den till fysiska objekt (äpplen, katter, ...)

"Förvalda fält"

För elever som är nya till den här typen av uträkningar så kan "förvalda fält" aktiveras, vilket gör att det första fältet är aktiverat för att fylla i en siffra i (i exemplet 1), när siffran är ifylld markeras fältet med minnessifra (om applicerbart) och så vidare.

För elever med större vana kan denna funktion avaktiveras, så att eleven får markera positionen själv.
Appendix C

Iteration 2

C.1 Wire-frame prototype

In this section, screen shots from the wire-frame prototype are presented. Some of the views are omitted, as they would be redundant.

![Figure C.1: The first page. The user can chose to either create own tasks or enter “practice mode”](image-url)
APPENDIX C. ITERATION 2

Figure C.2: Select operation. This view is presented for both modes.

Figure C.3: Enter the first term. The numerical panel is central and the green box indicates that it is the first term that is being entered.
Figure C.4: Enter the second term. The user gets to this view by pressing the green arrow to the left.

Figure C.5: Start counting. A number is inserted by first selecting a particular position, followed by entering a digit to it.
APPENDIX C. ITERATION 2

Figure C.6: A selected position gets high-lighted, which indicates that the digit selected will be entered there.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>+</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
</tr>
</tbody>
</table>

Figure C.7: Correcting the task. The green background colour indicates that the task is correctly solved.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>+</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0</td>
</tr>
</tbody>
</table>

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>9</td>
<td>0</td>
</tr>
</tbody>
</table>
APPENDIX C. ITERATION 2

Figure C.8: Menu opened. The symbols are: (i) "Home" (ii) Save calculation (iii) Close menu. The last button was omitted in order to get feedback to what else should be in the menu.

Figure C.9: Practice mode. In this view, the user selects the span for the terms generated.
Figure C.10: Span 0-10 selected. In this example, the motorcycles are used to visualize the task.
Appendix D

Iteration 3

Below are the documents that were used during the third iteration. It includes, test plan, information to team, observation scheme, quantitative metrics and a walkthrough of the final prototype.
D.1 Test Plan

Testplan – Tillfälle 1

<table>
<thead>
<tr>
<th>Skola:</th>
<th>Användare:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Datum:</td>
<td></td>
</tr>
</tbody>
</table>

Syfte:
- Introducera användaren för MathPlugin
- Ge användaren tillfälle att bekanta sig med gränssnittet
- Registrera användarbarhets- och tillgänglighetsproblem
- Måta tidsåtgång för utförande av enklare uppgift

Förutsättningar:
- MathPlugin finns installerad på användarens egen ET-enhet
- Assistent, lärare och eventuell logoped finns närvarande under testets inledande skede
- Användaren bör ha viss förtrogenhet med uppställningsalgoritmen

1. Introduktionen till programmet:
- Testledaren startar programmet och berättar därefter om de två lägena *Egna tal* och *Övning*
  - Skriva in siffror
  - Förklara sudda
- En addition, utan minnessiffra, med två termer ställs upp och räknas ut
  - Förklara "tvåstegs-inmatning"
  - Förklara sudda
  - Lös uppgift (Felaktigt)
  - Klicka på knappen för rättning
  - Korrigera fel och skapa därefter en ny uppgift
- En addition, denna gång med minnessiffra ställs upp
  - Lös som ovan, men med användande av minnessiffror
- Skapa, om eleven behärskar detta, en subtraktion med/utan minnessiffra
  - Lös som ovan och visa eventuellt om hur lån sker
- Bläddra mellan uppgifterna och visa översikten
- Gå till startmenyn
- Starta övningsläge (som tidigare ställts in till användarens egen nivå)

2. Användaren utforskar:
Användaren får i detta steg på eget bevak utforska användandet av programmet och uppmuntras att använda alla funktionerna som tidigare visats.

3. Utvärdering av interaktion:
- Får två eller tre uppgifter att lösa.
- Tid tas på denna aktivitet
- Tiden, samt eventuella problem och hjälpsatser noteras (skall jämföras med utförande av liknande uppgift i senare utvärderingstillfälle)
D.2 Information to team

Punkter över viktiga saker att ta upp med teamet

- Var observant på:
  - situationer där ofrivilliga felklick uppstår
  - tillfällen då användaren inte vet hur denne skall komma vidare
  - anledningar till att hjälp från utomstående behövs
- Visa autoselect
- Alla inställningar, olika färger och typer av tal
- För berörda användare räkna både med och utan visualisering
- Berätta om loggningen
### D.3 Observation scheme

#### Inmatning av termer

**Användaren skriver in fel siffra och suddar**

<table>
<thead>
<tr>
<th>Orsak</th>
<th>Antal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Användaren tänkte fel och korrigerar val</td>
<td></td>
</tr>
<tr>
<td>Användaren gjorde ett oavsiktligt val</td>
<td></td>
</tr>
<tr>
<td>Användaren &quot;testade&quot; programmet</td>
<td></td>
</tr>
</tbody>
</table>

**Vad händer när term 1 har matats in?**

<table>
<thead>
<tr>
<th>Utfall</th>
<th>Antal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Användaren försöker trycka på rutan för term 2</td>
<td></td>
</tr>
<tr>
<td>Användaren tvekar i några sekunder</td>
<td></td>
</tr>
<tr>
<td>Användaren trycker på pil ner</td>
<td></td>
</tr>
</tbody>
</table>

**Vad händer när term 2 har matats in?**

<table>
<thead>
<tr>
<th>Utfall</th>
<th>Antal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Användaren försöker trycka på rutan för svar</td>
<td></td>
</tr>
<tr>
<td>Användaren tvekar i några sekunder</td>
<td></td>
</tr>
<tr>
<td>Användaren trycker på pil ner</td>
<td></td>
</tr>
</tbody>
</table>
## APPENDIX D. ITERATION 3

### D.4 Quantitative Metrics

**Mätetal**

**Suddar per siffertryckning**

<table>
<thead>
<tr>
<th>Syfte:</th>
<th>Att se hur felfrekvensen förändras över tiden</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Genomförande:</strong></td>
<td>Logga varje siffertryck som genererar inmatning liksom alla klickningar på suddknappen som genererar att sifra suddas ut. Efter utvärderingsperiodens slut ställs ration upp för varje tillfälle.</td>
</tr>
<tr>
<td><strong>Hypotes:</strong></td>
<td></td>
</tr>
</tbody>
</table>

**Midas touch**

<table>
<thead>
<tr>
<th>Syfte:</th>
<th>Att mäta antalet oavsiktliga val</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Genomförande:</strong></td>
<td>Baseras på loggning av alla siffertryckningar och analyseras sedan i Excel med formal liknande: (=IF(AND(A2-A1&lt;2000;D2=D1);&quot;MIDAS&quot;;&quot;NO MIDAS?&quot;)))</td>
</tr>
<tr>
<td><strong>Hypotes:</strong></td>
<td>Det kommer att kunna ske en del dubbelval. Om detta är fallet, styrks belägen för det designval vi gjort</td>
</tr>
<tr>
<td><strong>Felkällor:</strong></td>
<td>I det fall då autoselect inte är valt kan det hända att användaren väljer att dövja på sifferpanelen och därmed triga dubbelval, då denne vet att detta inte påverkar gränssnittet.</td>
</tr>
</tbody>
</table>

**Uppläsningsknappen**

<table>
<thead>
<tr>
<th>Syfte:</th>
<th>Att undersöka hur ofta uppläsningsfunktionen används</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Genomförande:</strong></td>
<td>Logga varje tryckning på uppläsningsknappen</td>
</tr>
<tr>
<td><strong>Hypotes:</strong></td>
<td>Den kommer användas frekvent</td>
</tr>
</tbody>
</table>

**Är knapparna för små?**

<table>
<thead>
<tr>
<th>Syfte:</th>
<th>Att undersöka om Carry/Answer sitter för nära / är för små.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Genomförande:</strong></td>
<td>Logga varje fall som en Answer/Carry till höger om en tom Answer/Carry blir vald, varpå den tomma rutan blir vald och en sifra sedan mats in.</td>
</tr>
<tr>
<td><strong>Hypotes:</strong></td>
<td>Knapparna är tillräckligt stora för merparten av användare</td>
</tr>
</tbody>
</table>

**Learnability**

<table>
<thead>
<tr>
<th>Syfte:</th>
<th>Att undersöka felfrekvensen och tidsåtgång vid enklare test</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Genomförande:</strong></td>
<td>Ge slutanvändaren två tal och observera genomförandet</td>
</tr>
<tr>
<td><strong>Hypotes:</strong></td>
<td>Under det andra tillfället kommer användaren känna till gränssnittet bättre och låta tidsåtgången minska.</td>
</tr>
</tbody>
</table>
D.5 Debriefing Questions

Intervju

- Hur många gånger/mycket tid har MathPlugin använts?
  - Hemma/i skolan?
- Är det något speciellt som fungerat dåligt med programmet?
  - Svårt att välja?
  - Svårt att läsa?
  - Svårt att förstå?
- Om du skulle få förändra en sak, vad skulle det vara?
- I vilka situationer har uppläsningknappen använts?
- Hur skulle feedbackrutan se ut om du fick bestämma själv?
  - Ljud
  - Bild
- Hur har du löst liknande problem tidigare?
  - Vad är bra med det sättet att lösa uppgiften?
  - På vilket vis hjälper det nya programmet dig att göra det?
- Räkna talet
D.6 Walk-through of final prototype

In this section, a brief walk through of the work flow of the high fi prototype is given. It describes the basic work-flow and main design ideas. Each user got personalized of this work flow, to suit their needs.

For example, the branch that deals with subtraction was removed for one student, as he is not too familiar with this concept.

Figure D.1: Select task, either count you own tasks, enter practice mode or exit program.
Figure D.2: Select operation, addition, subtraction or addition with visualization.

Figure D.3: Entering first term. The digits are inserted by looking at the panel to the right.
Figure D.4: Entering second term. The digits are inserted by looking at the panel to the right.

Figure D.5: Start counting. The first result position is selected. The three buttons in the lower left corner are: toggling correction mode, read task and open menu.
Figure D.6: Correction mode toggled. Feedback are given to every position. In this example, the digit 5 is incorrect, why it has a red background colour.

Figure D.7: Task is correct. The user gets visual feedback and a short sound clip (applause) is played. This feedback can only be activated once for every task.
Figure D.8: The menu is opened. From here, the user can navigate through tasks, create a new task and return to "home" (the first page).

Figure D.9: An example of a more difficult task. The operation sign and the line between the second term and answer has dynamically been changed. The number of answer- and carry digits slots has also dynamically increased.
APPENDIX D. ITERATION 3

Figure D.10: An example with subtraction. The digit panel to the right has now been extended to have a button for selection ten, which is used when "borrowing". When doing this, a line is dynamically drawn over the number from which the loan has been done.

Figure D.11: An example with visualizations. The figures can be resized and changed in edit mode.
Figure D.12: The summary page gives an overview of how many tasks that are initialized. Green indicates that the task is correctly solved, red that it is not. This view can be used to navigate to a specific task (by looking at it).

Figure D.13: Edit mode. It is easy to move and resize buttons in edit mode.