UNIVERSITY OF OSLO
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The Augmented Reality Experience: Learning and Collaboration

Master thesis
(60 credits)

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Abstract

The purpose of this master thesis is to investigate advantages and disadvantages of software interfaces utilizing human motion based actions. The case discussed in the thesis is based on the Augmented Reality interface that was designed for that purpose. The focus has been on the effects of the augmented reality interface on user experience, how it affects the learning curve towards the large software and what it can do for collaboration. The initial research for this project was done at the User Experience department of Schlumberger. It was from here that the desire came for an easier way to interact with the many complex models they encounter in their daily work, and AR was the chosen technology to achieve this. A prototype has been developed for representing and manipulating models through using augmented reality, allowing direct control of the models and their environment by human motion and markers. It was then tested with users to get feedback on its advantages and disadvantages, compared with standard computer interfaces such as a keyboard and a mouse.

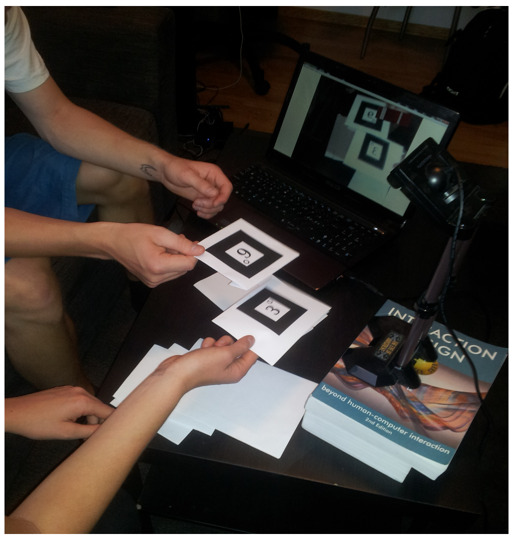

Figure 1. My augmented reality prototype.

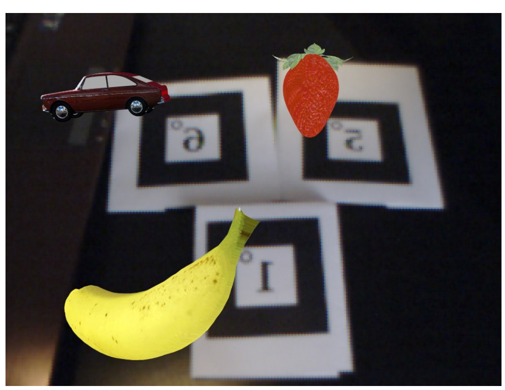

Figure 2. The prototype displaying multiple models.

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Chapter 1

Introduction

It can often be a challenge to learn and master a new interface in software, in particular when one is an inexperienced user and the software very complex. When this software is intended for collaboration, it becomes even harder, as teamwork enters the picture. While more experienced users can explain their understanding of the interface to novel users, these explanations can be just as complicated as the interface itself. However, the previous statement often does not apply to software intended for entertainment, such as video games. Video games have proven to be very efficient at teaching players subjects and lessons other more "seriously" themed methods have failed or struggled to teach, see [12]. The video games' targeted design towards a good user experience is often attributed to this. A video game is intended to be "fun", "engaging", "immersive" and so on. Many interfaces today show signs of incorporating these qualities, but many of them just attempt to add these qualities to existing concepts, and not building the system with these qualities as a core focus.

Objective of the thesis

The objective of this thesis was to explore the possibilities that Augmented Reality (AR) offers as an interface towards large software. AR has many qualities similar to those found in video games, and thus has a great potential for use in both the entertainment and work-related arenas. The desire was thus to explore if AR system can effectively replace or complement standard interfaces such as computers with a mouse and a keyboard. Further, perhaps its playful quality could contribute to improvement of the rate at which users understand, perform and master their tasks.

The goal of the thesis

The goal was to design and implement an AR system that would replace the classic interface of representing models and interacting with them, in such a way that it is intuitive and easy for new users to become acquainted with it's mechanics. This would be a positive step for system development in general as a pointer for looking outside the standard interfaces for efficient task completion.

Background information for the project

This project was formed during my internship at Schlumberger. I started the internship by working a project the aim of which was to create a help tool with interactive techniques to aid in familiarizing with new interfaces and interface changes in Schlumberger's working platform, Petrel. Petrel is massive software with a multitude of functions, and very few users, if any, become acquainted with all of them. This was a function that could potentially be added to Petrel at a later stage, to aid the novice users and improve the user experience for both novice and expert users. Gradually my focus shifted towards expert users. I implemented an interactive tool linking together the old interface with the new interface in Petrel, helping the expert users to see the connection between the two. A feedback from my mentors was that this was a good solution to their problem, and the interactive functions were indeed making for an easy and enjoyable experience in learning the new interface. This project sparked my interest in developing for positive User Experience (UX).

Upon completion of this first project, I was moved on to a different project, this time creating an AR interface for certain actions inside Petrel, attempting to incorporate more modern technology into the software to make certain actions more intuitive. Due to a limited amount of actual work-time, this project never truly left the planning and exploration stages, but a framework for the project was established. It is in this framework my thesis finds its base. It takes the idea of using interfaces based on AR technologies further and makes direct use of motions and gestures to interact with the system directly, without involving standard physical tools like a keyboards and a mouse.

Personal motivation

My personal interest in this field stems from my experiences with different gaming technologies, and knowledge about their success. This generations video game consoles, the Wii, Xbox 360 and PS3, are divided in what they focus on. The Xbox 360 and PS3 are power consoles, having performance values far above the Wii, and with this ranked higher in just about every cross console game that exist on all three of these consoles. However, despite this, the Wii sold the most units and had the highest popularity in general, which has mostly been credited to it's groundbreaking new interactive controls, highly favoring motions over buttons, creating a more intuitive and immersive gaming experience. I hope than the rest of the technological world can gain an increased appreciation of the insights the gaming world has uncovered with events such as the one mentioned above, raising the value of design towards user experience.

Academic motivation

AR has much untapped potential, and many researchers agree that AR brings a new aspect to the user experience of interfaces. In addition, it has many qualities that are well suited for collaboration and learning. However, despite my efforts, I could not find a direct comparison study of AR and a standard interface like the keyboard and mouse in regards to user experience and task efficiency. I wish to take a closer look on such a comparison, and explore both advantages and disadvantages AR holds in this regard, and find if perhaps some inspiration for improvements can be found in such results.

Problem area

Given that the purpose of this thesis was to explore the advantages and disadvantages of AR interfaces, I have designed and implemented a tool that was consequently used to make a study on AR interfaces and their influence on learning, collaboration and general UX. It has been seen from a perspective of comparison to the standard interface of a keyboard and a mouse.

Research questions

Considering the above, I form my research questions as follows:

RQ1: How does an augmented reality interface affect learning when compared to a keyboard and a mouse interface?

RQ2: How does an augmented reality interface affect user-experience when compared to a keyboard and a mouse interfaces?

RQ2: How does an augmented reality interface affect collaboration when compared to keyboard and mouse interfaces?

The answers to the above question do depend on a particular choice of the augmented reality interface that is used in exploration. There exists a magnitude of ways to implement augmented reality and what would be the most effective is subject to research itself. The tool I conceptualized was influenced by what I learned during my internship at Schlumberger. I am confident that this tool would fair well when employed with the kinds of software they use. AR technologies, like all others are changing fast and I think that improvements in any particular interface are possible, but my concerns were more of an inquisitive nature: does AR contribute to a more pleasant user experience? Is it more playful and offers increased motivation to learn about the software? Can it give support that improves quality of collaboration between multiple users? I am pleased to say that after finishing my research I can conclusively say that there are definite indications of AR to be a positive influence in regards to these topics.

I hope that any findings that are made in this thesis can be of use for anyone venturing into the field of creating new AR interfaces for any kind of use, increasing the focus on and a value of a good user experience when using the AR.

Chapter 2

Literature Review

The purpose of this chapter is to describe and explore previous research that is relevant for the issues considered in this thesis as well as a basic introduction to human-computer interaction and the place Augmented Reality (AR) and interface design have in it. In addition, I have reviewed the literature on the User Experience (UX) field, opportunities and challenges in regards to developing, using and experiencing AR applications, AR applications intended for multi-user sessions and finally, AR applications intended for use in learning environments, and possible benefits to these.

As far as I am currently aware, no studies have been done on the topic of my choice. I have found many articles mentioning advantages that AR brings to the table, but no study which includes user-generated data about user experiences with both AR applications and standard tool applications, and comparing the two data-sets, thus offering the possibility for the improvement of either.

General human-computer interaction

Human-computer interaction (HCI) is an area of research and practice that emerged in the early 1980's, see for example, [24] or for a brief introduction, [8]. It was a part of computer science that embraced cognitive science and human factors, as well as other fields, becoming a truly multidisciplinary field, no longer concerned with technology alone. It was along with the emergence of personal computing that the issues around software usability came into focus. In the era before personal computing, mostly trained professional or hardcore hobbyists used computers. Thus, the appearance of a less knowledgeable user group brought about the need to make interactions simpler, more efficient, easily learnable and more pleasing. The emergence of personal computing coincided well with the forming of cognitive science as a field. Just as a practical need of HCI became apparent, the concept of "cognitive engineering" arose from the field of cognitive science, and with it came the resources, people and skills that would be addressing these problems.

Thus began the era of usability, and the era of cognitive engineering represent well the first and the second wave of HCI [7]. Another view is presented by Harrison et al. [14], speaking of three paradigms of HCI: human factors (the usability wave roughly), classical cognitivist/information processing and the third paradigm or wave is phenomenological/situated HCI. HCI as a field has seen steady and rapid development, attracting attention, and adapting to and including a wide range of concepts and approaches into its folds. Today HCI is an essential part of most informatics-based research and practice. HCI is therefore a great example of successful merging of different paradigms and epistemologies under the same umbrella.

The main positivistic focus of HCI is perhaps still that of usability. A simple phrase encasing the original concept of usability is “easy to learn, easy to use”. This was a simple concept to grasp, which aided its stability and influence in the different circles of computer science and development. The term usability has been in a constant state of change and adaption since it's very beginning, moving away from it's initial simple concept to include more human factors, and also paying attention to more obscure factors like fun, beauty, flow and so on. The term “user experience” (UX) has its roots in this change, fully embracing these more difficult to measure factors as key to development and design.

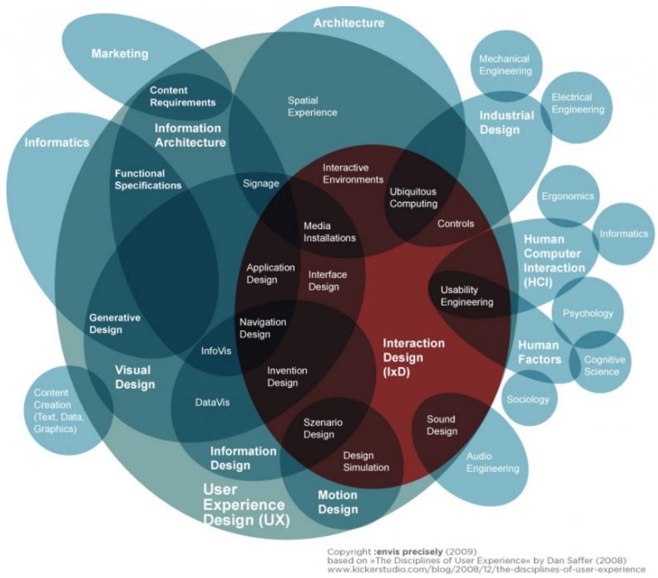

Figure 3. Venn diagram of Interaction Design as a field and it’s connections

Interaction design is a field with close relations to HCI, and as a field of research, it has embraced the full meaning of user experience in much the same manner as HCI has embraced usability. This is according to Sharp, Rogers and Preece, see [33], give to the relation between HCI and interaction design in their book “Interaction Design: Beyond Human-Computer Interaction”. The boundaries between interaction design and HCI are though often not that clear [10]. The increasing attention to, and influence of interaction design as a field of research has in turn affected HCI, mostly in its phenomenological/situated paradigm, which can be seen in articles like Blythe et al., [6], and Norman [27,28]. One factor in this change is due to a proven positive correlation between usability and attractiveness regarding the feeling of “ease-of-use” in a product. When users were presented with two functionally equivalent interfaces, but differing in aesthetic attractiveness, users would find the more attractive interface easier to use compared to the other. In particular, the computer games industry has acknowledged this relation between pleasure and usability, but there have been cases where it works the other way. Games that seem challenging to users are often ranked as more pleasurable to use, which defies usability goals in making things easy to use [31]. Interfaces requiring more effort and skill to operate can give more pleasurable experiences than more efficient interfaces, due to how the interaction is performed. Sharp et al. [33] give an example of using a plastic hammer to hit a virtual nail on a screen being more enjoyable for users that using command keys on a keyboard to accomplish the same task.

This short introduction of HCI does not cover all that HCI entails, but provides a general framework for understanding the position of my research. The next section focuses on a more specific area, user experience.

UX

UX and design towards it has received a lot of focus in computer science and fields of development in recent times, due to its apparent usefulness in making users more inclined to choose the designed object with this in mind over other objects, and to keep using it. This is an obvious factor of interest for the commercial market. But due to its relatively young state as a field, it may still be unclear what value it holds for the commercial market on one hand, and what it really is as a field on the other.

HCI practitioners have now begun to adopt concepts of UX in search of new ways to approach designing interactive products, with the intended goal of enhancing experiential qualities in objects over product qualities. This is a sign of a shift away from usability and towards UX. The challenge in designing for UX is to define what creates a good UX. Hassenzahl et al. [15] believe that a UX through study can be categorized into different types of needs and placed into groups of needs related to either “hedonic qualities” or “pragmatic qualities”. They collected and identified over 500 positive UXs and performed a study with those categories of experience. When the needs are defined and one can study the experiences the key needs were fulfilled in, one can search for patterns that can be used in future design for a positive UX. The nature of an experience is very situational and individual, and it can be hard to separate it from its context, as described in Culén [9] in relation to “coolness”.

The field of UX has opposition from those with the opinion that experiences cannot be measured sufficiently to base design approaches upon. In their article, Hassenzahl et al. [15] mention Schmitt [32], who states that while experiences can be described, they cannot be categorized or reduced to one or more factors. This would make design for future experiences difficult, and is therefor as a concept incompatible with HCI. This problem was handled by arguing that while each experience is varied and highly individual, it can still be classified by defining the primary basic human need that is fulfilled by the experience. By using that approach, one allows for design towards a positive experience, and more important to note, design towards certain kinds of positive experiences. A project can then present certain requirements in its design, e.g. design towards a feeling of competence, mastery or coolness from using the designed product.

An interesting result from their study was further support for the idea that hedonic qualities can act as “motivators”. This means that through fulfilling needs they create positive experiences. In addition it was concluded that pragmatic qualities hold a “hygiene factor”, which does not aid much in creating positive experiences. However, the needs they relate to are called “deficiency needs”, which are needs that can be the cause of negative experiences if not fulfilled.

Another challenge regarding UX and design towards it that has received more focus as of late is how the perceived UX of a product changes over time. Most measurements of UX that are done today are on initial experiences, and it follows that design concepts derived from such measurements will mainly be aimed toward improving future initial experiences, as they are not based on data from measurements of long-term usage experiences. However, there are factors of experiences that are not accounted for in initial experiences. One example of such can be emotional attachment. A good initial experience increases the odds of use long enough for emotional attachment to occur, but the experience over time can also decline, hindering the occurrence of emotional attachment. An example of cause for declining experience quality can be that functions the user at first found new and enjoyable were not satisfactory when the user becomes accustomed to them and they no longer seem as “novel” as in the past. By studying products that had good initial experiences, but differ in experience quality over time, can reveal patterns and results that can be key to true design towards a good UX, both initially and over periods of time.

UX is still in it's early stages as a field, and opinions about it vary, most complaints being around its lack of real theory, see Obrist et al. [29]. It can be said, though, that it is a versatile field capable of giving answers to different requirements and situations within product design. With its focus on experience, it may aid in the general improvement of designed products.

For all of the above-mentioned reasons and qualities that UX brings into projects, UX is a key area for my project. AR as a tool and technology needs good initial experiences to get acceptance in the personal computing and entertainment arena, and good experiences over time to keep up interest for further development. The next section connects UX with AR.

Uses, experiences and challenges with AR

This section gives an introduction to AR, its beginning, known uses and challenges with AR, and experiences with it.

AR has its origins in the 1960's, but it wasn't until the late 90's that it became a distinct field of research. A related area is virtual reality (VR), which is a lot more known to the general public. Benford et al. [2] classify a system as AR when it:

- *”Combines real and virtual objects in a real environment”*
- *”Registers and aligns both real and virtual objects with each other”*
- *”Runs interactively, in three dimensions, and in real time.”*

Besides this classification van Krevelen and Poelman [21] say that it is important to mention that AR is nor restricted to a single type of display or sensory input. While sight is the most common sense to perceive AR through, it can potentially be done through other senses such as hearing, touch and smell as well. They also state that removing a real object by overlaying virtual objects is also considered to be AR.

It was after the emergence of the ARToolkit and other developer tools for AR that development in AR saw real progress. The ARToolKit is a computer tracking library for creation of strong augmented reality applications that overlay virtual imagery over the real world imagery, first designed by Kato, see [18]. Despite higher technological demands for AR than VR, AR has the same key components today as it did in the 1960's [21]. The components however, have increased in possible variations since then. In Table 1 in [21], see Figure 4, one can see a list of the conventional display methods used in AR, and their advantages and drawbacks.

TABLE 1: CHARACTERISTICS OF SURVEYED VISUAL AR DISPLAYS.

Positioning	Head-worn				Hand-held	Spatial		
Technology	**Retinal**	**Optical**	**Video**	**Projective**	**All**	**Video**	**Optical**	**Projective**
Mobile	+	+	+	+	+	−	−	−
Outdoor use	+	±	±	+	±	−	−	−
Interaction	+	+	+	+	+	Remote	−	−
Multi-user	+	+	+	+	+	+	Limited	Limited
Brightness	+	−	+	+	Limited	+	Limited	Limited
Contrast	+	−	+	+	Limited	+	Limited	Limited
Resolution	Growing	Growing	Growing	Growing	Limited	Limited	+	+
Field-of-view	Growing	Limited	Limited	Growing	Limited	Limited	+	+
Full-colour	+	+	+	+	+	+	+	+
Stereoscopic	+	+	+	+	−	−	+	+
Dynamic refocus (eye strain)	+	−	−	+	−	−	+	+
Occlusion	±	±	+	Limited	±	+	Limited	Limited
Power economy	+	−	−	−	−	−	−	−
Opportunities	Future dominance	Current dominance			Realistic, mass-market	Cheap, off-the-shelf	Tuning, ergonomics	
Drawbacks		Tuning, tracking	Delays	Retro-reflective material	Processor, Memory limits	No see-through metaphor	Clipping	Clipping, shadows

Figure 4. A table from [21] showing characteristics of AR displays

The most focus in AR so far has been on head mounted displays (HMD's), but it has been advocated for projector based AR as well [35]. Compared to HMD AR, AR based on projectors has no need of compensating for motion, as the projector is stationary. The projections also remove any lag or delay issue from HMD's. A requirement exclusive to projector based AR however, is surfaces. If the target surface for projection is not suited for it, reflections and unevenness can disrupt the quality of the projection, and thus the AR experience. Since it is being projected into the outside environment, outside influence, such as lighting, texture and color of the surface also affects the quality of the projection, see Figure 2.

Tracking is also key component of AR. With recent technological advances, this area has really flourished. Modern ubiquitous augmented reality systems use one or more of the following tracking technologies: digital camera, optical sensors, GPS, modeling environments, motion tracking, mechanical, ultrasonic, magnetic, radio, inertial, optical and hybrid, accelerometers, RFID and wireless sensors. These technologies offer varying levels of accuracy and precision. However, one can use hybrid-tracking methods in order to improve accuracy of AR systems. GPS, motion tracking and optical sensors are the best-known methods, seen in many publicly common applications today.

Van Krevelen et al. [21] state that with AR, user interfaces reached a new paradigm, moving away from W.I.M.P (windows, icons, menus and pointing) towards 6DOF (six degrees of freedom), including selection, annotation and direct manipulation of physical objects. The keyboard and mouse as tools are not well suited to this paradigm, as they are too cumbersome to use in the environment, and thus reduce the user's immersion in the environment. Tangible UIs, using wands and paddles instead of a mouse, are a better way of interaction with AR. Another good way of interacting with AR systems are tiles with fiducial markers and personal interaction panels (PIP) with 2D and 3D widgets. The list continues with methods such as haptic and visual UI's with gesture recognition, eye tracking, aural UI with speech recognition and text input. Each has its own strengths, weaknesses and intended uses. Hybrid UI's exists that depends on several of these at once, to balance out the weaknesses of each and further enhance their strengths.

AR for the mobile platform has a few extra requirements compared to stationary AR systems, as stated by Höllerer and Feiner referred to in [1]. The computational framework remains the same, with only a few modifications for mobility, but the most significant requirement is now wireless networking. Most AR systems require connection to a wireless network to function at full potential. In addition to this, the commercial success of AR requires a decent amount of available content. The creation and/or recording of dynamic content could benefit from the techniques developed in the movie and games industries, as well as easily available 3D drawing software such as Google Sketchup.

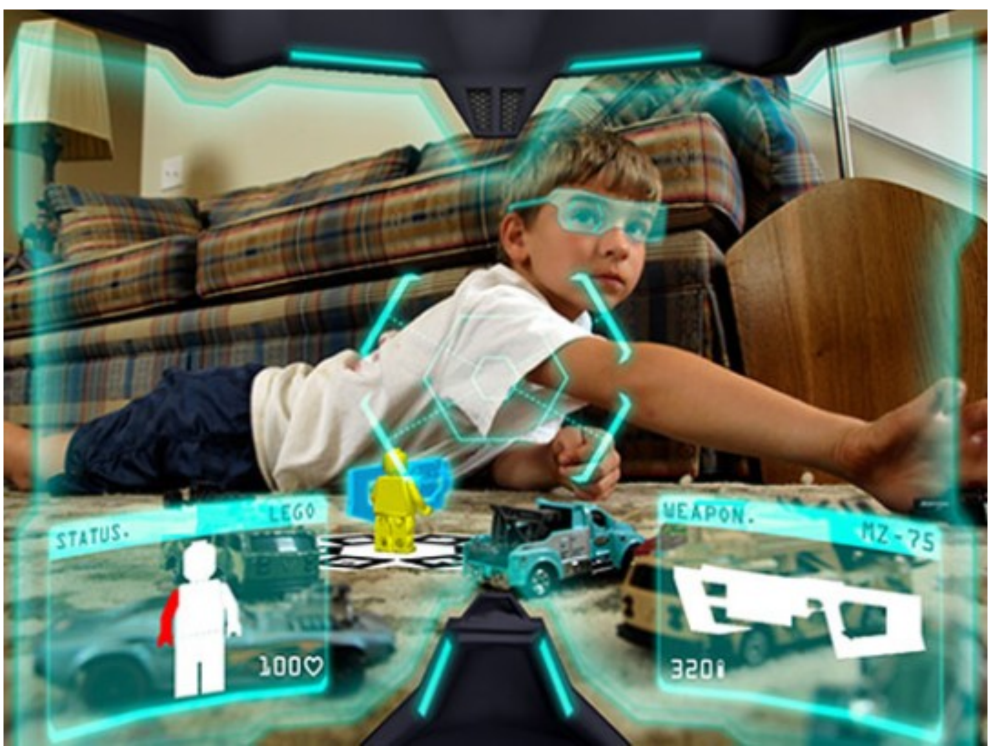

Figure 5. AR based games in toy industry, see [36].

Applications using AR have their beginning in military, industrial and medical fields, but soon after found their potential in the commercial and entertainment areas. Höllerer and Feiner, see [17], believe in the potential AR brings to the market in personal wearable computing. AR could serve as an advanced, immediate and more natural UI for wearable and mobile computing for personal use.

AR has a broad possibility for applications, and with the right context filter, could be well suited to personal assistance and advertisement applications. The use of GPS for tracking makes AR a natural option for navigational applications, and with some extra filters, touring applications see their possibilities in AR as well. As the origin point of AR, the fields of industry, military and medicine has many applications for AR, being design, assembly and medical injections, among others. Entertainment systems such as video games have used AR in several ways successfully. It has also been seen used in situations like sports broadcasting of ice hockey matches, where the puck moves at such speeds that it is hard to detect for viewer. An AR system named Fox-Trax marks the puck on the screen with extra symbols around it, making it more visible.

AR has also been used for purposes like collaboration at work or in education, and this will be more closely looked at in a later chapter.

Figure 6. a) AR can be used for navigation b) an AR application designed by students in INF5590.

So far, the focus has been on the uses and possibilities of AR, but there are many limitations to this technology that must be addressed for AR to rise to it's full potential, and become more socially accepted than it is today. Some of the issues regarding AR are; stereo view, high resolution, field of view, focus depth, intuitive interfaces, costs, power usage etc. The list is long, and while there are certainly systems that have come up with solutions to some of the problems, the challenge of addressing many or all of these, without increasing others, is something that is still being researched today.

Portability and outdoor use of AR are still a bit of an issue. With the rise of mobile AR system that followed the rise of the smartphone, this problem is no longer quite as prominent, but there is still some work left [25]. The mobile platform suffers from a lack of CPU power to handle the most arduous AR tasks, and other AR systems often require much equipment, making it hard to transport outside. This equipment can also encounter durability issues in outside conditions. While networking and tracking efficiencies are being improved on a regular basis these days, latency and calibration issues still remain, disrupting the immersion level of AR systems. Since most AR systems struggle with stereo view, depth perception becomes an issue. The release of the Google Glasses and other similar commercialized HMDs may address this sufficiently to no longer be a major issue. Since extra information is added with AR, an overload of information must be avoided in the interface, as well as making sure that it is not overly relied upon, creating possibilities of missing out on cues from the environment, a balancing issue for developers.

Kruijff, Swan and Feiner [22] took a closer look at perceptual issues with AR [3]. Below you can find two tables, see Figures 7 and 8, regarding their findings on issues with each area of perception of AR, and a short summary of actions taken to mitigate these issues.

Issue	Problem	References
Environment		
Structure *Clutter, patterns, visibility, depth, surfaces* (H, M, P)	Visibility, depth ordering, scene distortions, object relationships, augmentation identification, surface perception	Rosenholtz et al. [49], Sandor et al. [50], Livingston et al. [36], Lappin et al. [32], Grossberg et al. [19], Bimber et al. [5], Guehring, [20], Raskar et al. [45]
Colors *Monotony, opponency* (H, M, P)	Depth distortion, depth ordering	Gabbard et al. [17], Stone [54], Gabbard and Swan [16]
Condition *Indoor, outdoor illumination* (H, M, P)	Visibility	Stauder [53]
Capturing		
Image resolution and filtering (H, M)	Object relationships, object segmentation, scene abstraction	
Lens issues *Quality, wide-angle, flares, calibration* (H, M, P)	Object relationship, scene distortion, visibility	Klein and Murray [30]
Exposure (H, M, P)	Depth distortion, object segmentation, scene abstraction	
Color correctness and contrast (H, M, P)	Depth distortion, object relationships, object segmentation	Mantiuk et al. [39], Rastogi [46], Reinhard et al. [47], Stone [54]
Capturing frame rate (H, M, P)	Scene abstraction	Thropp and Chen [58], Ellis et al. [10]
Augmentation		
Registration errors (H, M, P)	Object relationships, depth ordering	
Occlusion *Object clipping, x-ray vision* (H, M, P)	Visibility, depth ordering, scene distortion, object relationships	Ellis and Menges [9], Wloka and Anderson [61], Berger [3], Klein and Drummond [29], Feiner and MacIntyre [12], Livingston et al. [38], Tsuda et al. [59], Kjelldahl and Prime [28], Elmqvist et al. [11], Kalkofen et al. [26], Lerotic et al [33]
Layer interferences and layout *Foreground-background, clutter* (H, M, P)	Visibility, depth ordering, object segmentation, scene distortion, text readability	House et al. [22], Robinson and Robbins [48], Bell et al. [2], Azuma and Furmanski [1], Leykin and Tuceryan [34], Peterson et al. [43], Gabbard and Swan [16], Stone, [54]
Rendering and resolution mismatch *Quality, illumination, anti-aliasing, color scheme, resolution mismatch* (H, M, P)	Depth distortion, depth ordering	Thompson et al. [57], Jacobs and Loscos [23], Rastogi [46], Okumura et al. [41], Drascic and Milgram [8]

Figure 7. Perceptual issues

Finally, I summarize some issues and their possible mitigations from Dunleavy et al. [11]. Issues regarding environment range from structural issues like visibility of structure, depth ordering, scene distortions, relationships between objects, identifying augmented objects and correct perception of surfaces, along with related issues due to color and conditions. Mitigations to these problems include having a better layout, to improve visibility, depth ordering and perception in general. By putting in pattern interferences in between objects, the foreground and background can be separated for easier distinction. If it is projected, there are geometric and photometric methods than can be used to solve color pattern corrections, angular and curvature corrections and illumination problems such as those caused by patterns from shadows.

Issue	Problem	References
Display device		
Stereoscopy (H)	Object relationships, visibility	Livingston et al. [36], Livingston et al. [37], Jones et al. [25]
Field of view (H, M)	Scene distortion, object relationships, visibility	Knapp and Loomis [31], Ware [60], Cutting [42
Viewing angle offset (M)	Object relationships	
Display properties (H, M, P)	Visibility, object segmentation, scene abstraction, object relationships, text legibility	Livingston [37], Rastogi [46]
Color fidelity (H, M, P)	Visibility, depth distortion, color perception	Livingston et al. [37], Fraser et al. [15], Seetzen et al. [51], Gabbard et al. [17], Jefferson and Harvey [24], Ware [60], Stone [51], Gabbard et al. [17]
Reflections (H, M)	Visibility, object segmentation, scene abstraction, object relationships	
Latency (H, M)	Scene abstraction, object matching	Thropp and Chen [58], Ellis et al [10], Drascic and Milgram [8]
User		
Individual differences (H, M, P)	Object segmentation, scene abstraction	Linn and Petersen [35]
Depth perception cues *Pictorial, kinetic, physiological, Binocular* (H, M, P)	Object segmentation, scene abstraction, depth distortion	Drascic and Milgram [8], Cutting [7], Gerbino and Fantoni [18], Swan et al. [55]
Disparity planes (H, M)	Depth distortion	Gupta [21]
Accommodation *Conflict, mismatch and absence* (H)	Depth distortion, size perception	Drascic and Milgram [8], Mon-Williams and Tresilian [40], Gupta [21]

Figure 8. Perceptual issues cont.

In augmentation, the main problem for AR is with registration errors, but new or improved tracking methods are developed continuously, so this will see better results with time. Occlusion of augmented objects can be fixed with contour based clipping methods and improved x-ray visualization, and correct illumination is helpful to avoid this. The resolution of rendered objects don't always match the video output, but there are applications that can match the resolution of rendered objects to the video, and focusing on blurring scenery and augmentations can also improve resolutions. The different display devices improve almost every day, with today's rapid development, so any issues related to display qualities would be improved over time. For the color fidelity in displays, which increases color quality and distinction, there exists methods of improvement that today is mostly used in projectors and hand-held devices, but these methods are suited for all displays. Coatings on screens can aid in reducing reflections, which can disrupt image perception if present.

Sustainable AR: AR interfaces for long-term usage

AR interfaces can be engaging and easy to use with natural movements. However, not every situation is suited for all AR interfaces. In an office situation, where the main work interface is an AR system, an example of what needs to be considered is the possible fatigue from the movement required to use the system. If a user quickly fatigues from using it, it is not suited for it's workplace, and therefore is not sustainable. This chapter looks into what is needed in general, and for AR specifically, for a system to be sustainable.

In general, it is most common to look at short-term usage results when evaluating user experience. However, as relationships are formed, the user experience changes, and this change can go both ways. The UX Curve method, as defined by Kujala et al. [23] takes this into account. Results from their study show that over a longer period of time, users often scored general *UX* and *attractiveness* as deteriorating, but *ease of use*, *utility* and *degree of usage* as improving. When asked to explain their changes in opinion, technical faults and bugs were mentioned more often in deteriorating curves, than technical features in improving ones. In the attractiveness curve, hedonic values were dominant, with things like appearance and social status. Users with improving curves had more positive reasons than the ones with deteriorating curves, but they all had about the same amount of negative reasons. Ease-of-use, utility and degree of usage all had more improving curves than deteriorating, but interesting to note is that users with deteriorating curves reported more of both positive and negative reasons than those with improving curves. Results from the study as a whole, point out that of all the categories, the attractiveness curve has the most impact on user satisfaction, and proves that design focusing not only on goal-oriented tasks, but also pleasure producing tasks, stands a lot stronger.

Szalavári and Gervautz [34] did a study on interaction options in AR. Conventional tools for desktops, like the mouse and keyboard, are highly developed and specialized. But, 3D input devices still have many flaws. Problems such as; low interaction bandwidth, overloaded metaphors, too complex gestures, too easily disorienting and messy interfaces. A lack of tactile feedback is also significant.

Szalavári and Gervautz handle this problem by replacing a fully virtual interface with a virtual interface extension on top of a real world interface, in this case, a tracked pen and pad. Users reported no signs of fatigue using this solution, as HMDs allows for rapid change in point of view, so actions like lowering the arm, sitting down, or putting it down does not affect usage. Interaction is designed to be as natural as possible, with a panel for tactile feedback, virtual interface "directly" connected to the user's hand through the panel, and supported distinction between 2D usage of pen on the panel or 3D usage of the pen as a 6DoF device for manipulation, selection, pointing and envisioning aid. The flow of this switch in viewing dimension is made natural by the 2D in 3D axiom. The PIP has its main focus on the interaction aspect, and not the technology. By utilizing "desktop" related interface functions, and having the panel as a constant reference point to the augmented content, all users, of varying amount of prior experience with AR and VR, quickly became familiar with the interface, even sometimes without introduction. Enabling natural "two-handed usage" also significantly improved performance. And finally, users reported no fatigue, despite poor quality displays and possible hardware disturbances, proving that in avoiding fatigue, the quality and options of interaction is more important than the technological and hardware factors.

Multiple-user AR systems

In recent times, multiple-user AR interfaces have slowly been receiving more attention. This can possibly be credited to a generally increased awareness of AR among the public, since mobile AR interfaces appeared on the commercial market and thus became better known and accepted by the public, allowing greater chance of success when introducing AR systems.

Billinghurst and Kato [3] state that Computer-supported Collaborative Work (CSCW) is a concept that has existed for a long time, and many thoughts and ideas about AR's potential in this arena have been made, in several different fields. A great example well known to the public is holographic conference calls with full-sized projected bodies of users, as inspired by such a system seen in the Star Wars movies. As of today, AR is one of the technologies best suited towards this kind of system. Such a system would also be capable of handling several of the challenges many CSCW systems face today.

The key to good collaboration between many people is good and clear communication, leaving as little room as possible for misunderstandings. However, communication between people exists on many different levels. Many of them are difficult to detect by computers. Speech, gestures, gaze, non-verbal cues, semantic references in objects; these are several ways in which people communicate, and they are often combined for enhanced or changed meaning, and the same action can have different meanings based on context and setting. Computers, possibly resulting in misunderstandings when using computer-supported communication systems, can easily miss a combination of these. For good collaborative work environments, the surroundings also play a significant role. Design tasks and spatial collaborative tasks are fields where this is even more the case.

The qualities and aspects mentioned above all belong to reality and real objects. Virtual environments have several challenges in incorporating these adequately for collaboration. Most computer interfaces for collaboration make too much of a distinction between the real and the virtual, and projection screens and other large shared displays often do not adequately support co-present collaboration, real object references or natural communication behaviors. Billinghurst et al. [4], mention that today many fully immersive virtual reality interfaces for multi-user collaboration may be found. However, they are also carriers of the flaws mentioned earlier, due to complete separation of the real and the virtual, making the use of real world notes and books and other tools much more challenging to use or disturbing for the immersion. AR, with its combination of both the real and the virtual, is much better equipped to handle these challenges, and doing so in new and more natural ways. For sessions with both co-located and remote users however, even AR struggles with providing the same experience to all users equally, despite doing so better than most other options.

Billinghurst et al. [4] also mention that today's interaction with GUIs is often dubbed as “direct”, but it is in fact just a metaphor, as no direct actions resembling those on screen happen in the real world. With the physical interfaces of AR however, this is no longer the case, thus leading to a more natural interaction. AR environments have three different levels of interaction. The reality-based environment can affect reality-based entities, for example, a user of an AR system physically moving a marker. Actions in reality can cause action in the virtual environment and vice versa. Moving or shaking a marker in AR, causing an earthquake to happen or the sun to go down in a dynamic virtual model is an example of this. Finally, entities in the virtual environment can affect each other. The TUI AR game “Eye of Judgement” for PS3 is an example of this, where creatures fight each other in different ways depending on how they are positioned in relation to each other.

Billinghurst and Kato define five key attributes needed for a collaborative AR environment to be complete [3]. Those are:

- Virtuality - digital objects can be viewed and examined
- Augmentation - real objects can be augmented with virtual annotations
- Cooperation - multiple users can see each other and cooperate naturally
- Independence - individual users control their own viewpoints
- Individuality - displayed data suits the needs and desires of each user.

In an AR environment, the task space is also the communication space, unlike the separation of the two as we see it in most computer environments. This quality allows for a more seamless workflow, granting a significantly faster task performance speed, and a feeling of a more natural condition for collaboration, which they see as a key characteristic in successful CSCW interfaces. The main reason for this is an improved perception of non-verbal cues. Collaborative AR interfaces can produce communication behaviors more like those used in face-to-face communication than screen-based interfaced. They are also well suited for object-centered collaboration, with the common presence of physical tools in the interfaces. More exploration is needed for sensitive task areas like negotiation and conversation, but there is potential here as well.

Some existing implementations of collaborative AR systems

“MagicMeeting”, as seen in Regenbrecht and Wagner [30], makes use of a “cake platter”, a shared space for 3D objects, where models are presented by users in 3D, for all participants to see. Each user can transfer models from 2D apps from PDA's given to each user. Models presented in the shared space can also be controlled through 2D apps on the PDA, and 3D data of models can be transferred into different 2D apps as well.

Figure 9. MagicMeeting in use.

In Kaufmann and Schmalstieg [19], we are presented with Construct 3D. It is an AR system using a 6DoF stylus, which enables users to see their body and hands as well as the effects of their actions, making the work have more of a resemblance to handicrafts than traditional operation.

An interesting potential quality for AR systems is displayed in an AR game similar to the classic “Concentration”, a memory game seen in [20]. AR markers are turned upside down, and when turned, 3D models appear, and players have to find models related to each other, which is signaled by a special interactions occurring between the two when both models are displayed. Users reported this game as very immersive and entertaining, and were impressed with the lack of delay in the game. This is the interesting part, as there was a rather significant delay varying between 200-300 ms. A very significant delay, in that in most gaming communities today, a delay above 100ms is seen as crippling for the game experience, with some variation depending on the nature of the game and it's gameplay. It is logical to assume that the immersion level is at least partly responsible of this lack of detecting the delay. Another interesting and important point for AR is then revealed, namely technology transparency. This aids in avoiding that users become disturbed by the tools they use, which would make the tools counter-productive to their purpose.

Challenges with collaborative AR include general AR challenges like high quality rendering and precise registration of virtual objects in real environments. However, an even more important challenge is to do so in interactive real-time. For efficient collaboration, any delay can be very disturbing. Display quality is much more important for collaborative AR compared to other AR systems as well, as many other AR systems function perfectly with rather low quality displays. But for collaborative AR systems, proper presentation of non-verbal cues is key. This requires high quality display options, ability to detect the miniscule scales and movements, many variations, context meanings and combinations of these cues. In general perception, despite continuous improvements, the virtual perception is still not on par with perception of reality. This is affecting e.g. the experience of users in sessions with both co-located and remote users. Here, some users are represented in reality and others virtually, thus throwing off the balance of experience for the users.

AR in learning environments and it's influence on learning

In the previous chapter it was mentioned that a shared workspace increases effectiveness of collaboration. It follows that when the work environment is for educational purposes, increased effectiveness of collaboration leads to an increased chance of learning something. Studies have shown that students work better when focused on a common workspace, and the performance is better when a group shares a computer instead of having individual computers, as stated by Inkpen 1997, referred to in Billinghurst [5]. It is interesting to note that most students will spontaneously choose to share computers as pairs/trios, when individual computers for all is also an option, indicating that it is natural to have a preference for a shared workspace.

For a computer tool to be most effective in use for educational purposes, the less technological background a user needs in order to use the tool properly, the better. AR's ability to interact through it's intimate relationship between virtual and physical objects, allows even people with no computer background to have a rich experience with the tool.

AR interfaces has the potential of “ubiquitous computing” models, meaning that they can be used anywhere, much thanks to the rise of mobile AR.

Dede, as mentioned in Dunleavy, Dede and Mitchell [11], describes the learning styles enhanced by educational AR-based communities as:

- Fluency in multiple media
- Learning based on collectively seeking, sieving and synthesizing experiences, rather than individually and absorbing information from some single best source.
- Active learning based on experience, both real and simulated, that includes frequent opportunities for reflection.
- Expression through non-linear, associational webs of representations rather than linear “stories”
- Co-design of learning experiences personalized to individual needs and preferences.

Some tools used in AR environments, such as for example the large HMDs that some systems use, may distract inexperienced users. That is why Liarokapis et al. [26] mention that to support the use of AR systems for such users, avoiding large tools in systems intended for such users or the general public is of importance.

But how easily will AR spread among the public, especially for educational purposes? AR systems can be used and set up with off-the-shelf software and hardware, and these tools can be relatively cheap, thus not be as restricting as to who can use this technology based on economical situations, as with some other tools. An example of this can be seen in [12]. In addition, an augmented workspace can be viewed and interacted with by non-immersed users through conventional computer tools like the mouse and keyboard.

Now, we have stated that little to no prior experience is necessary, it is relatively cheap to set up, and AR has been stated as having a high potential for educational use. But does today's students have any prior knowledge relatable to AR?

Many of today's younger generation are familiar with what has been dubbed Multiple User Virtual Environments (MUVEs), mentioned in [11]. Among these, Massive Multiplayer Online games are best known to the public. These are games with a collaborative and mediated gameplay, and players interact in a virtual, immersive and collaborative context. AR environments embrace many similar concepts, but compared to MUVEs, AR environments have both reality and virtuality. AR also has more face-to-face interaction, while MUVEs purely has variations of virtual avatars for interaction with other users. However, the similarities between MUVEs an AR still remains, and this familiar ground can provide prior experiences for people of the younger generations to more easily accept an introduction to AR interfaces.

Chaiklin and Lave (1993), Hutching (1995) and Wenger (1998), referred to in [11], have all done research suggesting that learning and cognition are complex social phenomena distributed across mind, activity, space and time. The engagement and identity of someone is shaped by collaborative participation in communities and groups, whereas these communities have their own practices and beliefs that influence the shaping of identity. This is called the situated learning theory perspective, and central to this is the belief that learning is embedded within, determined by, and inseparable from a particular physical and/or cultural setting. When analyzing learning, the target of analysis is the relationship between the individuals and the setting, and not each of these separately. This relationship is indicated by the students' level of participation.

Learning and cognition is twofold in meaning. On one hand, it is a progress along a trajectory of participation in communities of practice, but it is also the ongoing transformation of the learner's identity, based on the perspective of Greeno 1998, referred to in [11].

With this in mind, we can state that participation in schools develops patterns of participation that shape a learner's identity, and that this identity therefore is not constant, but continuously evolves over time at varying paces. It is this identity that grants a learner flexible continuity to engaged participation.

Now, what does all this have to do with AR and it's use in education?

In Gee [12], p.51, it is stated that games and tech-mediated simulations afford opportunities to *"recruit identities and encourage identity work and reflection...in clear and meaningful ways."*. This is due to a unique capacity of video games to activate, recruit and cultivate a sense of projective identity. This projective identity has a linked relationship with both the real-world identity and virtual identity, and through this link, the virtual identity can influence and shape ongoing transformations in the real-world identity.

It is within this principle that AR find so much potential for learning, with both it's resemblance to video games' immersive nature and it's already existing relationship with reality and virtuality.

Chapter 3

Research Methods and Methodologies

In this chapter, brief explanations will be given on the different methods and methodologies that have been used and considered during the work on this thesis. Research can generally be divided into two branches of research, these being quantitative research, and qualitative research. This thesis is mostly focused on the qualitative research aspect of the methods. In some cases, methods are a little bit of both depending on the situation. And quantitative methods can sometimes be used to either support or falsify results from qualitative methods. A short summary will be given on these two branches in general, before continuing with explanations of methods that have been used or considered for this thesis, and reasons for such.

Quantitative Research Methods

Quantitative data is data in the shape of numbers and statistics, or something that can easily be translated into such forms. It is often focused on large groups or happenings, such as a questionnaire done by hundreds of people, or a counting of how many times a day a plane lands at the airport. Analysis of quantitative data looks at the magnitude, amount or size of something, something that is easily measurable. It is important to note that no research method is purely quantitative or qualitative. What it becomes depends mainly on the purpose of the study and the chosen perspective on the results. But some methods can be more given towards a certain methodology. E.g. in interviews and questionnaires, closed questions are more likely to be analyzed quantitatively than open questions.

Qualitative Research Methods

Data that has a structure making measurement, counting and simple expression complicated is called qualitative data. It may not be impossible to do so, but it might not make sense, or distort the truth if it is done. A simple distinction between qualitative and quantitative data is that while quantitative data defines, qualitative data describes. Analysis of qualitative data is focused on the nature of the subject in question, through patterns, themes and stories.

Ethnography-based Methods

Observation

Observation is a form of ethnographic research, where the behavior of the test subjects is in focus, and how it is influenced by and how it affects its environment. It can be a challenging research method. It can often stretch over long periods of time, causing fatigue in the researcher. The observation must be approached the same way consistently in a session, to create meaningful and credible data. A researcher must consider who or what the target of study is. How the researcher may react to the target of the study and how the target may react towards the observer. These factors can greatly influence result if ignored. Most importantly, the study target must be in some way of interest in relation to the research goal of the researcher. And consenting study subjects is a natural condition for any successful observation. There is variation in whether the purpose of study is examination of an extreme case, or a situation that can represent general situations. This purpose is also a key consideration when choosing study targets.

The observation itself has a varying specter between two extremes, these being the role of a complete observer, or a complete participant [24]. The first refers to an observer fully detached from the situation, simply taking in everything that happens and neither reacting to anything nor influencing anything. The latter refers to someone immersing themselves completely in the setting, interacting with everyone and everything there just like those being observed. This way the observer becomes a part of the group itself. There are advantages to each method, with their own risks and challenges. As a complete observer, there is a much smaller risk of the observed setting being influenced by researcher's presence. However, as a complete observer, the researcher does not get up close to the situation and thus, there is a much higher risk of misinterpreting different actions and behaviors of subjects. This creates the need of more careful consideration when evaluating results from this angle. Complete participants, however, run the risk of being too influenced by the setting. They can become biased towards results and transform from a researcher to a normal participant. This is referred to as "going native". For a researcher who is a complete participant, to detect and hinder this kind of progression is a constant challenge. In 1958, Gold [13] defined this spectrum of roles for ethnographic researchers, where the more one becomes a complete observer, the greater the risk of misinterpretation. And the more one becomes a complete participant, the greater is the chance for losing perspective. Because of this, Gold mentions a solution with a common approach where one begins as a complete observer, and after analyzing the first results, prepares for a closer perspective of observation if this is deemed needed.

It is the latter approach that has been applied in the work on this thesis project. After setting up the application, the participants were to freely experiment with it. This with the purpose of enabling their initial first hand experience with as little outside influence as possible. The intention behind this was to observe how well the participants grasped the concept of the interface, and to measure their reaction of using it. It was also measured how long each pair of participants took to understand what the concept of the system was, which is a basic "Find 2 alike" game. The observation was kept as neutral as possible, but allowed for participants to make inquiries if they felt they needed aid.

Interviews

An interview is another data collection method based on ethnography. Here, a direct communication with participants is used to gather data for analysis. Interview as a method is commonly combined with observation. This is due to the nature of ethnographic research, trying to get as broad a perspective on something as possible. This is achieved by using different methods to triangulate for increased validity in the data that is collected.

Interviews can be structured and performed in several ways, but a common distinction of definitions is three different kinds of interviews. These are:

- Unstructured interviews
- Semi-structured interviews
- Highly structured interviews

Unstructured interviews are very informal in nature, having little to no absolute goals of data collection. They instead take a general approach on the researched topic aiming to attain a general grasp of the subject being interviewed. Angrosino [1] states that it is very common for these kinds of interviews to be the initial interviews in research using interviews. This is because a researcher may not know what he or she is searching for in the beginning of a research process. Unstructured interviews are well suited to mark out points of interest to pursue in later, more structured interviews.

Semi-structured interviews are still open, allowing digression, but now there is a desired frame of topics that the interviewer wishes to explore. The more certain the researcher is of specifics of desired the data, the more structured the interview becomes. Narrower questions and less room for digression from the interviewee is used to gain data inside the desired frame. However, new thoughts and ideas are still welcomed and can be discussed.

Highly structured interviews mainly appear late in the research process. By then the researcher has found clear goals to their research. Here, the researcher is quite clear on what the desired information area is, and has several questions for each aspect of the topic in question. No discussion outside this topic should occur. This kind of interview can feel very intense for the interviewee, so care must be taken to not case too much stress or pressure. For the researcher, staying on topic can be a challenge, not elaborating on aspects outside of the frame set for the interview. A highly structured interview can appear earlier in a research process. Then in the form of questions requiring little elaboration, mostly resulting in short and conclusive answers.

In this project use have been mainly of semi-structured interviews. Sets of prepared questions were made for each interview, but all participants were allowed to talk freely about details they found more interesting whenever such were discovered. There were two interviews in each session, one before the testing of the prototype, and one afterwards. The first interview was a short interview with the main purpose of exploring the basis of knowledge regarding AR for each participating user. The duration of this interview varied from each pair of participants, but lasted on average for 5 minutes.

The interview after the testing and survey was substantially larger. It started by exploring any changes the testing and survey might have had on the opinion on AR as a technology. Questions focused on the experience of using the interface, what features they enjoyed and what they would like to see changed or improved in a future version. They were also asked if the technology was something they could see themselves using on a regular basis, and reasons for their answer. Questions were presented regarding the AR technology's effect on learning and understanding the interface, and how it affected their cooperation. A follow-up question for these topics was their perception of AR´s general potential in this field in relation to the more standard interfaces like the keyboard and mouse. If after these questions any participants had more to say on the topic of AR, room was given for presentation of their topic and discussion with their fellow participant regarding the topic.

Grounded Theory

Grounded theory as a method is a systematic approach in the field of social sciences, see [24]. The process is almost a complete reversal of the common approach in social sciences. The first step is data collection, through a variety of methods. Examples of such methods are ethnography, interviews and case studies. There are four stages to a general method of grounded theory. The first stage is called "open coding". By analyzing the data collected, points of interest are marked. The marked points are called *codes*. The second stage is further analysis of these codes to enable "development of *concepts*", to make them more manageable. The next stage is grouping concepts into *categories*. These form the basis for the creation of a *theory*, or a reverse engineered hypothesis. Grounded theory thus differs from the traditional model of research, which is to start from a pre-formed theory and applying methods to test these theories.

In this project, grounded theory as a method was applied on the interviews for thorough analysis of each interview and all possible aspects of them. It should be mentioned that there is a risk of the data collected being biased, due to there only being one coder. In an ideal case, more coders would be brought in to compare coding of the interviews and increase the validity of the results.

Usability Testing

Usability testing is a method used to evaluate a product in user-centered interaction design. Often a prototype of varying fidelity is presented to a representable group of users, but a final product can also be used for this purpose. Evaluation is done based on the representative interactions performed by the users and the feedback given by them. This method can be considered a key tool of approach in usability. This is due to how it enables feedback directly from users. Depending on how representable the group of users is, this method grants valuable data and insights. The target of measure is how well a designed product accomplishes its intended purpose in the eyes of the users.

Usability testing has seen most use on screen layouts and similar interfaces, but it has also been applied to many others devices. This trend has increased in recent times with the rise of devices like the smart phones. Smaller screens filled with more content every day grants frequent need for usability testing on such interfaces.

The single main goal of usability testing is to uncover flaws in the interface based on the feedback from the users. In addition it also aids in revealing features that fulfill their intended purpose well, or in unintended ways.

In this thesis, usability testing as a method is used in the testing sessions to evaluate advantages and disadvantages to AR interfaces. The participants are presented with a prototype and allowed free reign for interacting with it. Afterwards they give feedback in the form of interviews and surveys as well as any comments they gave during the actual testing.

Design Methods

Prototyping

The basic value of prototyping as a concept is how it enables users and developers to visualize more clearly where a product is headed before it is finished. With prototypes one can evaluate functions to see if they achieve what they were intended to, and remove functions and aspects that were not desirable or attractive when implemented compared to how they appeared as a concept and a plan.

Prototyping as a process occurs in iterations, with each iteration providing some insights of possible improvements or changes required for reaching a final product. A prototype changes with each iteration, and some iterations can have completely different areas of focus from previous iterations. It follows then that prototypes come in many shapes and sizes.

At times all that is required from a prototype is a rough sketch on a piece of paper or a cardboard box in a certain shape and size. These are relatively cheap to produce yet can be very effective in their purpose. This purpose is to showcase one or more attributes of the imagined finished product, to evaluate whether it is a viable choice or not. These kinds of prototypes are categorized as low-fidelity prototypes, meaning that they do not hold much resemblance to the final product. They are rarely crafted of the same material as the final product. Their advantage lies in their cheap production and quick setup, allowing for much faster modifications than more advanced prototypes. This makes them well suited for the exploratory phase of design and development, and it can be said that this might be the only place they truly serve a purpose.

In later stages of development where much more resources have been put into development, it would usually be too costly to return to an exploratory stage. Prototyping still occurs after the exploratory stage, but prototypes at this stage are much more advanced. These are known as high-fidelity prototypes. In this stage, the prototype holds more of a resemblance to the final product both in material, functions and aesthetics.

High-fidelity prototypes are more suited to technical testing and can function much better as a marketing and sales tool. In general, a working high-fidelity prototype will present itself better than a low-fidelity prototype. It should be noted that it is commonly considered wise to use both levels of prototypes when possible in a process of designing and developing a product. This is because the two types of prototypes balance out the flaws of the other and both kinds have particular purposes in the process.

Using only high-fidelity prototypes can be argued for if the development path has already been set, leaving no need for an exploratory phase. This is rarely the case in a commercial or mass user target group setting. In other projects, high-fidelity prototypes have the flaw of taking too much time and resources to build. This makes it difficult for many iterations to be a reasonable goal. In addition, developers become more reluctant to make modifications when much time has been spent on a creation. This presents the risk where more design flaws make it through to the final product.

This project has mainly made use of high-fidelity prototypes. A completed and finalized product was not within the scope of this project. This allowed for the use of less complete prototypes in testing, as long as necessary functionality was in place. There was brainstorming and concept discussion in the beginning, at my time at Schlumberger. This session resulted in the desired end result being decided right away, before any use of low-fidelity prototypes were made. Considering that all the skills required to create these prototypes had to be learned from scratch, high-fidelity prototyping was also used as exploration of frameworks and programming languages in which the prototyping could be done. Progressing directly into the high-fidelity prototyping stage also allowed for more time to be spent on this stage, which was deemed important. It should be noted that there is a considerable difference of how advanced the initial prototypes were compared to the last prototypes that were used in the testing. But in their nature they can all be categorized as high-fidelity prototypes.

There are two branches of prototyping, focusing either on a wide range of functions or a high level of detail in a select few functions in the prototype. It is usually between these two branches that compromises in prototypes occur. These compromises are not intended to be included in the final product. Instead they are made in order to refrain from dedicating too much time and resources into a prototype. They mainly regard areas not important to that particular iteration of a prototype and its purpose. The compromises may not be very apparent to an outside viewer, as e.g. a customer during a sales pitch, but must be remembered by the developer to avoid implantation of these in the final product.

In this project, focus started on having a wide range of functions. But as time passed, and the challenges of developing the then desired functions became more apparent, functions considered less important were omitted in iterations in favor of more detail in the functions deemed key to a prototype fulfilling the requirements of the project. If the project were to end in a completed product, these functions would reappear for more work in future iterations.

User Feedback

User feedback is one of the most useful tools when developing for a large user group. User feedback is a versatile tool usable in all stages of process in design and development. In this project user feedback was used in the post-testing evaluation of the prototype due to time limitations. When done successfully, it can pinpoint and define core needs and desires of the users that developers might not have predicted. And it can aid in avoiding failure of products due to functions being added by developers perceiving them as useful, without realizing that the user group sees no need or desire for these functions and find them more confusing and bothersome than useful.

For valuable and usable user feedback, a representative user group of good quantity is desirable, or even required. The more users participating in a session producing user feedback, the more accurate the findings will be. This is a time and resource demanding process, and unfortunately very few projects can afford to have a large amount of users in sessions due to this. For viable user feedback sessions that still give credible findings, and approximation of 10-15 users participating in the project is commonly deemed an adequate amount.

In this project, only 6 users participated in sessions in pairs of two. This is due to the smaller scale of the project, and the time limit not allowing for more time to be spent on gathering people, arranging sessions and analyzing data afterwards.

Ethics

In any research where users are involved, it is important to ensure the privacy and ethical rights of each participating user. This involves anonymity if desired, full knowledge around the storage of data after the end of the project should it not be destroyed, and most importantly, an informed consent of participation in the project.

In Norway, there are rules and guidelines regarding what information should be presented to participants before agreeing, especially if the participants can be identified through any actions or information within the project.

For this project, I have followed the guidelines presented by “Personvernombudet for forskning”, see [16], using a predefined document for informed consent provided on their website, with the appropriate modifications to match this project. This document was presented to and signed by all participating users before participating in any testing sessions or interviews.

Chapter 4

Preliminary study and design process

This section serves to explain my progress and decisions resulting in the project explored in this thesis. At first, I give a small introduction about Schlumberger, the company that I had my internship at during this thesis. This is where the project originated, and the initial progress plan was made. Later on, I explain how I approached the task of creating a project, what influenced me, what inspired me, and what I aimed to achieve. Further on, my initial plans for the project will be revealed, and how it evolved into what it is now, and what I did in the different stages of development.

The origin of the project

I spent eight months at Schlumberger as an intern, and after a period of introduction and setting up the equipment properly, I started working with my managers on UX projects. I will now give a short introduction of Schlumberger and what they do.

Schlumberger, or SLB, is a worldwide company that is the leading supplier of technology, integrated project management and information solutions to oil and gas industries everywhere. The company has projects ongoing in over 85 countries, and their products and services range from explorations through production. There are two business segments within Schlumberger, namely Schlumberger Oilfield Services and WesternGeco. Schlumberger Oilfield Services is a supplier of products and services, with a great variation including formation evaluations, well cementing and stimulation, well completion, software, information management and IT infrastructure services that support core industry operational processes, among others. Houston, Paris and The Hague are the locations of the principal offices of Schlumberger, see [37].

During my internship at Schlumberger I was given two managers, and in cooperation with them, I was to find a project to work with. After some discussion, we formed my first project at Schlumberger. The presented problem was that Petrel, the platform in which most of the work that Schlumberger and it's clients perform is done, is a very complex platform, with a huge amount of functions of varying complexity available to most users right from the beginning. Just as I came to Schlumberger, they were mid-process in changing the interface of this platform to a new style. My task was then to develop a function that would ease the transition from the old interface to the new, and help users find their desired tools in this massive interface. For this purpose I made an interactive guide being given a target function to find, and then starting a simulation of navigation through the platform. This simulation showed the path from start to finish in real time. It was through this project, which heavily influenced the general UX of the platform, that I found the roots of my interest in UX, and the potential of interactive tools in this regard.

My second project at Schlumberger was to develop an AR interface aspect of Petrel. This interface was focused on 3D model presentation and manipulation, as users of Petrel see many different models in their work. The reasoning was that an AR interface could make presentation of models easier and provide support for several users at once, a collaboration tool. This project never progressed further than the planning stage, as I needed to learn basic AR programming first. During this phase, the license of the software Schlumberger had for the programming framework ran out. Before a new license was acquired by Schlumberger, my time as an intern was over. It was from the work done here that I found inspiration for the project described in this thesis. While not specifically created to suit Petrel's needs, the concepts used in this project could with some refining fulfill the intentions of the project at Schlumberger. By combining focus on AR and UX, I want to see if AR can benefit UX in general tasks now commonly performed by conventional tools like the mouse and keyboard.

The preliminary study

The plan at the beginning of the project was an AR interface with focus on easier presentation of models, but not necessarily exclusively models. A typical setup of menus and buttons could be integrated in the interface that could be controlled through hand movements. The intended use of the interface was easier familiarization of the interface compared to the present interface used in Petrel by Schlumberger. It would be fulfilled by interaction with the models and interface through hand gestures in place of a mouse and keyboard and 3D presentation of models. The buttons and menus element was dropped to avoid too much augmented content sensitive to hand movements. This could potentially appear distracting to users, and restrict movement as to not trigger unwanted actions. A function found desirable by Schlumberger was manipulation of represented models through hand gestures and motion tracking. No development was done on this topic due to its complexity. It was instead included in the future work plan of the interface. From this point, with the manipulation of a model, came the idea that many models made and used by different people in Schlumberger are often granted contextual meaning when placed with other models. E.g. models of fault lines in the terrain in comparison to a model of where to place wells or pipelines. This inspired a plan for the support of multiple distinguishable users. Multiple users could view and manipulate all models, present their own models and place them in comparison and or relation to each other, and view all models from viewpoints particular to their needs and desires. Another possible function to be explored allowed a user to make a private copy of a shared session. In this copy, the user could make modifications and additions, and present the new version in comparison to the original. These functions were deemed useful but not a priority in the development. In the end, it was decided that the basic requirement for a prototype was simultaneous representation of multiple models.

Technological exploration and understanding

What defines an AR interface?

As AR was chosen as the desired tool for the study, it was with the knowledge that I had no prior experience with creating AR systems. I had experienced AR in action and interacted with AR interfaces, but had no knowledge of any aspects in development in this area. My mentors were eager to see the possibilities of AR in action, but we found that no employees at Schlumberger had any experience with AR development. I would have no aid from them in this project in terms of training. Therefore, it became necessary for me to become more acquainted with AR, how it worked and how it was made. My first task became to explore the definition of an AR interface.

I started out with sifting through results from searching for applications utilizing AR on the Internet, studying many applications that could be tested directly. Marker-based AR, markerless AR, GPS-based AR were the three most common types of AR. Of these, GPS-based AR was not considered inside the scope of this project. Marker-based and markerless AR could both be used, but needed further exploration and consideration. This is discussed later on in this thesis.

Stationary platforms vs. mobile platforms for AR

AR is compatible with stationary hardware like computers and mobile hardware like mobile phones and similar devices. It was necessary to take a closer look at the options to determine which platform would be most suitable for this project. AR-interfaces with stationary hardware are the most flexible option. This is due to the advantage in performance power that computers have over handheld devices and the wide range of additional tools compatible with computers. Another consideration was that this project was intended to be in conjunction with Schlumberger. All of their offices are equipped with stationary computers, making the stationary platform a natural choice. Assessment of the mobile platform was still performed. It is not as powerful as its stationary counterparts, but mobility allows for a much more versatile area of use. Mobile devices have a larger distribution among users in today´s society. This allows for more familiarity with the platform, enabling the possibility of easier understanding. The large flexibility and complexity of the stationary platform can become a disadvantage in relation. However, in terms of mobility, tools like HMD's add this to the stationary platform. The conclusion became that while mobile devices as a platform have their uses, in this project the stationary platform is the most relevant.

Display methods for AR

AR has a wide range of display methods, with different strengths and challenges. For stationary platforms, there are primarily three common methods that are used. HMD-based systems, projector-based systems and video/camera-based systems. HMDs have two variations. The glasses can have transparent screen, where direct input of the world to the user is enabled. The augmented content is added based on video input from a camera, but the video input is not displayed to the user. The other option is closed glasses. Here the glasses become a headgear with screens displaying the video output of a camera after adding augmented content. HMDs allow for the greatest movement in the user, enabling users to view the augmented object from different angles by physically moving around it. A disadvantage to HMDs is their potential of becoming confusing and uncomfortable for users with little to no experience with AR, particularly if the HMDs are large. Projector-based systems make use of a projector for output. One or more cameras can be responsible for input for gesture tracking. The advantage of projectors is the general public´s familiarity with their function. Their function makes them well suited to presentations and similar situations. They are relatively common and easy to acquire compared to devices like HMDs. The disadvantage of projectors is their dependence on surfaces and environments fit for projection. Even surfaces, non-intrusive coloring, correct lighting. These are conditions that need to be correct for suitable projection environments, among others. The most common form of display methods in AR is camera/video-based systems. The best example is the webcam on a computer as the camera input, displaying the output together with the augmented objects and/or environment on the screen of the computer. The majority of laptops today are made with an integrated webcam. Due to this, most users today are familiar with their functions and operation. When used with AR the augmented content stays in the same display area users are familiar with, namely the computer screen. This is the cheapest setup for AR, and the easiest to acquire. Based on these reasons, a laptop with a webcam is the display method of choice for this project.

Choice of programming language

There are many programming languages out there, and they all have their own primary field of use. They therefore have certain software types they are more suited to develop. The ARtoolkit [38] is a software library developed with the purpose of easier development of AR applications. ARtoolkit is designed towards us with C and C+ languages, but there has been many developments and modifications to create other versions of this toolkit to support other programming languages. The versions explored in this project were ARtoolkit itself, FLARtoolkit and SLARtoolkit. FLARtoolkit is aimed towards Actionscript 3 for use in Flash 9+, and SLARtoolkit is for Silverlight. The reason for my interest in the ARtoolkit is the fact that it is the point of original for all other versions. I had little prior experience with any C or C+ languages, so after a little experimentation it was concluded that any advantages it might bring were not significant enough to allow for the time disadvantages in learning a completely new language. SLARtoolkit was considered due to Schlumberger having working licences for Silverlight. Licences were an issue as correct licenses were required for Schlumberger to be allowed to use anything I developed for the commercial use. SLARtoolkit was dropped due to the same reasons as ARtoolkit, I did not have the time to become acquainted with a new language and framework. FLARtoolkit with its use of Actionscript 3 (AS3) therefore became my library and language of choice. I had prior experience with the language, and had also developed a project during my internship in Javascript, which has many similarities to Actionscript 3. Schlumberger had licence agreements with

Adobe, so they began the process of acquiring licences for the necessary software while I worked there. Another fact in favour of FLARtoolkit was the existence of an abundance of easy to understand tutorials of AR development with AS3 in mind. These were in open code and had explanations of functions within the library. It should be noted that FLARtoolkit is not the most flexible or advanced of the ARtoolkit variations. It is instead well known for being relatively simple compared to many others libraries, a point in it's favour in a project with a strict time limit such as this.

Development frameworks

Frameworks for development and programming have a large amount of variations, in similar fashion to programming languages. There are different advantages and disadvantages to each. Factors to be considered for choosing a framework were ease of learning, license restrictions, compatibility with software libraries, compatibility with projects from other frameworks, support for various API's, existing tutorials using these frameworks and useful functions within the framework. Flash Professional became the initial platform, due to easy access through Schlumberger's cooperation with Microsoft, and fully functional free trials online. Despite the cooperation with Microsoft, Schlumberger faced problems in acquiring an up-to-date version license for me to use in time. This resulted in having no software to code in for a short period before my internship was over. A personal edition of the software was purchased, but this was installed on my private laptop, which was not allowed to be used on Schlumberger's network. It could therefore only be used at home, which had its effect on the work efficiency. This caused consideration to find a new framework to work in, but it was kept as a framework due to the amount of work accomplished with it so far. After the internship period at Schlumberger had ended, I found that while Flash Professional functioned as intended, its interface was difficult to become acquainted with. By searching through development communities, recommendations were found to use FLEX Builder, if one had experience with Java based programming. This framework closely resembled the more common Java development frameworks. With this new framework, it became easier to progress with the development and substantial progress was made. As no free version could be acquired, this was a trial version. When the trial period ended, I discovered FlashDevelop, which functioned in a similar fashion and had a similar interface, but it was free to use. During this extensive period of framework exploration, I discovered information on a lightweight framework for FLARtoolkit named FLARmanager. This framework is applied within another framework, and supports development of AR applications. It managed calibrations and sensitive tuning of AR techniques that quickly become complex when coded manually. This made it suitable for developers new to AR, and ideal for this project.

Marker-based AR vs markerless AR

It was conluded while exploring different AR applications, that marker-based AR and markerless AR would be the variations of AR most suitable for this project. In a marker-based application, a camera detects and recognizes a predefined marker. This detection triggers the display of a 3D model connected to the marker. The model displayed will be influenced by any interaction with the marker. Based on how advanced the application and setup is, interaction can occur through other mediums as well. Examples being gestures, speech, motion. This type of AR interface is considered the simplest to develop of the two methods discussed in this section. A quality of marker-based AR is that the marker becomes a physical reference point for users in interactions.

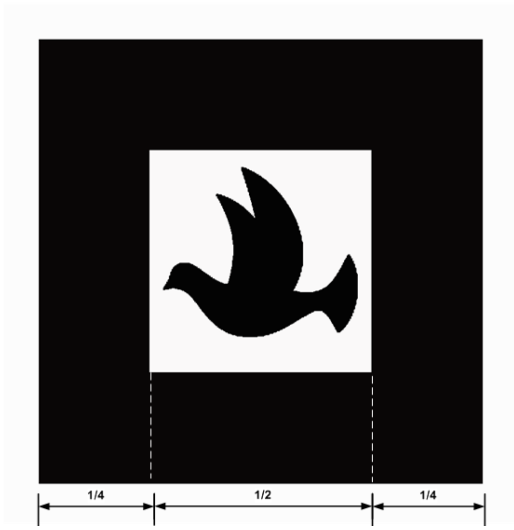

Figure 10. Ideal qualities of a marker for best detection.

This enables users to use the marker to perceive effects of actions, in comparison to looking at the display for reference. This allows for easier understanding of the mechanics of the interface and AR. Markerless AR applications remove this physical reference point. The removal of the marker allows for a smaller workspace because the only object requiring real space in the augmented space is the user. The techniques for interaction balance the lack of physical tools by becoming more advanced. The main form of interaction in markerless AR is gesture recognition and motion control. There are many levels of quality for these techniques, and markerless AR generally requires a higher level than marker-based AR. A goal commonly set for AR in general, but especially this kind of AR, is to simulate the necessary motions and gestures used as close to natural actions as possible. This is to enable ease of use through familiar motions, and avoid distracting users with what they could perceive as unnatural and counter-intuitive motions. For this project support for collaboration was a desired attribute. To best enable this, avoiding markers would be ideal. This is because several users all using separate markers or sharing the same markers, are both situations that can become disturbing for the work environment. However, the advanced level of programming required for markerless AR with motion and gesture control would be too time-consuming when put in relation to all the rest of the work needed for this project. With this in mind, marker-based AR was chosen as the AR application type of choice, with its advantage of shorter and simpler development stages. Markerless AR holds more potential for positive experiences of the product in a collaboration environment, therefore it is added as a point of future development in the project.

Motion tracking and gesture recognition

Motion tracking is a function that enables different motions and gestures to interact with and manipulate the interface of AR applications. There are varying levels of how advanced the motion tracking is. The basic form detects motion through color changes in pixels. When pixels change in predefined areas, an action is triggered. This can be used to trigger virtual button, or move objects based on the calculated direction and speed of the changing pixels. More advanced versions of motion tracking can become gesture recognition. It can be set to detect the shape of hands, and through this track their movement and recognize preset patterns as gestures. This allows for a larger flexibility of motion triggers, and a higher quality of "natural" actions and environment. For this project, motion tracking was a highly desired function, despite the choice of marker-based AR, but the complexity of developing this function demanded too much resources to be accomplished within the timeframe. It is instead added to the future work plan if development were to continue after the project.

System setup

The system setup required for this project is focused on cheap and easily available tools. The display device is a standard laptop with an integrated webcam, to allow for marker-detection and motion tracking from a stationary viewpoint. It is on this laptop that the application is running. With using a laptop instead of a stationary computer, one can with little effort enable increased mobility by adding an external webcam, if mobility is desired. Markers are plain sheets of paper with the marker pattern printed on them. This allows for easy access and sending to other users. A disadvantage to this material for the markers is that the paper can easily be bent, risking disruption in the detection of the marker. Flash is used through FLARtoolkit and AS3. Because Flash is a very common software and multimedia platform that that is supported on many devices that most users own, it is not likely to cause many access problems for users. It also allows for easy change of hardware should that be necessary. This is the basic setup for this application. More tools and software can be added for increased functionality in the future.

Design Process

Inspiration for the design concept

As mentioned earlier, this project has its origin from my time at Schlumberger, but this is not the exclusive reason for the existence of this project. For this project, Schlumberger produced the desire of developing something interactive to aid in use of their software. Due to lack of time, focus on what Schlumberger desired was removed as there was no longer much contact between us about the development after the end of my internship. When troubles with development arose, priorities in development made for Schlumberger´s gain were removed due to difficulties in developing them. The project required a relatively young technology to be valid. AR was chosen both by Schlumberger´s interested and my own. My inspiration for this choice stems from the gaming community. This community has earned a reputation of pushing limits and finding new paths for technology. In recent years, AR has made its appearance here as well. However, the methods of using AR in games are currently relatively limited compared to its capabilities. My inspiration for choosing this technology and creating this project came from my desire to acquaint myself with AR as a technology and explore its possibilities. UX states that most users find pleasurable experiences to often come from actions that feel natural and are intuitive. AR holds a lot of potential in this field compared to standard gaming controllers that we know today.

Iterations of development

The previous segments mainly explain the details of the initial study in the development of a prototype. On some occasions changes were made that affected decisions made in the initial study, such as the case with the framework mentioned earlier. But in most cases, the development of the prototype was kept within the iterations explained below.

Initially, a list of desired functions and actions was made (a), with the necessary and desired progression of development for these to be made properly. From this, I would create the code to fulfill the next step on the list, or find such code in existing applications (b). If the code was inspired by or taken from other applications, close study was required to allow understanding before inclusion in the code (c). If this was not the case, the process would continue to expand or replace code depending on the current iteration goal(d). Then came the time to test the code (e). Based on the results from the testing, it would be judged if the current step on the progression list was sufficiently fulfilled. If so, the process could move on to the next stage. If not, more calibration was necessary for proper function in the prototype. Thus, the process would either move back to point (d) to make changes in an attempt to improve results, or move on to (b) to work on the next function on the progression list.

Development progression

The first development task was to create a functional AR system. After a few hours of work, a functional prototype with marker-based AR was made. Models could be changed.

Figure 11. The first iteration prototype: a single marker displaying a 3D Collada model.

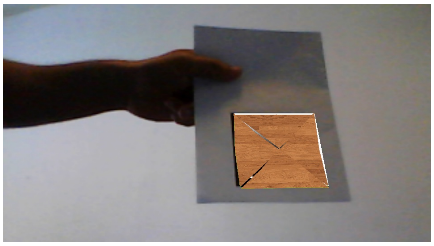

Figure 12. The second prototype has dynamic coded models and supports multiple markers.

Figure 13. The second prototype model after "opening".

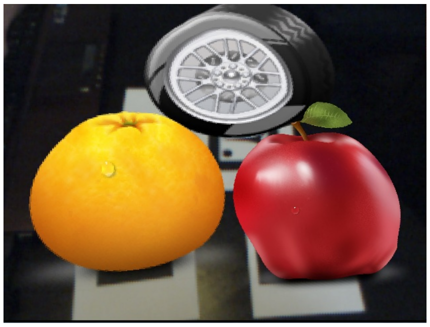

Figure 14. The third prototype supports multiple markers and displays multiple images.

and their scale and other attributes modified. The next stage with a marker-based system was to allow for multiple markers and models active at the same time. This was achieved very quickly by following a tutorial given online. A later tutorial using FLARmanager became the prototype from which the prototype used in the user testing sessions grew from.

The next part was to be able to make a motion tracking system. Tutorials and guides were plentiful, but many used outdated code or software, making real progress difficult. After some time it became functional, but the motion sensor was of basic quality. It was very erratic regarding accuracy, and interaction with virtual objects was possible, but very unpredictable, as the sensor had a hard time detecting anything that didn't move very slowly. After several iterations of tweaking the sensitivity, it became precise enough for simple use. It was however not able to reach a level of functionality required for motion tracking in this project, and was dropped in favor of more important functions.

If the motion tracking function had been completed, the two functions would be combined to create an AR interface where models would be manipulated directly with hand movements.

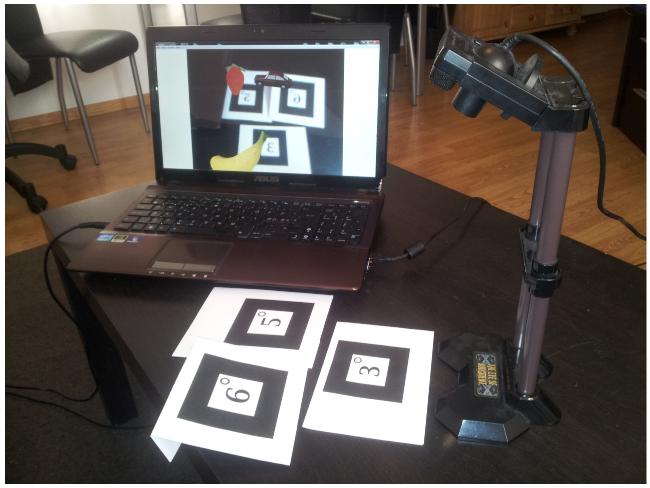

Figure 15. Setup for testing with final prototype, with three markers.

Testing sessions

With a testable prototype ready, preparations for testing could be done. The setup for testing will be with a computer with the AR system installed, and a camera for the AR enhancement. Initially, a short semi-structured interview is held, regarding their prior experience and knowledge of AR. Then the users will be given a brief introduction of what the interface is, but no explanation as to how to use it. This is to study how easily users new to the interface can learn and adapt to it with little or no prior experience. After a 5 to 10 minute session of free interaction with the interface, or until the user has had enough, they will be given instructions on the purpose of the prototype if they have not discovered this themselves. They will then be allowed to interact more with the interface, to allow interaction when informed of its purpose. When this session has ended, users will fill out a small survey ranking their opinion on different aspects of the system, followed by a semi-structured interview for more information. The whole session will be performed under observation, to detect anything that could affect the performance level of the user without the user being conscious of it, or remember to add in the survey or interview.

Participant recruitment

Participants in the testing were recruited from the interaction design students of UiO, due to ease of access and understanding of general procedure in situations like this. One of the goals were to measure learnability of AR systems compared to conventional systems. Interaction design students may have been more in contact with this kind of technology than desired to fully measure this, therefore it was considered prudent to gather some participants from outside the interaction design students at UiO. This fulfilled the aim of achieving an approximation towards a "general population".

Pre-testing prototype evaluation

The pre-testing evaluation of the prototype is a measurement of level of quality in the functions of the prototype compared to a final product. Tests were performed of the prototype and evaluations on the performance as perceived in comparison to ideal goals. Aspects that were focused upon in the testing were the following:

- Detection quality of markers
- Stability when detecting multiple markers simultaneously
- Correct representation of models
- Performance level compared to amount and detail-level of models
- Quality of interaction events

Detection quality of markers refers to measuring how well the camera detects the marker presented, if it detects it as the correct marker, and if the detection is smooth and constant, not lagging behind or causing flickering of the related model. This greatly affects all other qualities of the interface and is of the highest priority. If not at an adequate level, this can cause devastating effects on the UX. The stability when detecting multiple markers simultaneously tests the stress put on the interface when more than one marker is presented to the camera at once. Early versions of the prototype would crash as soon as another marker entered the frame when one marker was active. This is a vital attribute as a multi-marker interface would not be possible without it. The camera must be able to detect and correctly identify each marker, and the model related to each marker must be represented in an adequate fashion. Each model has different base sizes and shapes. These attributes must be scaled to match each other to avoid causing distraction in the users and disruption of immersion. In addition, models must as best as possible appear in the center of the marker. This can be a challenge depending on the structure of the model. Models have a varying quality of detail and amount of textures attached to them.These are factors that can affect the performance level of the interface when one or more models are being displayed in the interface. Testing this allows checking on whether a model is too advanced in detail or textures to be usable in the prototype. It then also reveals if there is an opportunity for using models of higher quality. There are certain events that should occur if different conditions are met. A smooth execution of these can improve immersion and general UX, but they are not necessary for the correct function of the interface. This is therefore a factor of less importance in comparison to those previously mentioned.

The evaluation of the prototype concluded with that the detection quality of markers was heavily influenced by lighting and marker detail, and when one of these factors were slightly off it caused major disturbances in the representation of the models. The marker material was paper, which has known disadvantages. Markers of a different and sturdier material would be desirable in future development or a final product. The quality of detection is on a functional level, but enough issues are present to potentially cause negative experiences. It is deemed adequate for the prototype for testing, but further development is required for a final product. The interface can handle many markers very well when all markers have good detection quality. But, if only one marker has problems being detected correctly, it has considerable effects on all markers, causing flickering or wrong identification in all markers. This may be due to bad programming as well, having no exceptions or countermeasures to execute when detection of a marker is too low. The models are presented smoothly when isolated from other factors in the interface, but this feeling is disrupted whenever earlier mentioned issues appear. Models could be more centered over the marker, but this would require an algorithm to suit the differing structures of models. With the exception of rare instances of freezing completely at seemingly random points, the interface shows no particular stress when representing one or more of the models used in the prototype. Earlier testing attempted to use a model with a high amount of textures once, which caused an instant crash in the interface. This might indicate that besides an upper limit of texture quality that it can handle, the interface has no easily reached limit within normal intended use that affects performance levels. Finally, for the events triggered by interaction, they are by themselves 100% functional, but rely on stability of the other factors for correct execution. When they are not executed correctly, they become a significant disturbance to the experience, and will therefore be removed for the testing. The final conclusion of the pre-testing evaluation is that it can be used for testing, but it has possible flaws that can negatively affect the UX.

Chapter 5

Testing with users

Introduction

The testing sessions with users were set up and held in my personal residence. This was chosen as target location due to both short travel distances for the majority of participants and availability at all time. All participants had some degree of familiarity with the location, enabling a more relaxed environment for the session. All participants were also presented with the option of selecting a different location if it was desired. The only requirement for the setting of test sessions was a table for the laptop and markers, and something to sit on for the participants. All sessions were held with two participants working together as a pair. Two of the pairs were colleagues, were one of these were also students in the field of informatics and interaction design. The third pair had met on a prior occasion, but was not interacting socially on a regular basis. The sessions were held within a period of 7 days. The first session was held 5 days before the second sessions, with the third the following day.

Preparations for the session included creating a set of questions for both the pre-testing interview and the post-testing interview. The interviews were focused on AR in general, and the participants´ experience on different aspects of AR. In the first session, only notes were used for registering the content of the interview. This interview was transcribed before the two later sessions were held. The time spent on this process was substantial, and my supervisor informed me of a tool used to shorten the time spent on transcribing interviews. This tool was HyperTRANSCRIBE. This tools utilized audio files containing the interviews, which led to use of an audio recording device for the remaining sessions. A mobile phone was prepared for this purpose. Testing of correct function in the code and tools of the prototype were performed before each session. The setup was placed on a low table with a L shaped couch for participants to sit on. An external webcam was connected to the laptop, to allow participants to switch between the integrated and external webcam at will during testing. Participants were also tasked with filling out a survey. This was made before the first session. The website kwiksurveys.com enabled quick and efficient setup of a survey, and collection of registered answers with statistical analysis. It can compile registered answers in an excel file for easy overview.

Findings

Here the findings of each session will be stated, along with the duration of each sessions and its stages. The registered complete duration is a general approximation of start to end duration of the session. There were preparation times for each stage as well as other influences not stated in the measured stages e.g. restroom break. This is represented by a longer complete duration than added total of stage durations. Session 1 contains a higher degree of approximation due to the lack of audio recordings showing exact duration of interviews. All sessions were spoken in Norwegian as this is the native language of all participants, and clear communication was considered key for best cooperation and discussion between the participants.

Session 1:

Complete duration of session: 1 hour 20 minutes.
Duration of pre-testing interview: 7 minutes.
Duration of testing: 20 minutes.
Duration of filling out surveys: 10 minutes.
Duration of post-testing interview: 25 minutes

In this session, the two participants were not acquainted, and thus have no knowledge of each other's skills or behavior. They are both employed in workplaces with a standard office environment. They therefore have professional experience of computers as tools for work-related tasks. They also through their work are used to working with people on a professional level without any social or private interaction outside of work.

Pre-testing interview

Both participants stated that they had little to no prior experience with AR. They had heard of the concept, but not seen or interacted with an AR interface themselves. After a brief introduction to AR given by me, they were asked to discuss their opinion of the potential use and usefulness of AR. Despite their lack of prior experience with AR, they both mentioned several perceived possibilities that actually exist today. A GPS application with AR was mentioned first, stating that it could be useful to have directions presented right in front of you. This is a concept that has existed for a relatively long time, and there are many variations of it in use. X-ray goggles were mentioned more as a joke, but there has been use of AR in medicine to overlay x-ray images over limbs and body parts through AR during operations and examinations. Video games were briefly mentioned as an option, but not delved into further. Using AR for instructions and walkthroughs was stated as well, an application of AR existing in e.g. industry settings today. It was finally mentioned that architects and other people working on large-scale could make good use of this technology, to place a virtual model where the real object would be placed before creating it. After these examples, the participants stated having difficulties in seeing more possibilities for AR. They discussed that AR had not seen enough use in the general public for them to envision real possibilities.

When asked if they thought AR could become a standard for interfaces, they both considered it possible. But they thought that the transition would require time to make people less dependent on the mouse and keyboard as the main interface. They also believed it a requirement that the cameras commonly used today to be improved for AR to get a foothold in a social setting. No change of interface would be considered until there was a practical advantage of doing it.

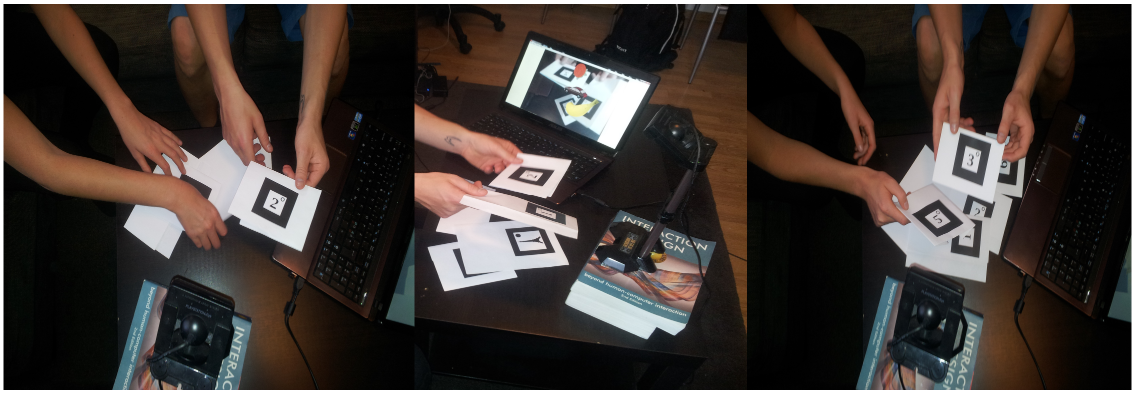

Figure 16. Testing session in progress.

Their initial reactions to the markers made of paper were hints of uncertainty. They quickly grasped the purpose of the markers printed on the paper and showed these to the camera. At the appearance of the first 3D model, shock and fascination were the initial reaction. They eagerly continued to play around with the interface and different models, becoming very animated when discovering that multiple models could be shown at the same time. They always referred to the models instead of the markers when asking each other to move a model in some way. This could indicate that the markers became a transparent tool for them in the interaction with the interface. This would then be a testament to the immersive nature of AR.The external camera was used at one point, and it faced the open space on the table. With this workspace, they silently agreed on their own spaces in the background of the workspace to toy around with. The foreground of the workspace was shared for closer inspection of each individual model.

Early in the session they started cooperating and taking note of markers that produced the same models. They quickly deduced that there were pairs of each model, and that this interface was a “find 2 alike” game. After stating this they continued to explore the interface. They placed markers in different angles from the camera and made use of both the integrated and the external camera. They ended the session with the statement that while the detection quality of the camera often caused flickering in the models, they still had greatly enjoyed interacting with the interface.

The observations from the testing indicated a good support for collaboration in that the participants flowed easily between focus on each others actions, and cooperated as equals. Communication was continuous between them, but also wordless agreements were seemingly made. Working as a team, they quickly grasped the concept of the interface and its general functions. If this rapid understanding was a product of their effective cooperation, or a quality of the interface itself can be a topic of further study. Their experience with the interface itself seemed to be a thoroughly positive one. Their actions and expressions stated interest and entertainment, and they confirmed this themselves at the end of testing.

Post-testing interview:

After the testing and survey were concluded, the participants were again asked for their opinion on AR and its potential. They replied that they perceived AR to have a large potential, but still underdeveloped. It was an “infant”, and needed to grow more first. Concern was also displayed about how “real” AR could make be. Violent video games could have a larger negative effect on young children. It could cause worse cases of users becoming so immersed that they removed themselves from reality, similar to events related to the virtual world “Second World”. Interesting to note, this concern was immediately put aside when asked what it would take for AR to become a social success. The first reply was that it had to become more “real”. It had to be like what we see in movies today. A smoother representation of models was desired, as a tool it would be unusable with constant flickering of the models. Finally they agreed that must be more appealing to the eye. If not it would become tiresome to use. They concluded with that the way AR is today, they did not feel the need to use it, as it was not effective. They did however see advantages of using an AR interface in the future compared to a mouse and keyboard interface.

Next they were presented with the issue of possible fatigue from using AR interfaces for a long period. They immediately stated that this was a non-issue. They used office environments specifically as an example of people today not being active enough, and saw this kind of interface as a positive method of bringing more activity into the daily schedule. When asked how they would react to the fatigue in e.g. the arms, they both replied that they would prefer fatigue from activity compared to stiffness from lack of motion. This could indicate an overestimation of the issue of fatigue from motion in AR.

With regards to learning, the participants stated that the more “physical” nature of AR could contribute to a better understanding of what was worked on compared to typical interfaces today. Having the ability to “pick up” an object for closer study, instead of clicking on a mouse and keyboard. One participant stated it as “sensing it without really sensing it”. They also perceived the use of motion in users as a positive quality of AR to enable adjustment to a new interface. The believed that with motion, a user had more input from experiencing the interface. The motions themselves could then aid in learning the interface. A small reference to “muscle-memory” was made, with the example of one participant always pressing wrong buttons on her keyboard at home due to having adjusted to the keyboard at work.

In terms of cooperation, it was stated that if HMDs were used, one could remove the “working together without working together” factor that could appear from a group of users with individual computers. Presentations and collaborations could also be improved by the ability to point at the model displayed on the table and say that that is what you were referring to. Suggestions for modifications could be shown by “physically” interacting with the model instead of being explained. In cooperation with distant users, the participants perceived AR as a good improvement for today’s videoconferencing tools, but noted that they believed this was still 10-20 years in the future.

Session 2:

Complete duration of session: 1 hour 55 minutes

Duration of pre-testing interview: 11 minutes.
Duration of testing: 35 minutes.
Duration of filling out surveys: 10 minutes.
Duration of post-testing interview: 30 minutes

The participants in this session are colleagues working in customer service, and are used to working together. Through their work in customer service they are used to working directly with people, with direct communication. They make use of computers in their work, but it is mainly a tool for private use to them.

Pre-testing interview:

Both participants have had some experience with AR, though in different ways. One participant has used TINE´s AR application using their milk cartons as a marker. The participant found the application entertaining at first, but the feeling faded quickly due to lack of variation in the interaction. It can be noted that this application primarily is aimed towards children. The other participant has not experienced AR directly, but recent video games give examples of AR from an in game perspective. When discussing potential use for AR, video games are mentioned without further specification. Use of AR for simulations and tutorials is mentioned, followed by remote control of appliances in a home, with reference of AR seen in the movie Minority Report. They continue by considering that while technology-oriented people most likely will use AR, people who are not particularly interested in technology can make good use of AR by its simulations and tutorial potential.

When asked their opinion of AR potentially becoming a standard for interfaces, they reply that obvious factors like ease of use, accessibility, performance and comfort must be better that current interfaces for that to happen. But they elaborate by stating that if AR interfaces become as smooth and appealing as e.g. the ones seen in the Iron Man movies, it would almost definitely become a standard for interfaces.

Testing:

When presented with the application and the markers, the participants quickly deduced the purpose of the markers. They showed fascination with the 3D models, particularly with the fact that when they rotated the marker the model rotated with it, making it "really 3D". This could indicate a reference to the "physical" quality often applied to AR interfaces.

During the first part of the session, the model of the banana behaved erratically, with flickering and moving seemingly at random, especially when other models were displayed at the same time. While a serious error in the interface, the participants found this very amusing. They even made a “game” of it, varying between trying to get the banana to behave and intentionally making it move erratically. They seemed to greatly enjoy this activity. This could be an indication towards a connection between AR´s interactivity and enjoyability. It can also be argued that the displayed enjoyment stems from their perception of it as a “game”, and not AR as the interface.

When they discovered that the models were sets of pairs of identical models, they divided the respective markers so that each participant one marker for each type of model. Before they had separated the markers between them, communication between them was constant. They both requested actions from each other and discussed what they wanted to do. However, as soon as the separation of markers occurred, they became more quiet, seemingly doing more individual study of actions and their consequences when using the interface. This could indicate a connection between direct cooperation with communication and perception of tools as “shared” or “individual belongings”. A non-vocal agreement to study individual interests could also have occurred. None of the participants made any attempt to further identify the purpose of the interface besides displaying models through markers.

When asked what their opinion was on the purpose of the interface was, they both immediately replied “ to display models”. They expressed no need for a further purpose in the interface, having greatly enjoyed that simple aspect of the interface. When presented with the explanation that it was intended as a “find 2 alike” game, they expressed understanding in hindsight of this purpose. They commented that they could imagine this interface as very suitable and enjoyable for this purpose.

They had both expressed fascination with the interface throughout the whole session, seeming wholly absorbed by it. No comment was ever made on the flickering of models or the erratic behavior of the banana as disturbing to the experience, and neither participant showed any signs of frustration during such episodes. These observations could indicate a strong potential of immersion in the interface and AR in general. When ending the session, they stated that “it was fun” and “I would like to do this more”.

Post-testing interview:

Both participants started by stating that they believed AR had many possible uses. One participant discussed content seen in one video in the survey, where by placing a video game case in camera view, a review of the related game appears on the table. This made the participant see a possibility of accessing much more information using very little physical space. It would also remove the need for clicking and searching for the desired information. The other participant mentions that Sony had stated that they wanted to make their users “interact with their whole living room”. The participant stated that what they could mean by this seemed more possible after seeing AR in action.

When asked on their experience with using the prototype, they both stated that it was fun. One participant remarked that it had been a game they were using, which brought out the fun factor. This could potentially confirm the indication observed that their enjoyment stemmed more from the game itself than using an AR interface. They did state appreciation towards the interface, and could imagine many practical uses of AR interface in work-related environments. When asked if the errors and flaws in the interface negatively affected their experience, they both said no, they had still enjoyed the interaction. However, they stated that they probably would have enjoyed it in a different way if it worked better. One participant remarked " But the ability to see 3D models pop up on the screen because you´re holding up a number. That is something I find pretty cool in itself". This could be an indication of AR having a strong potential for positive initial experiences. Again the low amount of workspace required to use such an interface was brought up as a great advantage for the interface. They expressed this as a particularly strong advantage if HMDs were used. One participant felt that you could look a bit silly wearing a HMD. At this the other participant remarked that people thought people using handsfree devices for mobile phones looked silly when that technology appeared in public, but it isn´t noticed much today. It was stated that it would just be an adjustment to make, to get used to it. One of the participants thought that the movements used in interaction with AR interfaces would contribute positively to AR becoming popular and accepted. It would be an advantage with that it demands more physical activity from users and could possibly remove the perceived correlation between watching screens and being lazy through this. The other participant was a bit skeptical to how well AR would become accepted simply based on its movements for interaction. It was stated that it would possibly be a factor more easily accepted by the younger generations today, and this would then not be a problem when AR becomes mainstream. The participants also considered that the way the interaction works could also make playing video games together with friend a more social experience than today.

They were asked what they thought it would take for AR to be socially accepted and used. These were the factors the participants mentioned as important:

- Accessibility through low prices and availability
- Ease-of-understanding without training or education in the field
- A targeted area of use with enough interest.

They also expressed the opinion that video games would be the arena where AR would first get a firm foothold for social acceptance. This could indicate positive opinion on their behalf on AR and its potential for enjoyment.

The participants were given a short summary of the first registered uses of AR in the commercial market. At the mention of use of AR interfaces in industry to simulate assembly, both participants became lively with fascination. "That is actually really clever" one participant stated. The other participant continued by saying that this would be great along with complicated furniture from IKEA and assembly tasks they receive at work. The first participant then stated "I am looking forward to when this can become something". This expressed eagerness could be an indication that people currently unfamiliar with ARs can become interested if given a proper introduction to AR, as this participant had.

When asked if they could see themselves using an interface that is exclusively AR today, one participant stated “Well, I have already used Eye-Toy. That uses only AR”. When asked if they could themselves using such an interface for a more serious purpose, they started discussing. They both agreed that it would be possible if they used HMDs. One participant further demanded that only the arms would need to be moved for interaction. Both participants stated that they would have to adjust to using AR before sessions of longer duration would be likely to happen. Having to wear the HMDs at all time was perceived as potentially tiresome. There were no worries regarding fatigue of the arms and other limbs, but strain on the eyes were an issue they discussed for some time. Long periods of watching screens today can tire the eyes, and HMDs was regarded as possibly worse in relation.

The participants discussed for some time whether AR could replace the mouse and keyboard as the main interface. One participant was very positive initially, but the other participant disagreed. The other participant stated that on the smart phone, the participant still missed a physical keyboard, even though having possessed a smart phone for 2 years. Further discussion on the topic between the participants reached a point of agreement that this was likely a generation gap factor. The younger you were, the less likely were you to see a problem with an AR interface replacing the now used mouse and keyboard.

They were then presented with a situation where AR interfaces were the standard for interfaces, and asked how AR interfaces then would affect their experience. The portability of whatever they were doing if they were using HMDs was brought up as an advantage. They became really focused on worrying about the social implications of wearing HMDs all the time, feeling that it could isolate people further than mobile phones can do today. People sitting around a table all using their phones was used as an example. This could indicate a concern of AR interfaces with HMDs worsening the situation due to their portability and instant feedback. It was also mentioned that with the smart phone, you already have access to all information in your pocket. They did not see the need for it constantly available in front of their eyes. In the end they remarked that AR interfaces using cameras like a webcam would have less such problems, but would remove the portability. These concerns and considerations indicate a strong awareness for social implications, perceiving objects that disturb social interactions as negative.

The participants where then asked for their opinion on AR´s influence on learning and adjusting to an interface. They mentioned the same things as earlier, with AR needing some adjustment to in general, and it depended on area of use. They also noted that we have two hands in comparison to only one mouse. This could improve managing and organizing actions. In terms of ease-of-understanding, they think that it again is a topic of generations. That the younger you are, the more adjusted you are to this kind of technology. At this, one participant comments that when trying to teach a grandmother how to use a computer, “she lifted the mouse up in the air when trying to move the cursor up”. The participant then humorously remarks “She was living in AR already at that time.” This could indicate that AR interfaces can be easier to understand for less computer-smart users, due to the more “natural” movements that can occur in their interactions.

And the opposite, that people more set in todays standard interfaces will need more adjusting to understand and learn AR interfaces.

On the topic of collaboration, the participants agreed on AR interfaces having some advantages. One could present changes or additions in front of everybody instead of on a screen, and feedback could be given instantly. It would also be more “free”, by not restricting all the users to look at one specific point from a specific angle, e.g. a computer screen. HMDs seemed a requirement in their eyes for decent collaboration, as the factor of not having to share a computer screen was stressed several times. A negative point stated for AR interfaces regarding collaboration was that more users able to interact simultaneously could potentially become messy and chaotic. This is a possible indication of AR not improving teamwork itself. It then instead aids a team with good teamwork to perform better.

As a last comment, one participant stated that it would be exciting to see what becomes of AR. It seemed likely that it would require a long time before it became socially accepted. Something completely new might have appeared before that happens.

Session 3:

Complete duration of session: 1 hour

Duration of pre-testing interview: 3 minutes.
Duration of testing: 15 minutes.
Duration of filling out surveys: 10 minutes.
Duration of post-testing interview: 16 minutes

In this session, both of the participants are students in the field of informatics. They also work in the same company, but in different departments. They have not worked with each other directly before.

Pre-testing interview:

One of the participants had only seen a brief example of AR before, and had basic knowledge of it as a concept. The other participant had not used AR but knew of its use in video games and in technology aiding physically or mentally disadvantaged people. The participant had no further knowledge besides that it had been used in these fields.

When asked their opinion on AR´s potential as a technology for interfaces, they both said that they had no faith in AR becoming “the next big thing”. It could be used in areas where it sees use today, as long as the movements and software required were simple. For any further use they felt that AR needed to be improved a great deal to be used by the masses. When discussing the possibility of AR becoming a standard for interfaces, like the mouse and keyboard is today, both participants agreed that it would be some time before it would be likely. One participant stated that 10 years would be an appropriate time before AR was developed enough to become a standard.

Testing:

Both participants had enough knowledge and experience of AR to immediately identify the purpose of the markers put before them. They quickly proceeded to place the markers in front of the camera and evaluate each model. They simultaneously discussed the quality of each model and how it was represented while doing this. They did express some fascination and enjoyment with the 3D models. However, they also continuously searched for flaws and possible improvements in the interface. This behavior can potentially be connected with their knowledge and education in the field of informatics.

They cooperated seamlessly, but one participant behaved more like a leader while the other answered mostly to instructions from the "leader". The participant that behaved more as a leader was the participant with the most knowledge of AR and how it works. This could be the reason for why the other participant was more receptive to instructions. They both vocalized observations as they made them, and quickly and efficiently identified the models as thee pairs of identical models. They quickly surmised that the interface then was intended as a "find 2 alike" game. After making this conclusion, they started exploring the mechanics of displaying a model. One participant eagerly asked to be allowed to see the code for the interface at a later time. They expressed fascination with how well the displayed model reacted to rotation of the marker. This was the only positive comment they had on the quality however. They were not satisfied with the flickering of the models or the occasional detection failures of markers.

They ended the testing session with the statement that it had been interesting and entertaining to see, but that the level of quality needed serious improvement before any serious use of the interface could be done.

Post-testing interview:

With the testing and survey completed, the participants were asked if their opinion of AR had changed through these experiences. One participant said that it looked really fun, but it still needed time before people become properly aware of it. And it needed to improve for this to happen. The other participant said that AR has attempted to reach the commercial market before. You would always be impressed at first, but a week later it just became a "gimmick", and interest was lost because it was not as deep as you desired. It became boring very quickly, because it was so simplistic. The participant said that AR had become better and better each time it appeared, but it was still never good enough to break through to the market. This could be an indication that AR interfaces have been well designed towards strong positive initial experiences, but lacks work on experiences over a longer period.

It was also stated that it took much more time to use an AR interface. While it looked cool, people usually choose whatever is most efficient. One of the participant mentioned the Nintendo 3DS as an example. When it was released, it exploded around the world and was immensely popular. However, it ended up just lying there and not being used for almost a year, until some good games appeared. This indicates that "fancy" technology and display methods are not enough, the content is also required to be at an adequate level. For AR, this could refer to that while the quality interaction needs improving, it also needs to find relevant and interesting areas of use for users.

The participants were asked what they thought would be required for AR in interfaces to become a big success. The reply was that the response time of the interface needed to improve. Smarter software and better hardware was also required. "There is a lot of good "augmented" out there, but it would cost a fortune to get it in you living room". Neither participant could see themselves using an AR interface today. One participant said "It takes too much time. It isn´t fast enough. It isn´t effective enough.". The participant also said however, that it could be used for people with disabilities like mentioned earlier. To use AR interfaces to help others. This could indicate a point of view where AR interfaces are not advanced enough to sufficiently fulfill complex task people encounter. It could instead aid in simplifying tasks people with disabilities have trouble with. This would make AR good for use in "Smart-devices".

Both participants felt that despite never having used an AR interface using motion, it would be tiresome to use for longer durations. One participant remarked that it could depend on the motions required for interaction. The movie Minority Report was brought up as an example of an AR interface that could work for long duration usage. If the motion was restricted to sitting in a chair, moving just a few part of the body, it would become tiresome. This could indicate that e.g. complete arm motions would be preferred over wrist and hand movements.

The participants were now asked if they could imagine AR interfaces replacing the keyboard and mouse interface. One participant was skeptical to a complete replacement, but was open for a partial replacement, a combination of the two types of interfaces. The other participant said that while it was difficult to say, it did seem a possibility in the future. The participant continued by stating a belief that it then could react to thoughts as well, allowing users to send messages and communicate purely by thought.

The next question was to consider how the interaction with AR interfaces worked, with motions instead of buttons, 3D representations instead of flat images. The participants were asked to discuss if this had any effect on learning and adjusting to an interface using AR. One participant noted that it could go both ways. An example based on the participants experience with 3D software was used. The participant preferred using a trackball device instead of a mouse when interacting with 3D models in 3D software. The device removed the need for constantly clicking the mouse and keyboard, making it easier. Replacing the trackball with an AR interface could be an improvement, according to the participant. This could indicate that support for more seamless motion with no space restriction like a mouse has, is more suitable for 3D environments. Which would

imply that AR has an advantage for use in this field. Next, an example was presented for the participants, using the "file management interface" seen in the Iron Man movies. The participants were unsure about such an interface being easier to learn. They agreed that it was cooler. It was also mentioned that the ability to use two hands could help. The participants were after this explained that some researchers were of the opinion that interfaces with AR would be easier to learn due to "natural" and familiar actions being the triggers for interaction. It would reduce the need of learning new techniques. At this, one participant expressed an opinion of AR interfaces being suitable for people with little computer experience. More experienced users might have more trouble due to being set in the techniques we already know. Since there are very few people left with little computer experience, the participants believed that it would be young children that would be introduced to AR interfaces right away that would first get used to AR in interfaces. These opinions could indicate that AR is suitable for users with less computer experience, and having a potential for easy adjustment.
When discussing AR interfaces´ potential effect on collaboration considering their qualities, both participants seemed positive. One participant stated that it would be much better than two people sharing a computer. The other participant was concerned about it becoming a bit chaotic, with two people interacting with and looking at the same object. They were then asked to consider the option of having a model displayed on a table in the middle of a group. It was then stated that it would simplify things. It would remove the need of gathering around a single screen to see changes being done. Both participants talked as if using HMDs was a given when used in collaborative settings. This could indicate that removing the restriction of focusing on a small screen is a strong incentive for use of AR interfaces in collaborative environments, if not a requirement.

The testing session was concluded with the participants talking about what they were eager to see AR interfaces in. Video games were the most prominent, but other luxury actions like remote controlling different devices in a home was also mentioned. This viewpoint could indicate that AR interfaces are more prone to be viewed as a luxury technology than practical or necessary technology.

Survey results

The surveys were held after the participants had tested the prototype, but before they were interviewed again. This was to enable the participants to remain as unaffected as possible from outside influence. The interview could bring up topics of discussion that could alter their opinion of their experience with AR in hindsight. The survey was structured to extract information from participants on their experience with the AR interface and AR in general. The site where the survey was created allows the creator to see what each registered participant of the survey answered, which allows the creator to se patterns in individual participants answers.

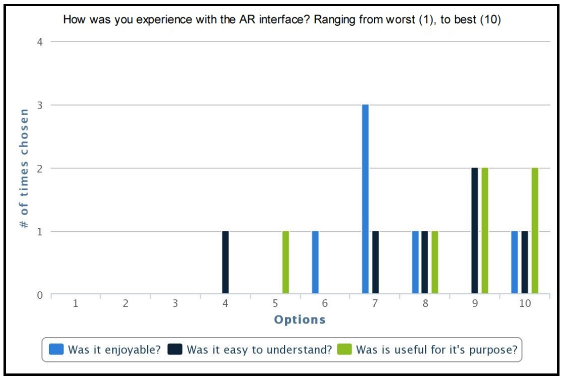

Figure 17. Survey question 1.

The first question was to range their experience of the AR interface from worst (1) to best (10). There were three subquestions, asking them to rate their experience in terms of enjoyability, ease of understanding, and usefulness in its purpose. All the results were relatively positive. In enjoyability, the average was 7,5. With the exception of one 10, the scores were values within the range of 6-8, three of them being 7. This indicates a generally positive experience of enjoyability, but with room for improvements. With regards to ease of understanding, the average value was higher, with 7,83. However, the lowest value here was 4, and the rest were 7 or higher. This indicates that the interface is generally easy to understand, with a few exceptions. When asked if they found the interface useful for its purpose, the average became 8.5. With two values of 10 and two of 9, this is the most positive factor of the experience so far, with a lowest value of 5 lowering the average some amount. This indicates that the use of AR for a "find 2 alike" game is generally a good choice, enabling positive experiences of usefulness in most settings. The total average of experience became 7.94, indicating that the interface was an enjoyable experience in general. If these results hold true for other AR interfaces, then AR interfaces in general have strong potential for positive experiences. It is important to note that this survey only explores initial experiences, and no results from this survey can with good accuracy indicate a positive experience over time.

The next question was for participant to state their opinion on how long it took for them to understand the purpose of the interface. Their answers were compared to the observations made during the testing. From the observation, all participants spent about 4-5 minutes before they stated that they understood its purpose.

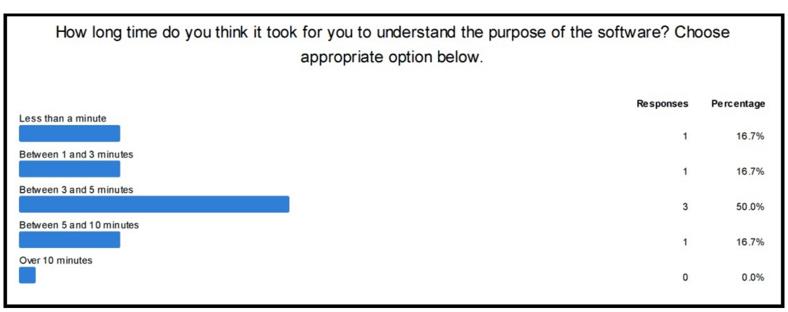

Figure 18. Survey question 2.

This matches well with the results in the survey. 3 participants claim that between 3-5 minutes passed before they understood the purpose of the interface. One participant chose between 5 and 10 minutes, but this can be a participant from a pair that came very close to going over 5 minutes. Two participants stated they believed less time had passed, one even choosing less than a minute. It is possible that the participant understood the purpose that quickly, but did not state it until later. It is also possible that the participant was so immersed in the process that the sense of time was reduced. Despite the interface being a relatively simple game, to understand its purpose generally within 3 to 5 minutes is a good indication of ease-of-understanding. One has to consider that AR interfaces and markers was an unfamiliar setup for most of the participants. This could negatively have affected the ease-of-understanding, as it was not only the purpose of the interface that needed to be understood, but also the interface itself.

The participants were then asked for their preferred interface if they were to do this task again. All answers were that an AR interface would be preferred. One participant did not register an answer to this question, for unknown reasons.

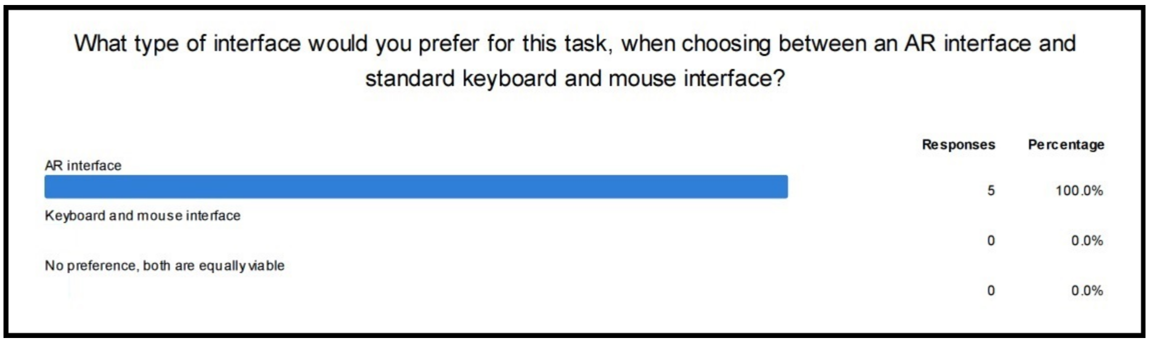

Figure 19. Survey question 3.

The results indicate a perception of a more positive experience using AR interfaces for this task than a mouse and keyboard. Enabling this perception to be carried over to more serious or complex tasks is important to create a path towards social acceptance for AR interfaces.

In the next question, participants were tasked with choosing factors that affected their choice of preferred interface in the previous question in a positive manner. As all registered answers in the previous question were AR, then all the positive factors registered in this question is directed towards AR interfaces. The answer sheets on the webpage show that the participant that did not register an answer in the previous question did mark collaboration support, and only that, in this question. Therefore, of the 5 participants that chose AR interface as the preferred choice, 4 of them did so because of collaboration support. All the users who preferred AR interface chose enjoyment as a factor for this. This again indicates a strong potential for enjoyable experiences with AR interfaces. 4 out of the 5 participants chose collaboration potential and intuitiveness as factors positively affecting their choice. It can then be stated that if this group of participants are a representable group of users, AR interfaces hold good potential for uses related to collaboration, and are relatively easy to understand.

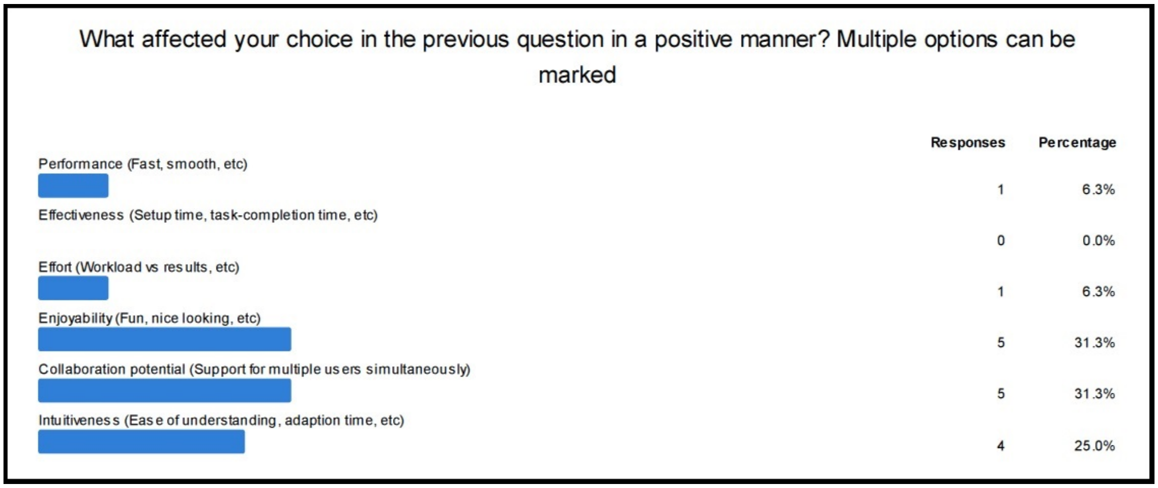

Figure 20. Survey question 4.

An interesting result is that not a single participant marked effectiveness as a reason for their choice. Two options that only received one vote were performance and effort to set up and use the interface. These three factors are more functional than experiential, indicating that AR interfaces are more balanced towards experiential qualities than functional. It must be stressed that a prototype is the base of these results. A finished product, an interface of higher quality, might alter the results towards better scores for the functional qualities.

The last part of the survey asks users to rate their interest in using an AR interface after the experience they had in the testing session. 4 of the 6 participants rated it the higher possible amount, indicating that AR interfaces evokes strong interest or curiosity in some users. The two other scores were 4 and 6. After this question, the participants were urged to watch three videos of more advanced AR interfaces than the one encountered in the testing.

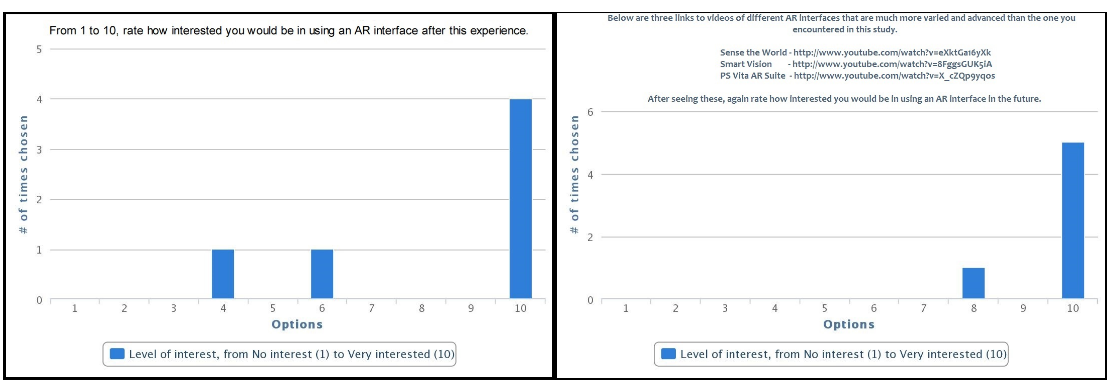

Figure 21. Survey questions 5 and 6.

They were then asked to again state their interest in using AR interfaces, while considering what they just had seen. Now 5 of the 6 participants rated their interest the highest as possible, and one participant rated it as an 8. What this indicates is perhaps not that AR interfaces are very interesting to a majority of users. But it does indicate that AR interfaces hold a strong potential for being perceived as attractive by users. As a participant said during the sessions, “AR has a huge ´wow´-factor”. This needs to be considered in development when evaluating initial experiences of use, as it can create many “false positives” if considered a guarantee of user satisfaction in the long run. This is an indication of AR interfaces needing evaluation of long-term UX to increase the chance of valid results.

Possible future paths for test sessions

Based on the results of these testing sessions, there are numerous factors that can be improved or added for new and better results.

The prototype used in sessions was just barely within the set requirements during development. Improving this could greatly affect all results, and grant more validity to any indications derived from these results. The participants expressed great interest in motion as a controller, and use of HMDs. Including these aspects would then be a good improvement for any further testing. Another useful change could be going from a marker-based interface to a markerless interface. This would allow participants to focus more on the actual interaction and not the tools. Including audio feedback in the prototype could also have effects on the experience of the participants. The testing sessions themselves could accommodate more participants at the same time, to better evaluate AR´s potential for collaboration. Designing the testing sessions to allow users to attempt to set up the equipment and initiate the interface themselves can give insights to how users would experience use of AR interfaces in their daily lives, where they would have to do such actions themselves.

Chapter 6

Discussion

RQ1: How does AR affect learning compared to classic interfaces?

Part of the purpose of this thesis was to evaluate the effect interfaces using AR have on learning compared to well known interfaces, i.g. the mouse and keyboard. Through performing and analyzing observations, surveys and interviews, results have been produced for evaluation and comparison of the inherent ability of AR interfaces in this field.

All testing sessions were organized with participants working in pairs. This was to enable the connections between learning and collaboration stated by different researchers (Dunleavy et al. and Billinghurst). By presenting the participants with a common goal of using and understand a prototype of an AR interface, these qualities become more apparent for study and analysis. The pairs also all had different levels of familiarity with each other. One pair had never met before and had no knowledge of the skill sets and behavior of their partner. Another pair was colleagues, and friends outside of work. They therefore are familiar with working together, and also have knowledge of the skills their partner has. The final two are colleagues as well, but as they are in different departments and have never worked directly with each other, they do not hold any certain knowledge of their partner´s skill sets or behavior. They do have knowledge of general skills and preferred behavior in their workplace, so they know of cooperation techniques that they share through their common workplace.

During the testing of the prototype, the participants expressed understanding of the basic function of the interface at an early stage in the process. Later in the process, the majority of the participants expressed understanding of the purpose of the interface. Understanding is thus not an instant event, but a gradual process. It comes partially as more aspects of the interface is discovered and experienced. Therefore, these expressions of understanding do not necessarily indicate that "true" understanding has actually taken place. However, a user who has gained a perception of understanding an object or a concept will accordingly feel a sense of accomplishment because of this. A sense of competence. The magnitude of this sensation can vary greatly depending on the situation. Gaining this sense of competence is a primary need in humans according to Hassenzahl (2010), and is a facet of user experience. Furthermore, this is a positive experience motivating for continued use of the interface. This continued use will potentially lead to more experiences of understanding, as more aspects of the interface are encountered and familiarized with. This process will gradually move the user towards a true understanding of the interface in question. By this reasoning, this process needs to be considered in the design of the interface to enable better ease-of-understanding. Video games are the greatest example of design for this process, as big complex video games rarely allow players access to the full extent of functions and interaction options from the very beginning. Instead, the most basic and core factors of the game are introduces first and at a slow pace, whereas the more advanced functions will be introduced along the way. While a work-related product cannot reasonably hold back functions until more usage has occurred, the setup of the interface can e.g. be designed toward larger focus on the basic functions and concepts in the interface for beginner-level users. During the testing session, there were no displayed reactions signaling confusion or frustration in any participant. This is another indication of good ease-of-understanding in the interface. Presence of such emotions can have major negative impact on a user´s experience, and will to continue using the interface. As these results mentioned here are based on observations, they can be misinterpretations on behalf of the observer. However, most participants later registered answers of similar opinion in the survey, adding more validity to the results.

In the survey 5 participants chose a preference for the AR interface over a standard interface. 4 of these participants stated one reason for this choice being its ease-of-understanding. This indicates that the prototype interface is perceived as easy to understand, and it follows that interfaces of higher quality with the same purpose should retain this attribute. Interfaces of more complexity will depend on better design for easier understanding, but inherent qualities of ease-of-understanding in AR interfaces should still be present. In interfaces of higher complexity, the resulting sensation of competence from understanding will be stronger. However, the transference of this ease-of-understanding cannot be guaranteed based on this study alone. In addition to the issue of more complex interfaces, it should be stressed that this study only evaluates initial experiences, and thus only the "experience" of learning and understanding. Initial experiences do not hold enough certainty of true understanding to guarantee it. Analyzing only initial experiences is adequate for a simple interface as the one presented here. For a more complex interface, a study over longer duration would be necessary to measure true understanding in comparison to perceived understanding.

Some of the participants mentioned during the interviews the more "physical" nature of AR interfaces. By granting a more physical "feel" to the virtual objects, the participants perceived them as more familiar and easier to understand for. This is due to users being able to more successfully incorporate real world experiences in the understanding of the interface. In addition, this enables the use of both hands, a factor most participants noted as a more familiar method of interaction than using only a pointing device such as the mouse. These perceptions and opinions expressed by the participants match well with what Billinghurst refer to as the "Tangible Interface Metaphor". It is mainly connected with qualities that improve collaboration. However, the interaction methods with such interfaces have more resemblance to actions in the real world than those used on standard interfaces today. This quality allows users access to a wider range of prior experiences to compare with for understanding.

This therefore enables users with little or no computer experience to interact more successfully with the interface, which coincides well with the opinions of participants claiming that AR interfaces will be very suitable for users lacking computer experience. These opinions and perceptions do not guarantee a better experience, but are still important as these perceptions can aid in the social acceptance of AR use in interfaces. The participants in this study further discuss the physical qualities in the interfaces as potentially hindering the adjustment to them for users already well adjusted to interfaces common today. They believe that the change could be too different from what such users are familiar with, causing them to prefer the familiar interfaces instead of learning new techniques. This is also a factor to consider for the social acceptance of AR in interfaces.

All participants referred to similarities and connections between games and AR one or multiple times during the sessions. All participants displayed signs and perceptions of AR interfaces potentially being as immersive as game environments. When considering this, and Gee stating that games act as learning machines, one can see a huge learning potential in AR interfaces. Assuming Gee´s viewpoint on games as correct, AR interfaces have a greater potential for users to cultivate and adapt identities, and its immersive and engaging nature will motivate users to continue using the interface, encouraging the understanding of the interface.

According to the participants of this study, an advantage of AR interfaces is how they enable a more seamless interaction through motion. A steady flow in the task completion allows for more attention towards the task itself and less on the interaction. This quality was retained even using markers in the prototype, where the markers became a transparent tool in some sessions, allowing the participants to more fully immerse themselves in the 3D and physical experience of the interface.

RQ2: How does AR affect collaboration compared to classic interfaces?

Another aspect of AR interfaces studied in this project is their effect on collaboration. This was the primary reason for having pairs of participants in each session. Observations of the pairs working together granted insights to the potential of AR interfaces compared to standard interfaces. Having the participants work together allowed them to experience collaboration with an AR interfaces and give their opinion on how well AR facilitates this.

In the testing sessions, the participants all displayed effective collaboration, but with great variety. One pair cooperated continually and kept a constant flow of communication between them both to explain what they were doing and what they wanted to achieve. Their communication consisted of more than words, often looking at each other and using gestures to aid in their explanations. This is a positive change compared to what many participants in the interview explained as “working together without working together” and similar situations when using the standard interfaces on computers today. It also supports what several researchers state in papers, that AR interfaces have a higher potential of enabling use of non-verbal gestures in communication. This is considered a strong improvement for interfaces used in collaboration environments. Another pair very efficiently interacted with the interface, and after a short session of shared exploration, they declared their opinions on the purpose of the interface. After this, they started individual exploration of the interface, with minimal amount of communication between them. They shared a few insights when discovering them, and used direct communication when doing so, with eye contact and non-verbal gestures. While not as strongly as the previous example, this pair also displayed a removal of the “working together without working together” aspect, but kept to a similar work pattern as most often referred to as such by the participants. The participants worked individually, which was mentioned as a negative aspect of collaboration tasks with multiple computers, but they were much more focused on their partners, sharing and showing insights as they were discovered. It can also be considered that since they also share the interface, the partner had the option of watching the actions of the other while doing his/her own work. This is an indication that while AR interfaces can change the work pattern used with standard interfaces through it qualities, it can also negate negative aspects in these work patterns. The final pair took the approach of “leader” and “follower”. One participant chose a spot more centered in front of the camera for input to the interface, and the other participant chose a spot more one the edge. Both did small actions of individual exploration, but mostly expressed different topics of interest and explored these together. While the “follower” participant did some individual actions, the participant never gave any commands or voiced any desired actions from the other participant. The “leader” participant however, often gave out commands to aid in exploration of different issues currently being studied, and gave instructions directly to the “follower” by showing the desired actions with a marker previously assigned between them in agreement. They both equally demanded each others attention when wanting to speak simply by starting to speak. None of the participants needed any further actions to claim the full attention of their partner. While this could be an effect of both participants being used to collaboration with computer tools through their educations, it can also be an indication of AR interfaces increasing the awareness of partners in collaboration, enabling easier communication. All of the results for collaboration based on the observation are heavily influenced by the individual teamwork skills of the participants, and how they all get along.

The amount of positive results can be outside the normal range if the 3 pairs of participants all are better than average at cooperating with each other. In a study where time was not an issue, the pairs could be mixed up on several occasions and given new tasks each time, to more fully explore the effects of the interface on collaboration, while minimizing the possibility that the designated pairs get along better than a pair of average users.

In the survey, 4 of the 5 participants preferring AR interfaces stated support for collaboration as a cause for their choice. This is an indication that despite the low quality of the prototype, the participants had a positive perception of how the collaboration worked when using this interface. In the testing they all had much improved communication compared to what they talked about as negative aspects of collaboration with standard interfaces on laptops. None of the participants elaborated on this opinion in the interviews however. They all mentioned different interactions with the interface that they regarded as positive for collaboration, but there was little mention on the interaction between other participants or the quality of the communication other than saying that it would be better. It can be an indication of communication quality being a subconscious quality to most participants. It influences their experience of collaboration, but the participants are not aware of it as a reason. It can also be that it did not come up as a topic in the course of the interview as something the participants perceived as positive for collaboration. All participants did state different advantages with possible interactions in AR interfaces, and many of these are for supporting explanations and presentations, which is a form of communications. By being able to interact directly with any displayed content, users will be able to get a better grasp on the situation as a team. Each user will have direct view of the interactions of other users, allowing better understanding and a reference point connected with any expressed opinion or conclusion from a user. The participants however never focus on the communication aspect. An interesting factor is that all participants were unified in their opinion of HMDs being a key component in the interface setup for proper collaboration setup. Some participants mention this directly; other participants instead discussed interactions mainly possible only with HMDs. HMDs enable users to freely move around the augmented content, which frees users from the fixed reference point that e.g. a computer screen is. This is an aspect that really fascinated many of the participants. It is by mentioning the removal of the screen that several participants explain the different advantages they perceive AR interfaces to have. By not having a single fixed focal point of attention in the environment, the participants envision a more social task environment, where users will both work better and enjoy the interactions more. AR interfaces with HMDs will require less space for displaying any content. This allows for more space for multiple users to cooperate in task completion. This expressed interest in removing a fixed screen from the work environment is an indication of AR interfaces having an area of introduction to the social community, enabling the fulfillment of this desire while also being a potential improvement to collaboration environments in general.

RQ3: How does AR interfaces affect UX compared to classic interfaces?

Based on the results from this project, it is in the area of UX that AR interfaces really have their advantages. In all of the observations, survey results and interviews, AR interfaces are attributed with a generally positive UX. There were also results showing that AR interfaces enable users to overlook flaws in the interface when positively engaged.

In the testing sessions, some participants who had stated no prior experience with AR interfaces expressed skepticism when seeing the markers. This could be due to the tools having an unfamiliar look compared to computer interface tools common today. This skepticism needs to be considered when designing marker-based AR interfaces for large user groups, to avoid the interface to be shunned due to misunderstanding the markers and their purpose with the interface. All participant displayed reactions of either shock or fascination, and sometimes both, when seeing 3D models displayed over the markers captured by the camera. The shock aspect can be a possible indication that the mere possibility of such a function was unexpected or unimaginable by the participant. If so, it is an indication of a possible hindrance of the spreading of AR interfaces to the public. If it cannot be imagined, then it follows that any use for it cannot be imagined either. However, all users who initially reacted with shock quickly changed into displaying fascination with the displayed content, and marveled at the quality of reaction to their actions, like rotating the markers. The fascination displayed by all the participants is a strong indication that AR interfaces in general appear very attractive to users. The fascination further manifested itself in the participants as continued eagerness to interact with the interface, and animated movements when talking about their experience and opinions. This indicates that the experience of interacting with the interface was a positive one, and this quality is very likely present in interfaces of higher quality as well. In must be considered that the relatively simplicity of the interface could have contributed to it being an enjoyable experience, and there were no trouble with understanding for any of the participants. A stronger indication that AR interfaces were enjoyed is how most participants expressed positive experiences despite the flaws of the interface. From a functional perspective, the interface was severely lacking, with flickering models and detection errors. However, all participants still expressed enjoyment from interacting with the interface, and some participants even made a game of trying to cause as much flickering in the models as possible, trying to identify the causes for some of the flaws. It should be considered that some of the enjoyment displayed by the participants playing this "game" might stem from the game itself and not the AR interface. Also to be considered is that while participants mainly ignored the flaws in the interface, letting it have little or no negative impact on their experience, this might only be due to the less serious nature of the interface. In interfaces with more serious purposes, where efficiency in task completion would be more important, the presence of such flaws will potentially be much more disruptive than perceived in these testing sessions. There is therefore no guarantee that AR interfaces have an inherent quality of enabling flaws to be ignored instead of disrupting the experience. Despite this, the ignorance of flaws displayed by the participants is a strong indicator of the immersive nature of AR interfaces, as the participants where wholly absorbed with the enjoyment had from interacting with the interface. The participants often remarked with positive expression at how the response to their actions was so "physical", as if they directly interacted with the displayed content instead of the markers. One participant stated it as "feeling without feeling", a "real" 3D experience. This indicates that this physical aspect of AR interfaces is a strong catalyst for interest and enjoyment. The previously mentioned aspect of how AR interfaces enable users to ignore flaws in the interface through its immersive nature also point out another interesting possibility for AR interfaces. Interfaces with more serious purposes most likely will not be as allowing for flaws in the interface. The lowered demands of quality in interfaces with less serious purpose, e.g. games, can be an indication of this arena to be the ideal place for truly introducing AR to users on a broad scale. This arena is more forgiving for flaws as long as there is positive engagement, granting AR interfaces both time and feedback to improve their quality to fit users, and be further developed for more serious uses.

In the survey, the results displayed very strong potential for positive experiences with AR interfaces, with the assumption that the qualities present in the prototype can be transferred to other interfaces using AR. In their rating of their enjoyment of interacting with the prototype, all participants scored it values ranging from 6 to 10, which are all positive values on the scale. All 5 participants who chose a preference for AR interfaces stated enjoyment as one of their reasons for this choice. With this quality being the only aspect of AR interfaces that all who had a preference for AR interfaces agreed on, it can be concluded that enjoyability is AR interfaces´ most prominent feature. This should be taken into consideration when designing and developing AR interfaces. A factor displayed in the survey results is the presence of a “wow-factor”. This is also referenced to in some of the interviews. This is a factor that implies that most users will initially be very impressed by AR interfaces, heavily influencing their rating of their initial experiences. This is then a very important factor to consider in user studies, as it can lessen the validity of initial experiences, which is what most UX measurements are based on. Instead, AR interfaces must depend more on long-term UX measurements for valid results. This will heavily affect the development process of the interfaces, due to long-term UX measurements being a very time consuming process. The lack of social acceptance and awareness of AR might be a contributing factor to this “wow-factor”, as users are not accustomed to the interactions involved. Also to be considered is the possibility that this lack of social acceptance and awareness is itself the whole cause for the “wow-factor”, and not AR interfaces. An influence on social acceptance is the movie industry. In movies such as Iron Man and Minority Report, very advanced AR interfaces can be seen. These contribute to higher expectations in users for what AR interfaces should be like, setting a higher standard expected for AR interfaces than what might be feasible for most developers in the initial stages.

Some participants displayed concern for how “real” AR could become, and how this would affect users. This concern holds similarities to the “Uncanny-valley” effect seen in robotics. With AR and the continuous growth in quality of graphics, the possibility of very realistic AR environments is very imaginable for the participants. They expressed concern for how much worse influence violent video games using AR could have on young children compared to the games today. Another expressed concern was the potential AR could have to further abandonment of reality in favor of a fake reality, such as the cases seen with the virtual environment Second World. As AR is more based in reality than VRs like Second World, it might not be as likely, but the concern is still a factor to be considered. Such concerns could greatly hinder the social acceptance of AR. The participants unanimously agreed on AR interfaces needing improvement before AR will become common to use. It can be considered that a lack of available high quality content is a possible cause for this perception, not a lack of development.

An interesting result from the interviews is a shared opinion only between participants that do not have an education in the field of informatics. These participants expressed positive opinions toward physical motion through interaction with AR interfaces. A concern for long-term UX of AR interfaces is fatigue caused by interaction with AR interfaces over long durations. However, these participants stated that they would prefer fatigue from motion to stiffness from lack of motion, a sensation they had often experienced. This could be a “novelty effect” in AR interfaces, an opinion that will fade as users become more adjusted to AR interfaces. Some participants added that the fact of AR interfaces requiring motion from users might be a factor more suitable for younger generations. It was believed that the younger generation would more readily adapt to this kind of interaction.

An aspect of AR interfaces especially appealing to some participants was the ability to bind any information or virtual object to a real object or space. This was one of the aspects of AR interfaces that seemed to ignite the most inspiration for possibilities in participants, and could thus be a key quality to promote for spreading the awareness and acceptance of AR.

Figure 22. Spaceglasses - a recently developed HMD

One tool connected to AR that was the focus of much fascination and opinions was HMDs. All participants were very positive to the use of HMDs, despite some expressed concerns. Some participants stated that they thought they could be seen as “silly” if seen wearing a HMD. Other participants dismissed this as an issue of adjustment. This is an indication of the process towards social acceptance. With HMDs and AR interfaces, some participants expressed a possibility of gaming with friends becoming a more sociable event, as the interactions would be more influenced by the other players, especially if the players are in the same room. An interesting side to the topic of HMDs is that the participants with no background from the field of informatics were much more inclined to positive opinions on the possibilities of HMDs and their use. A participant stated a concern for how usage of HMDs could cause more strain on the eyes, but soon added that if it were possible to switch between use of HMDs and other display modes then it would not be much of an issue. Another concern with HMDs was possible isolation from surroundings, with users focusing more on the displayed augmented content than the actual real content surrounding them. This concern might not have taken into consideration that AR as a concept act along with the reality, and is generally not intended to overshadow reality. The concern is still important to consider, as it can influence the perception of AR and its use. But all in all, the greatest quality of HMDs as perceived by the participants is the portability they enable.

With HMDs, the possible settings for use of AR interfaces are dramatically increased, a potential noticed by all participants. This is their most prominent feature, and adds great flexibility to AR interfaces. Many of the participants discussed interactions with AR interfaces with clear assumption that use of HMDs was a given. This strongly indicates that HMDs will almost be an obligatory tool for most AR interfaces that will be accepted by users. AR interfaces in general have a strong “coolness” factor according to the participants, but especially so with HMDs. It indicates that the attractiveness of AR interfaces is increased with the addition of HMDs. Another factor pressing the importance of HMDs is an expressed desire or positive opinions of the majority of the participants. Many of them mentioned that the removal of the screen from collaborative environments as a positive change, and HMDs would be the replacement in combination with AR interfaces. All these reasons together are a strong indication of HMDs improving the positive experience of AR interfaces.

Chapter 7

Conclusion and future work

Conclusion

In this thesis I have developed a prototype through several iterations, and the final prototype was used several test sessions with participants. Observation, interviews and surveys were used as data collection methods.

The results had indications of positive potential for learning and collaboration in augmented reality (AR) interfaces. But the most prominent indications were towards positive user experiences (UX).

In learning, all participants quickly and efficiently became acquainted with the interface. They also expressed perceptions of AR interfaces being easier to master and become adjusted to. However, the majority of participants agree that it is a change more suited towards the younger generations, as the older generations have become to set in the routines and interactions with the more standard interfaces today. Learning can be improved both through good collaboration and generally positive UX, but on its own it can be said that there is potential for better learning in AR interfaces. Through the more physical aspect of AR interfaces compared to other interfaces in use today, there is support for more familiar interaction motions to users, even those with no or little prior computer experience.

In collaboration there are indications of positive potential in AR interfaces through improvement in flow of communication. By allowing better perception of non-vocal gestures and cues, users have more output and input for communication with cooperating users, and the physical aspect of AR allows for a more familiar method of presentation and explanation. All participants expressed enjoyment with using the prototype despite several flaws in the interface, but stated opinions that further development was desired before use in daily routines was an option. There were also several positive statements regarding the removal of the screen as a focal point in collaboration environments. The participants perceived AR interfaces as an opportunity to lessen or remove the isolation that can occur between team members when working together on individual computers, and the challenges of many users on one computer and screen. There were expressions of concern of possible chaos from equal interaction opportunity for all users in AR interfaces.

Finally, for UX, AR interfaces show great potential, despite indications of a “novelty effect” being present. AR interfaces prove themselves through the prototype to be positively engaging, immersive and motivational for future use. Many participants expressed eagerness and hope for AR interfaces to become a more common feature in the future, if the development allows for it. There were statements of challenges for AR however. While there is high quality equipment and tools for AR in existence today, these are too expensive and difficult to obtain to allow for much common use. The participants express desire for development to allow cheaper and easier access to such tools, while retaining the high quality displayed in such tools today. There were also concerns present regarding the effect introducing AR to the public will have. Some of these were:

- Stronger negative impressions on young children viewing violent content
- Further enabling isolation and escape from reality
- Looking “silly” or other negative perceptions in social settings when wearing AR equipment like HMDs.

AR has some issues of social acceptance to handle before proper introduction to the public can truly happen, but the participants express willingness to wait for this, and eagerness for that day to arrive.

Future work

This project was limited both by time and skills in developing. Given more time to acquire more skill to develop better prototypes, further testing could be done to better evaluate the advantages and disadvantages of AR interfaces. Adding feedback like sounds and graphical effects for improved UX, improving detection and tracking quality in the interface, adding motion control without use of markers and creating a prototype of higher and deeper complexity. These are a few factors that can drastically affect results from evaluation, and would be closer to the true potential of AR compared to the prototype used in this project. In addition, several testing sessions with the same participants over a period of time is desired, where participants have been given access to AR interfaces outside of sessions as well. This will enable measurements of long-term UX, enabling the removal or lessening of the novelty effect and “wow-factor” in results. This will then grant more validity to indications of advantages and disadvantages in AR interfaces.

This project has also uncovered from the participants a great interest for HMDs. A study where HMDs are used would allow for better exploration of this interest, and what it can produce. It can answer if HMDs are the key to proper introduction of AR to the public.

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Appendix A

Grounded theory example

Grounded Theory Open Coding Example

	=	Experience
	=	Functionality
	=	Effectivity
	=	Interaction
	=	Interest
	=	Usability
	=	Purpose
	=	Skill

Da har dere fått sett litt mer av AR, og dere har fått testet det ut selv, og dere har litt mer grunnlag om AR nå enn dere gjorde før forrige intervju. Så har deres mening om mulighetene til AR endret seg igjennom disse erfaringene?

L: Det kan ikke jeg svare på føler jeg. Holdt jeg på å si. Det ser jo kjempemorsomt ut, jeg tror det kommer til å bli ganske bra, etterhvert. Men, at det fortsatt trenger litt mer tid før folk kanskje får øynene opp for det og at det må bli bedre først.

A: Ja, det er nok det. Fordi, dette er prøvd før på en måte, sånn veldig jevnlig da, la oss si en gang i året, også blir vi like imponert hver gang, men så viser det seg en uke senere så er det bare en gimmick, og du mister jo interessen fordi det ikke er så dypt som en skulle øsnke det var da, og man blir jo veldig fort lei av det, fordi det er så simplistisk. Men så klart, det har jo blitt mye bedre igjennom årene. Som sagt, vi opplever det på nytt og på nytt og på nytt igjen, så blir jeg jo mer og mer interessert jo bedre det blir, men likevel blir det aldri bra nok til at jeg noen gang skal bruke noe mer tid på på en måte.

L: For det tar jo ganske mye lengre tid enn andre ting, så selv om det ser kult ut så gjør man jo ofte det som går raskest.

A: 3DS'en er jo et kjempegodt eksempel på det, hvordan det eksploderte når det første ble annonsert, og alle kjøpte det. Eller alle fansene da, også ble den sittende i stua, ingen som brukte den på ett halvt år eller ett år inntil noen kule spill kom ut, så det viser jo hvor fort det dabber av da.

HVa mener dere må til for at det her faktisk skal kunne bli kjempestort?

A: Responstiden synes jeg da. Det er det. Enklere å bruke, lettere å sette seg inn, mye kjappere respons. That's it. Smartere software selvfølgelig, det er det det går på. Og hardware som klarer å takle det. Det er mye bra augmented der ute men, det hadde kosta en million å få det inn i stua ikke sant?

Kunne dere ha brukt ett brukergrensesnitt basert kun på AR i dag?

L: I dag? Nei.

A: Nei, aldri. Eller, ikke i dag.

Hvorfor ikke?

L: Det tar for lang tid. Det går ikke fort nok, det er ikke effektivt nok. Men spørs jo litt på som A nevnte i sted at til funksjonshemmede så kan man jo kanskje bruke det, men da blir det ikke for eget bruk på en måte, da blir det heller til for å hjelpe andre, til å lære noe eller hva enn de bruker det til.

Hvis dere skulle se for dere at dere skulle bruke et AR brukergrensesnitt, tror dere at dere kunne ha brukt det lenge? Hadde det blitt slitsomt eller ikke?

A: Det er noe jeg ofte har tenkt på. For det å sitte å holde hendene i luften og bevege det sånt, jeg har aldri fått prøvd det, men jeg tror kanskje at det bli litt slitsomt, at man kan bli sliten i hendene og armene generelt.

L: Ja, at det kan bli litt mye.

A: Ja, ingenting å hvile på, altså hele armen på ett bord og å bevege en mus mot å stå og vifte.
L: Ja, en hel arbeidsdag hvor du skal bare vifte. Ja, det kan kanskje bli litt slitsomt.

Vil det ha noe å si hva slags bevegelser det er som trengs?

L: Helt sikkert.

A: Jeg vet ikke jeg altså. Jeg tror det har veldig med sånn spesifikt hvordan du beveger deg. Som for eksempel om du kjører den greien som han gjør i den filmen med Tom Cruise. HVa heter den filmen?

Minority Report?

A: Ja! Det kan gå, for da bruker du hele kroppen og du har en jevn og god bevegelse, men om du sitter foran en skjerm sånn som du gjør nå, og har den stillingen her, i en kontorsetting for eksempel, da vil du bli sliten og det vil fungere litt annerledes. Da bruker du ikke hele kroppen, men bruker bare noen få ledd.

Kan dere se for dere en mulighet for at AR brukergrensesnitt kan erstatte keyboard og mus?

L: Det er vanskelig å se for seg at det skal gå ann. Jeg kan se for meg en slags blanding av det, men at det helt skal erstatte det er vanskelig å se. Men, hvem vet.

Men det er bra nok svar det altså. Det er lov å si at det er vanskelig å se for seg.

A: Ja det er vanskelig, men jeg tror at det kan skje en dag altså.

Men da er det presisering på en dag?

L: En dag ja, når det er superbra.

A: Det er lenge til. Da tror jeg det blir sånn at hvor den klarer å fange opp dine tanker, at du skal kunne skrive meldinger og kommunisere bare igjennom å tenke.

Med tanke på hvordan AR funker, det er bevegelser istedenfor trykking på knapper, og du ser det i 3d i motsetning til på en skjerm, osv osv. Har det her noe effekt på læring og tilvenning til et brukergrensesnitt? Tror dere det?

A: Hva sa du nå?

Vil det gjøre det lettere eller vanskeligere å lære seg ett program?

A: Ja, både og altså. Noen aspekter av programmet kan sikkert være lettere, mens andre kan være vanskeligere. For eksempel 3D program, da kan det kanskje bli litt lettere vil jeg tro. For da vil du kunne bevege deg i det 3D rommet uten å bruke mus og tastatur konstant. Det vet jeg selv er lettere med en sånn ball. Så hvis du da bare bytter ut den med noe som det her, så kan det bli bra.

Det kan du jo også tenke på, at modellen du driver med vil være på bordet ved siden av maskinen din og ikke på skjermen.

A: Ja, du vil kunne gå dypere inn og kjappere bevegelse.

Hvis vi da går på andre typer programmer utenom 3D, for eksempel i Iron Man filmene hvor han flytter filer osv bare ved handbevegelser. Tenk deg hvis du hadde fått et slik filsystem satt foran deg, hadde det vært lettere å lære seg det når du bruker bevegelser sånn?

A: Det hadde vært kulere.

L: Det hadde vært kulere ja, helt klart. Men jeg vet ikke om det hadde vært lettere. Men det ser mye stiligere ut.

A: Ja, men i praksis gjør du det samme som med musa da, når du tenker på filbehandling da. Det er jo den samme bevegelsen. Men du får kanskje bruke begge hendene, så den kan kanskje gå litt kjappere. Kommer jo an på systemet du jobber på. Fordi når du tenker sånn så skal jo filene være oppe konstant på en måte. Så kan du bare hive dem rundt. det kan bli litt rart.

L: Ja det kan hende at det blir litt mye.

Forskere mener at en av styrkene til AR er at bevegelsene osv som skal til for at du skal gjøre ting er som oftest nesten helt like om ikke en ganske god tilnærming av hva du ville gjort med det objektet i den virkelige verden om det virkelig var foran deg. Altså, skal du løfte opp på en modell, så tar du tak i modellen og løfter opp. Skal du

flytte på en fil beveger du armen som om du flytter på noe. Da mener de at det vil bli lettere å lære seg fordi bevegelsene du skal gjøre er allerede kjent for deg. Det er ikke slik at du må lære deg en ny teknikk.

L: Det gir jo mening.

A: Ja, jeg kan se for meg det. Men det vil jo gjelde for folk som ikke har vært borti pc før så veldig mye. Det blir litt vanskelig for oss å forestille oss det. Men ja, folk som ikke vet hvordan en mus fungerer vil jo automatisk gå for det der.

Hvis vi da går ut fra det du sier da, vil det si at det nesten blir bedre for folk som ikke kan data?

A: Jeg vil tro at det blir bedre for folk som ikke kan data.

L: Ja, enklere å lære.

A: Fordi vi er så set i det vi kan.

L: MEn det er så veldig vanskelig å se for seg folk som ikke kan det. Da den eldre generasjonen dør ut nå så er det jo ingen som ikke kan det.

Hvis vi ser for oss at vi skulle begynt å presentere til hele det sosiale samfunn AR nå den dag i dag. Introdusere det som et brukergrensesnitt. Ville det da være slik at den nyere generasjonen, de som tar over etter oss...

L: De lærer det først på en måte? Ja.

Akkurat som vi lærte internett.

Hvis dere ser for dere AR med at dere kan ha modeller på bordet, dere kan ha på briller istedenfor for å se på en skjerm osv osv, hva slags effekt kan AR ha på samarbeid? Positivt og negativt.

L: Jeg kan se for meg at det er positivt. Det er veldig mye enklere med det enn å sitte to stykker på en pc.

A: Negativt vil det jo være at jeg føler at det vil kræsje litt, på en måte. Hvis folk driver og skal jobbe på den samme tingen da, samtidig, og se på det sammme som den andre ser på. Men alikevel vil samarbeidet sikkert være mye lettere også. Er vanskelig å komme på noe sånn on the top of my head.

Men hvis dere ser for dere at man f.eks kan presentere en modell på bordet foran dere? Hva gjør det for samarbeid?

A: Selvfølgelig, det hadde gjøre prosessen litt lettere, det er sant. Du kan ha folk sittende rundt et bord hvor du har modellen presentert i midten istedenfor at alle bare samler seg rundt en skjerm og må liksom komme forbi for å se, eller sende rundt på dropbox osv osv. Det er jo en positiv greie. Da sitter alle med Google Glass.

Er det noe mer innen enten læring eller samarbeid eller generelt med AR dere kan tenke dere å si noe om?

A: Ja, jeg gleder meg til at vi kan spille spill, ordentlig, med de der brillene der. Kickstarter har jo begynt på det, med Oculus Rift, og det ser jo ut som om det kan fungere. Men jeg kan ikke se for meg at de skal klare det med noe annet enn spill. Eller i leiligheten også. Styring av lys og lyssetting og de tingene der da. Kjøleskap, komfyr, det kan faktisk skje ganske fort.

Når vi tenker på annet potensiale med en leilighet da, hvis du skal ommøblere en leilighet?

L: Ja, det kan jo funke, for å teste møblene og plassering.

A: Det kan bli litt vanskelig. Men ja. Jeg hadde virkelig likt å sett et program som kunne lest møblene dine sånn at du kunne "bevege" dem rundt i rommet.

Vi kan jo for eksempel se for oss at vi sitter på IKEA på nettet, så synes du at den sofaen var kul, så kan du få ut den og prøve å plassere den i stua, i ekte mål.

L: Det er jo skikkelig spennende. Det kan jo bli noe. Det har jo stort potensiale, vi må bare få det til.

Appendix B

Grounded Theory Analysis

The original data collected is shown in the Excel file bellow.

	A	B	C	D	E	F	G	H	I
1									
2	Enjoyment	Acceptance	Fascination	Perception	Attractiveness	Potential	Possibility	Physical	Time
3	kjempemorsomt	får øynene opp	imponert		ser kult ut	bli ganske bra			etter hvert
4			mister jo interessen		kule spill				trenger litt m
5			veldig fort lei av det						aldri
6									
7						bra augmented			
8									
9									ikke i dag
10									
11				å lære noe					
12									
13				litt slitsomt				bli sliten i hendene og armene	
14				litt mye					
15									
16								jevn og god bevegelse	
17								bli sliten	
18									
19						vanskelig å se for seg	vanskelig		
20									
21							vanskelig, men jeg tror		
22									
23						da tror jeg det blir sånn			
24									
25				konstant					
26									
27				rart	kulere				konstant
28				litt mye	stiligere				
29									
30						kan se for meg det			
31									
32				er så set i det vi kan			veldig vanskelig å se for seg		
33									
34				positivt		se for meg			
35				føler at det vil kræsje litt		samarbeidet			
36									
37				litt lettere				komme forbi	
38									
39			gleder meg	ordentlig		ser jo ut som det kan fung	kan ikke se for meg		
40									
41			virkelig likt å sett et program						
42									
43			skikkelig spennende			stort potensiale			
44									
45	Quality	Time	Ease-of-use	Situation					
46	blitt mye bedre	tar jo ganske mye lengre tid							
47	jo bedre det blir	går raskest							
48	aldri bra nok								
49									
50			enklere å bruke						
51									
52	ikke effektivt nok	tar for lang tid							
53		ikke fort nok							
54									
55	det kan gå			det vil fungere litt annerledes					
56									
57	at det skal gå ann								
58									
59	superbra								
60									
61			bra						
62									
63		kjappere bevegelse							
64									
65		litt kjappere							
66									
67			først						
68									
69			mye enklere						
70									
71				folk sittende rundt et bord hvor du har modellen presentert i midten					
72				samler seg rundt en skjerm					
73				sende rundt på dropbox					

74			
75	det kan funke		litt vanskelig
76			
77			få det til
78			
79	Quality	Diversity	Possibility
80	bli bedre	ikke er så dypt	
81	bare en gimmick	simplistisk	
82			
83	Responstiden		
84	mye kjappere respons		
85	Smartere software		
86	hardware som klarer å takle det		
87			
88			en slags blanding av det
89			
90			klarer å fange opp dine tanker
91			skrive meldinger
92			og kommunisere
93			
94			kunne bevege deg i det 3D rommet
95			
96	i praksis	samme bevegelsen	
97			
98			Google Glass
99			
100		spille	brillene
101			Oculus Rift
102			
103		teste	
104			
105			lest møblene dine
106			
107			
108	Interaction		
109	sitte og holde hendene i luften og bevege det sånt		
110	Ja, ingenting å hvile på, altså hele arme på ett bord og å bevege en mus mot å stå og vifte		
111	skal bare vifte		
112			
113	hvordan du beveger deg		
114			
115	da bruker du hele kroppen		
116	sitter foran en skjerm som du gjør nå		
117	har den stillingen her		
118	bruker du ikke hele kroppen, men bare noen få ledd		
119			
120	bare igjennom å tenke		
121			
122	uten å bruke tastatur og mus		
123	en sånn ball		
124			
125	med musa da		
126	bruke begge hendene		
127	jobber på		
128	hive		
129			
130	jobbe på den samme tingen da, samtidig		
131			
132	prosessen		
133			
134	styring		
135			
136	"bevege"		
137			
138	Interest	Phenomenon	
139	mer og mer interessert	eksploderte	
140	bruke noe mer tid	ble den sittende	
141	alle kjøpte det	fort det dabber av	
142	ingen som brukte den		
143			
144	ofte har tenkt på		
145			
146	gå for det der		
147			
148		bli noe	

	A	B	C	D	E	F	G	H	I
149									
150	Ease-of-use								
151	lettere å sete seg inn i								
152									
153	lettere								
154	vanskeligere								
155	litt lettere								
156	lettere								
157									
158	lettere								
159									
160	bedre								
161	ja, enklere å lære								
162									
163	lettere								
164									
165									
166	Purpose								
167	til funksjonshemmede								
168	ikke for eget bruk								
169	hjelpe andre								
170									
171	kontorsetting								
172									
173	3D program								
174									
175	filbehandling								
176	systemet								
177									
178	spill								
179	leiligheten								
180	lys og lyssetting og de tingene								
181									
182	møblene og plasering								
183									
184									
185	Existing knowledge/skills	Acquiring knowledge/skills							
186	ikke har vært borti pc								
187	ikke vet hvordan en mus fungerer								
188									
189	set i det vi kan	lærer							
190	ikke kan det								
191	ikke kan det								

Appendix C

Pre-testing interview questions

These are some of the main questions taken during pre-testing. The questions were asked in Norwegian, please see the original text under this Google translation.

1. What are your experiences with AR?
2. What do you think AR can be used for?
3. How likely do you think it is that AR is big? Could it be a standard user interface?

1. Hva er deres erfaringer med AR?
2. Hva tror dere AR kan brukes til?
3. Hvor sannsynlig tror dere det er at AR blir stort? Kan det bli en standard for brukergrensesnitt?

Appendix D

Post-testing interview questions

These are some of the main questions taken during interviews. The questions were asked in Norwegian, please see the original text under this Google translation.

1. Have experience of testing and survey changed their opinion about the capabilities of AR and AR in general?

2. What do you think now required to enable it to be big?
3. Could you use a user interface based only on AR today? Why / Why not?
4. If you were using an AR user interface, you could use it for a long time?
5. Can you picture a possibility that AR user can replace the keyboard and mouse as standard?
6. Based on what you now know about AR, do you think that an AR interface can have an influence on learning and adaptation to the user interface? Positive and negative.
7. Based on what you now know about AR, do you think that an AR interface can have an influence on collaborative between multiple users? Positive and negative.
8. Is there something more general about AR you would like to highlight?

1. Har erfaringene fra testingen og undersøkelsen endret deres mening om mulighetene til AR og AR generelt?
2. Hva mener dere nå må til for at det skal kunne bli stort?
3. Kunne dere brukt et brukergrensesnitt basert kun på AR i dag? Hvorfor/Hvorfor ikke?
4. Hvis dere skulle brukte et AR brukergrensesnitt, kunne dere brukt det lenge om gangen?
5. Kan dere se for dere en mulighet for at AR brukergrensesnitt kan erstatte keyboard og mus som standard?
6. Basert på det dere nå vet om AR, tror dere at et AR brukergrensesnitt kan ha en inflytelse på læring og tilvenning til brukergrensesnittet? Positivt og negativt.
7. Basert på det dere nå vet om AR, tror dere at et AR brukergrensesnitt kan ha en inflytelse på samarbeid mellom flere brukere? Positivt og negativt.
8. Er det generelt noe mer om AR dere vil trekke fram?