Using Augmented Reality and Tangible User Interfaces in a primary school learning situation

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Abstract

The use of ICT in the Norwegian education system is encouraged, and is believed to have positive effects on the pupils learning outcome. However the use is often limited to writing and reading, and the potential of ICT systems in education is not taken advantage. This thesis looks at implementing an alternative interaction paradigm to the widely used mouse and keyboard approach. Augmented reality is used for providing a tangible user interface for the pupils. The justification for the positive aspects of introducing this tangible approach is grounded in developmental and educational theory, as well as previous work using tangible user interfaces and augmented reality in an educational context. Collaborative aspects, and how AR can encourage it, has been one of the main focuses throughout the thesis. Contact was made with a primary school, more specific a 6th grade class. An AR application was developed, based on theoretical background. An early test using a simple AR application was conducted, however the further developed and more advanced application was not user tested due development taking more time than estimated. Based on reviewed related work and the results from the initial user test, there are indications that AR can offer positive aspects in an educational context.

Preface

This master thesis has been a long journey for me. From starting out with knowing little about Augmented Reality other than what it was, to actually starting to implement an application using it. This meant working with programming and technologies that was outside of my comfort zone. It has been a sometimes frustrating journey, but ultimately a rewarding one.

I would like to thank Øyvind Nygård and David Tverbak for being involved in the pre-project for the thesis. Jayson Mackie for help with the coding and for improving parts of my coding. I would also like to thank Gjøvik Skole for being cooperative.

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1 Introduction

This master thesis looks at developing sample applications that are using Augmented Reality (AR). Part of the curriculum of a 6th grade class has been used as the theme for these applications. More precisely European geography. The ultimate goal is to find concepts that can encourage and support collaboration and multiple coherent interactions. Justifications for why collaboration and the use of AR might have a positive effect, are given in the form of related work from areas such as pedagogical theory, tangible user interfaces and previous works using augmented reality. The concepts proposed builds on existing theories as well as experience from other projects. Implementation of one of the concepts into an actual applications was started, and the future goal was that this could be the basis of a framework used for further development. Lastly, a conclusion and discussion of the work and the experience from the work will be given, followed by suggestions for future work.

1.1 Keywords

Augmented reality, tangible user interfaces, collaborative learning, primary school learning

1.2 Context

In this section context for the project is given. Section 1.2.1 gives background on how much computers are currently being used at school, as well some information about what kind of activities they are used for. Digital learning resources are also mentioned as well as some background information about Norwegian students low level in math and science courses.

1.2.1 ICT supported learning

The ITU Monitor is a report that is compiled by "Forsknings og kompetansenettverk for IT i utdanning" [1]. Every second year they compile a report on the use of ICT for education in the Norwegian education system. This is conducted by using questionnaires for both teachers and pupils at 7th, 9th and 2nd year high school. The report states that primary schools, the target group for this thesis, are far behind the middle schools and high schools concerning the use of ICT in daily teaching. It is also reported that the use of digital learning resources are fairly limited. Computers are used primarily for reading and writing. However some learning resources are used, the teachers state that this content usually comes from the web pages of the publishers of the books they are using in the different courses. `www.lokus123.no` [2] is a webpage that also is mentioned by many teachers. At the end of the report it is mentioned that teachers think there are a limited number of digital learning resources available. Also it is mentioned that developing good digital learning resources that offers something extra is time consuming to develop and implement.

The report suggests that computers are used frequently in schools currently, however it is used mostly for traditional tasks, such as reading and writing. The use of digital learning resources is something that is not mentioned in detail. It is therefore difficult to say how much they are used, and how they are used. After reviewing some of the content of www.lokus123.no it is obvious these "mini games" are not meant for collaboration among pupils. There is no clear indication of the effect of games like this in teaching. However in most cases teachers comment that it increases the pupils motivation. In addition to what is stated in this report, after having a meeting with some of the teachers of the 6th grade involved in this project, another web page was mentioned, www.gruble.net [3]. The content of this is very similar to what is offered by www.lokus123.no. The teachers also mentioned that the pupils seemed to enjoy using pages like this as part of their learning.

The Norwegian government rates using ICT in education as important and valuable for the pupils education. However the focus so far seems to be on digital learning resources that are distributed through the web, and which is meant for only one person at a time. Pedagogical theory however supports the use of collaboration during problem solving and learning [4]. This can lead to discussions among the pupils which can result in more reflection about the topic and a higher learning outcome. In addition it is mentioned that exploring on their own at their own pace is also something that is useful. The digital learning resources provided many places are not very open ended. Often the only feedback is a multiple choice assignment, resulting in a drill and skill exercise rather than emphasizing the pupils understanding of topics. As will be discussed in Chapter 2 it is suggested that having a more open ended approach leaves more room for exploration which might have a positive effect.

A current problem in the Norwegian educational system is that the math and science level of Norwegian students is lower than many similar countries. According to the PISA survey [5] Norwegian students in primary school score lower than the average of the OECD[1] countries [5, p. 14]. Some of the suggested reasons are that these courses have a high level of abstract concepts. It is pointed out that the Norwegian educational system has a low level of following up students and giving feedback, and also there is a high level of individual work. Doing practical work is something that is looked upon as having a positive effect on learning. However this often requires the teacher to directly control what is being done [5, p. 15-16].

1.3 Motivation

The motivation for much of this project is grounded in pedagogical theory. Classical pedagogical theory will be introduced, as well as learning styles and the effect of collaboration in learning. Further augmented reality and tangible user interfaces will be one of the main focuses, as these solutions offer alternative means of interaction. These can also make it easier to take into consideration the concepts introduced concerning the pedagogical aspects, as well as focus on some of the problems introduced in Section 1.2.

1.3.1 Alternative Interaction Paradigm

As has been discussed thus far, ICT in education is seen as having a positive influence on student learning. However the potential of computing technology is still an untapped resource. The goal

[1] Organization for Economic Co-operation and Development

of this thesis is to merge current theories of best pedagogical practice with currently available technology. Computers no longer have to rely on merely a mouse and keyboard as input. Taking into consideration concepts from the theories introduced is part of the goal of this project. Some of the problems with implementing a system that build on these theories might come from an HCI [2] problem. A standard personal computer has very limited input devices, in the form a mouse and keyboard. They also usually have a simple screen as an output display. This means that things like multiple and coherent interactions are difficult. Which is important when doing collaboration. Moving away from the mouse and keyboard paradigm is something that might better support these pedagogical concepts. The term PC, personal computer, also implies that they have been designed to be used individually, and not by a group. When used in education this turns the experience into a solo activity, rather than a social one. This is where augmented reality and tangible user interfaces comes into the picture and can offer alternative means of interaction better suited for collaboration.

1.4 Objective of Thesis

Learning and development is a complex and difficult subject to measure. Many external factors influence assessment, making it very difficult to measure if a specific intervention has actually led to more effective learning. This is not the focus of the thesis, rather it focuses on observable behaviors, such as collaboration among students. The thesis builds on established theories related to the types of behaviors that result in effective learning. Reasoning on how AR can be implemented in a way that supports these behaviors is an important part. Section 1.4.1 lists the thesis' research questions.

1.4.1 Research Questions

1. What are the possible advantages of collaboration in learning?
2. Can an augmented reality application encourage collaboration among students?
3. Can an AR application take into consideration several learning styles?
4. Does having a public display and work space support discussion and collaboration?

1.5 Methodology

This master thesis looks at previous work done in a cross-disciplinary field. More precisely within fields such as pedagogy and development, tangible user interfaces and augmented reality. Established theories and frameworks has been reviewed. Where the theories tries to explain specific phenomena, while a framework offers concrete advice on how something should be done [6, p. 84-86]. The findings from the reviews of previous work has been used for making conceptual designs for educational applications that are based on the best practices from the reviewed literature. Conceptual design means having a high-level description of how a system is organized and works [6, p. 51-53]. Implementations of one conceptual design into an actual applications was started. The results from this is planned to be used to develop a framework that can be used for further development of similar applications. In addition a questionnaire was developed for

[2] Human Computer Interaction

the teachers involved in the project. The questions role was to see if the involved teachers had a similar conception to what was found in the research literature. The research questions will be answered based on the reviewed literature as well as the experience from the development and an early application test.

1.6 Planned Contributions

The planned contributions of this thesis is focused on reviewing relevant and established pedagogical theory in the context of learning applications. The theories lays the foundation for concepts that can be implemented into actual applications. Further, development focusing on implementing one of the concepts was started. The development performed is thought to have the potential for laying the foundation of a possible framework for further development of additional augmented reality applications for educational use. So to summarize shortly the contributions are concerned with justifying the use of AR in education, as well as providing a stepping stone for developing them.

1.7 Outline of Thesis

Chapter 2: Introduces related work that influences the thesis. The chapter gives background information from research fields such as augmented reality, tangible user interfaces, cognition and development and collaboration.

Chapter 3: Describes the contact with Gjøvik Skole and the activities that were planned and done with the school.

Chapter 4: Gives a high-level description of the workspace and sample applications are given.

Chapter 5: Describes the development phase and which technologies that was used for the programming. Certain problems are introduced, and how they were solved. Last a short illustration of the functionality is given.

Chapter 6: Introduces the results achieved results from testing.

Chapter 7: Gives a short discussion of the thesis and answers the research questions before a general conclusion is given.

Chapter 8: Suggests some future work that can be done to extend and improve the thesis.

2 Related Work

Section 2.1 introduces augmented reality and provides background information about the key technology in the thesis. Previous work using AR is also introduced. Section 2.2 introduces tangible user interfaces and some of the advantages they can offer, in addition to some previous work based on these concepts. AR is a technology that can implement tangible user interfaces, making the more general concepts of TUIs important. Section 2.3 introduces theories about learning and development. Section 2.4 and 2.5 are related to people having different learning styles and collaborative theory. The three latter sections provides a theoretical background of concepts that are considered good practice, and that will have a positive effect on learning. Together these sections provides necessary knowledge for using AR in such a way that it utilizes the introduced theories and advantages.

2.1 Augmented Reality

Augmented Reality (AR) is a technology that has been around for a while, but is not widely known. Most people have heard about Virtual Reality (VR). As will be defined in Section 2.1.1 AR happens in the continuum between the real world and VR. Augmented Reality is a technology that is very suitable for visualizing concepts. In addition it provides a tangible and hands-on way of working, which is an advantage pupils of younger age.

2.1.1 AR Definition

This section defines defines what augmented reality is, and what it is not. Milgram and Kishino [7] has made a simple overview of mixed reality and its' subclasses. MR is the concept of having virtual reality and the actual reality mixed. However the way this is done is of importance. As can be seen in Figure 1 augmented reality is between the real world and the virtual reality. In VR you, as a real person, are put into a virtual environment. AR on its' side puts virtual objects into the real world. To clarify this Milgram and Kishino has defined it as following:

> Real objects are any objects that have an actual objective existence. Virtual objects are objects that exist in essence or effect, but not formally or actually.

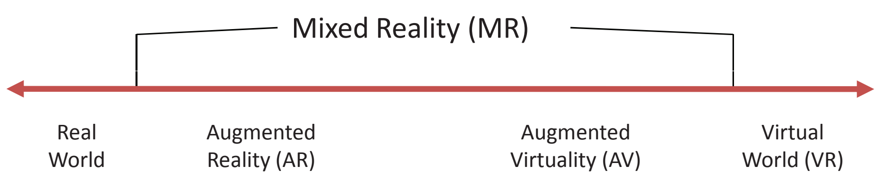

Figure 1: Virtuality Continuum

A more specific definition concerning only AR is well defined by Ronald Azuma [8]. Firstly it is about combining real and virtual objects, in AR specifically putting virtual objects in the real world. Second the virtual objects has to be tracked in real time, for example if a marker is moved the virtual object is instantly following the marker. It is not enough to simply superimpose a static 3D object on a scene and call it AR. Lastly the objects must also be blended with the real environment in 3 dimensions.

2.1.2 How it Works

In this section we present one possible implementation of AR. A graphical representation of how ARToolKit works is shown in Figure 2. ARToolKit is the framework that was used for development, and is further introduced in Section 5.1. First of all a camera needs to be set up, as video tracking is used in this project. The frames from the camera are captured. The image is then thresholded. An image thresholded in ARToolKit with a value of 100 is shown in Figure 3. After thresholding markers in the frame can be identified. The position and orientation relative to the camera can then be calculated. At this point the system has only identified the black frames of the marker, so it knows that there is a marker, but not which one. The next step identifies which marker it is. This is done by checking the pattern against previously registered patterns. If it finds a stored marker it can apply a specified 3D object to this specific marker. This is done by using the transformation matrix for this marker, and applying it to the 3D object. This will place the 3D object so it matches the position on the screen. The last step simply renders the 3D objects on top of the video stream.

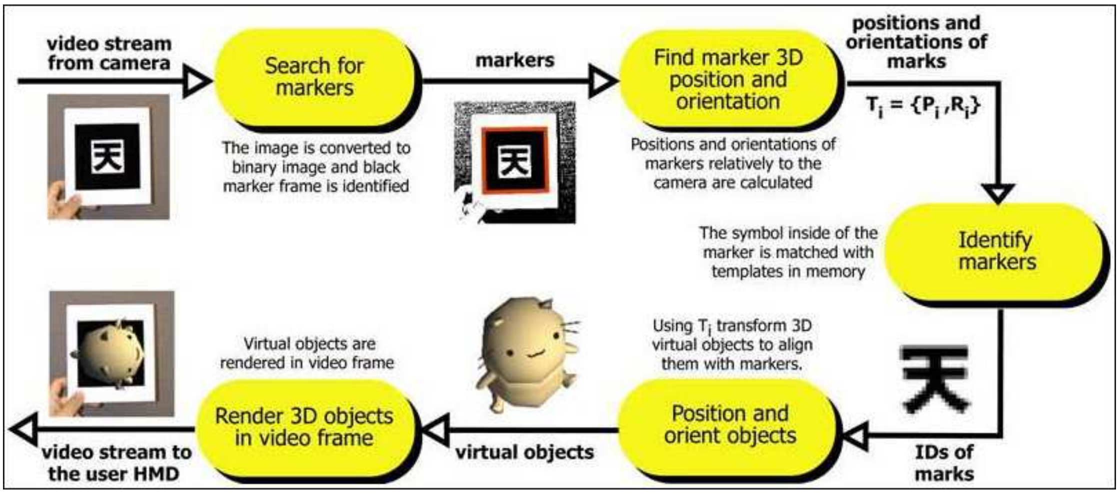

Figure 2: ARToolKit tracking

2.1.3 Alternative Tracking Methods

The application built in this project is based on Vision-Based Tracking and the use of markers, as was described in the previous section. Other solutions do exist, and will be briefly discussed below.

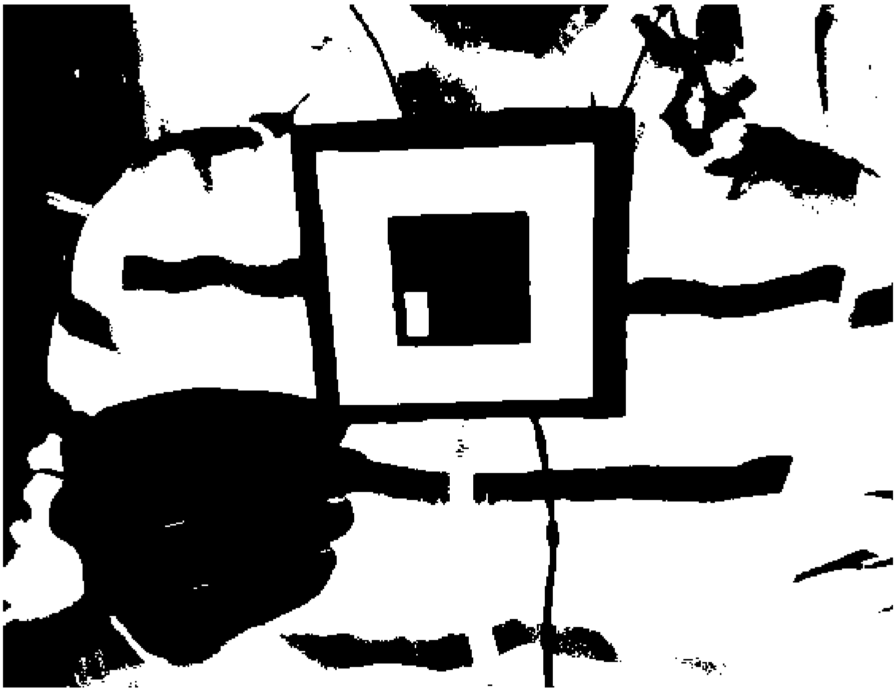

Figure 3: Thresholded Image

Sensor-Based Tracking are, as the name suggests, based on different kinds of sensors, such as magnetic, acoustic and more. It has been mostly used in virtual reality and little research has been done using exclusively non-visual sensors [9, p. 195]. Around 80% of all articles with the subject of tracking that has been published in the AR conferences the ten last years is concerning vision-based tracking [9]. In addition fiducial markers are the most common and mature method used. This project uses square fiducial markers, variations of this exists, but the concepts are much the same. However much research has been done on using natural features for tracking, meaning no markers are needed. This is a complex area of research which is not the focus of this thesis, as a marker based approach is used. Hybrid Tracking Techniques are the last. It combines different techniques, such as visual-based tracking, GPS and inertial tracking. Since visual tracking can have problems handling rapid movements, inertial tracking which can measure acceleration and rotation can improve results when combined. A commercial solution can also be mentioned with regard to this. It is concerning the coming Playstation Move. This is basically a hybrid tracking method, that combines inertial tracking and vision based tracking. It does not use markers, but a Light Emitting Diode (LED) in the form of an orb on the controller [10]. What is special about this system is that it uses a dynamic color tracking system.

> [...] the PD element can have a color that has a high contrast relative to a color of a portion of the body adjacent to the PD element. Further, each of the at least one PD element can include a pattern that includes at least two different textures. For example, the textures can differ in at least one of brightness, color, roughness and/or other such relevant textures [11].

PD is an acronym for photonically detectable, meaning the LED orb on the Move controller. The reason for introducing this is that one of the major problems when tracking markers is that unstable lightning conditions will also cause unstable tracking of markers. Dynamic color tracking is a solution to this problem, as the LED orb can change in appearance, it will have better contrast, and therefore can be tracked more accurately.

2.1.4 AR Used in Education and Teaching

The potential of augmented reality in an educational context is starting to get more and more attention, and previous work has been done. This subsection reviews some of these works.

Cheok et al. [12] implemented a mixed reality (MR) classroom. The themes were the solar system and a plant system. Head-mounted displays and cups were used for interacting with the system. The mixed reality solar system functioned like an exploratory system where there were no specific goal to reach, Different materials could be brought close to different planets to see how the material would react. At the end a quiz was given so the pupils could review what they had learned. The plant system was more goal oriented. The pupils could add soil and seeds to a flower pot, and then water it. A button is pushed and if the requirements are met the plant will start growing. This study looks at understanding the acceptance of using MR in an educational context. A qualitative study was done on the solar system, and a quantitative study was done on the plant system. The pupils involved in the study were from 11-12 years of age. The results from the study suggested that the pupils enjoyed using the systems. However there were some issues with the sensitivity of interactions, that made interactions difficult. Overall the results were positive regarding the acceptance of MR systems in the context of education.

A mixed reality book used for edutainment was introduced in [13]. Existing books was augmented by adding virtual objects and auditorial content to increase immersion. It had little interaction to not interrupt the storytelling, but on certain pages paddles were provided for interaction. It is mentioned that the users of the book were very impressed by the visual effects and animations. The users also seemed to enjoy using the book, however as it was formed like a book, people tended to use it like a book. Which led to jerky movement and tracking problems.

Tan et al. developed what they call Tools 4 Schools [14]. Several applications concerning material science was made. They pointed out positive aspects of using AR in education, like the mentioned problems of using mouse and keyboard in collaboration and how AR provided a better way. The teachers who saw the applications thought this might be excellent for use in teaching. In addition the pupils enjoyed using the applications. However no structured questionnaires was conducted on neither the students or the teachers. It is claimed that it supports collaboration among the pupils. However no empirical evidence of this is given, but future work included doing structured evaluation of the applications.

An unpublished article by Kaufmann and Papp [15] described a system used for manipulating geometrical objects using AR. Head-mounted displays were used and a panel used for selecting different tools was provided. A tracked stylus was used for manipulating the objects, meaning it was an expressive system rather than an explorative one. The system was used for more than 500 teaching hours, and questionnaires filled out by teachers were also conducted. The results were not presented extensively but the strengths of the system pointed out by the teachers were presented.

> In questionnaires and discussion teachers described three main strengths of Construct3D: (1) The ability to construct dynamic 3D geometry and nearly haptic interaction with geometric objects. (2) Students can walk around geometric objects, building an active relationship between body and object. (3) The application's strength to visualize abstract problems [15, p. 3].

Even though this article was not published it is of interest as the system described was extensively used by both teachers and students, and provides important notions of the advantages it might provide.

In addition to these presented systems there have been developed more systems with focus on education, training and storytelling [16, 17, 18]. AR is emerging within many contexts, such as museum exhibitions, military training, for understanding physics and also for unveiling interactive stories. Similar to all of the work presented is the lack of empirical research data from the systems developed. There is little proof of the actual effect the systems have on instruction and education. What most of them conclude with is that most users find using their systems are easy and intuitive to use, in addition to being enjoyable to use. Other than this there are little evidence of other effects. Even though there is little empirical evidence of the positive effects of AR, the potential seems obvious. AR can provide natural ways of interacting with seemingly physical objects and might enable people to better collaborate. In addition most of the articles introduced are using the same technologies for realizing the applications. ARToolKit is one of these, as this is the selected framework for the thesis, it should prove to be a good choice.

2.2 Tangible User Interfaces

Fitzmaurice et al. [19] introduced what they at the time called Graspable User Interfaces. They suggested this as new paradigm opposed to the much used Graphical User Interfaces (GUI). Physical objects were used as input devices, these were also tightly coupled to virtual objects that could be manipulated. The objective was to seamlessly blend the virtual and physical world. The reason being the better affordance the virtual handles could offer. They also make a distinction between space-multiplexed and time-multiplexed input devices. Space-multiplexed input devices have dedicated devices that occupies their own space. Time-multiplexed has one input device, this device is used to do different functions at different points in time. The latter is typical of how traditional GUIs are navigated. This also means that tasks have to be done sequentially. Space-multiplexed devices therefore offers a greater potential for collaboration than the sequential time-multiplexed devices. An example is in the context of computer games. A console typically has a specialized controller, where the the actions of the different keys are remapped from game to game. In one game the jump button is assigned to be X, while in other games the same function can be mapped to square or triangle. This leads to a learning period, as it is not intuitive what the different buttons do. It is easy enough to understand that the buttons can be pushed, however the underlying functions are not immediately clear. Having objects that are tightly coupled in both the physical and virtual world avoids these problems, and are intuitive and easy to use without any training.

Fitzmaurice et al. has claimed that Graspable UIs have several advantages over the traditional GUIs [19, p. 2]. These include: encouraging two handed interactions, allowing more parallel input specifications by users, similarity to manipulating everyday objects, meaning it is intuitive and easy to use. In addition they take advantage of the spatial reasoning skills humans have, externalizes computer representations and lastly it supports multi-person collaborative use. Additional advantages are mentioned, however for this project the already mentioned ones are the most relevant. The article clearly defines what Tangible User Interfaces (TUI) are, and how they might be used. It has been mentioned that working on regular computers is not very suitable for collaboration. The time-multiplexed aspects is one of the reasons for this. Since interactions have to be performed sequentially the pupils have to take turns at the keyboard, which is not optimal when collaboration, as collaboration often tend to be a spontaneous and ad-hoc activity. Having space-multiplexed input devices supports some of the advantages mentioned, such as natural interactions which can be done in parallel. When objects are externally represented it is easy for all of the involved users to see what is going on. Similar points are mentioned by Ishii and Ullmer [20]. They describe a divide between the worlds of bits and of atoms. Meaning that we already have many skills for doing haptic interactions, but they are not taken advantage of in the computer world. Figure 4 illustrates how they move away from the GUI provided on the computer screen and how the world can be used as an interface.

The next section introduces a conceptual framework that explores some of the advantages TUIs can offer, if implemented in a helpful manner.

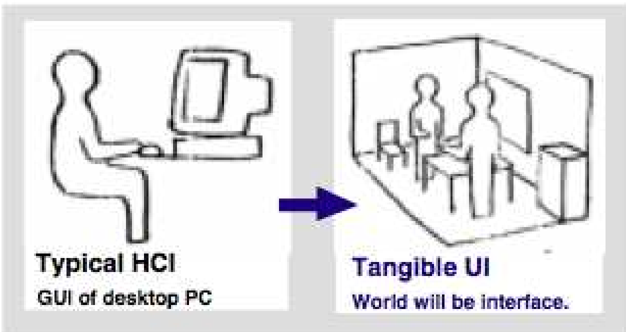

Figure 4: From GUI to Tangible User Interface

2.2.1 Tangible Interactions Framework

Hornecker and Buur [21] argued for the need of a conceptual framework that explored the positive aspects tangible interactions could offer to its' users. Their focus was interaction oriented and four overlying themes with their own set of concepts have been introduced.

- Tangible Manipulation (TM) involves directly manipulating material objects, that are representations of objects of interests. This is different from using a mouse, which is a generic device that are used for many different interactions.

Lightweight Interactions involves a shared view and that constant feedback on interactions are given such that tasks can be done in small steps.

Isomorph Effects provides relations between the cause and effect of interactions. Interactions do not necessarily need a one to one mappings, but should provide a clear understanding between the action and effect.

- Spatial Interactions (SI) is about events in space, and the concepts that objects take up space and have locations. Also the user can move in real space.

Inhabited Space since space is important, it is important that the interactions happen in a meaningful space.

Configurable Materials means that rearranging objects is meaningful for interactions and solving goals.

Non-fragmented Visibility is a public view provided, such that all participants can see what is happening.

Full-Body Interaction concerns if expressive and skilled body movement can be used.

Performative Action can something be communicated while doing interactions.

- Embodied Facilitation (EF) is about facilitating, prohibiting and directing certain behavior. Tangibility embodies these structures.

Embodied Constraints looks at the physical set-up and if it can make some interactions easier, while others are limited. Meaning that wanted interactions might be easier to do, while unwanted ones are constrained by the embodiment of the object.

Multiple Access Points is the control distributed, such that a single individual cannot take full control.

Tailored Representation do the representations take advantage of the users previous user experiences so that these can be connected and be taken advantage of, such that users are invited to do interactions.

- Expressive Representation (ER) is concerning the representation of digital functions and data.

Representational Significance are the physical tokens are easy to understand for the users.

Externalization aids the users, such that objects can be used as props to augment explanation and similar.

Perceived Coupling is there a clear connection between actions and consequences. Do the physical interactions seem to correspond with the digital representations.

This overview of the framework gives some cues about what should be considered as important design principles when developing systems using tangible interactions. An overview of the principles is illustrated in Figure 5. Hornecker and Buur [21, p. 442] provided three case studies showing how the framework can be used for pointing out strengths and weaknesses of systems. The expressions and design implications will be further used when introducing the different applications that will be developed as part of the thesis. This will be done in a similar way as in

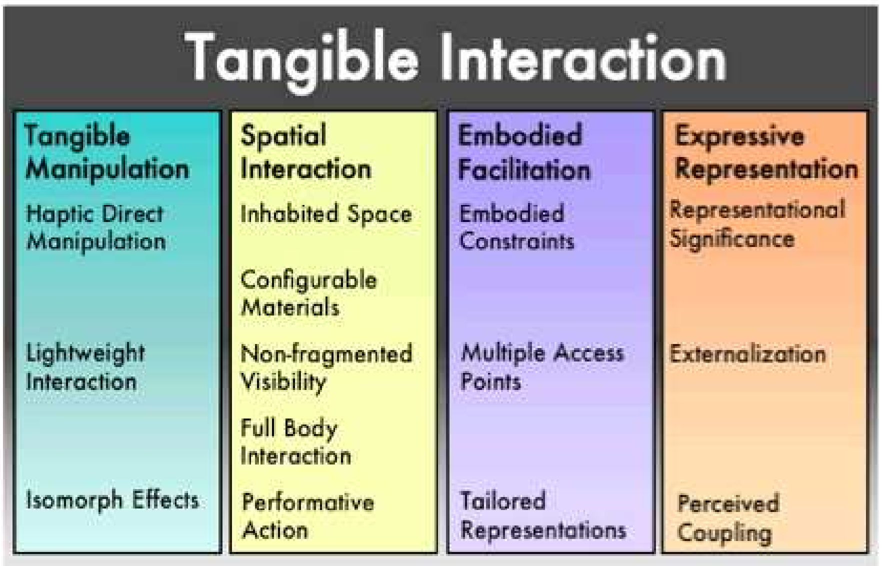

Figure 5: Tangible Interaction Framework with themes and concepts

the case studies mentioned. It is also argued that some of the themes are more important in certain areas than others. Meaning that not all concepts and themes might be relevant for all kinds of applications. An example is that the externalization concept is most relevant concerning communication, negotiation and shared understanding [21, p. 444-445].

2.2.2 Sample Tangible User Interfaces

This section introduces two sample TUIs. The first had similar goals as this thesis, and is focusing on collaboration among younger children. The second one is introduced because it provides many devices that can communicate with each other and might have potential in a learning situation.

As mentioned in Section 1.2.1 the use of ICT in education is encouraged. This thesis has especially emphasized the collaboration among students as an important concept. In Section 2.2 it was mentioned that the regular mouse and keyboard interface is not especially suitable for collaboration. Collaboration using mouse and keyboard usually is done by students having to do interactions in turns, meaning very sequential and not supporting coherent interactions. Africano et al. [22, p. 856] states that computers are mostly used for individual learning, and a traditional computer does not support multi user activities. Their initial research and user studies found that one child would sit by a computer and controlling the activity, while the others were standing behind watching, trying to get involved in the process. This is not optimal for collaboration, discussions among the collaborators can still happen, however the control of the system is not distributed, which makes collaboration difficult. The authors have worked with tangible interfaces for kids at a young age, two to five year old. The goal was to provide examples that could encourage social interaction, increase engagement and usability. The prototype built uses touch-screen technology and physical artifacts, in the shape of a doll, a camera and some cards. The conclusion of the paper states that the children enjoyed and were engaged while using it. In addition the system supported sequential and concurrent interaction as well as collaboration. No conclusions are made based on the interaction and collaboration, but the data they collected this far seems positive.

Siftables [23] are a Sensor Network User Interface (SNUI). It uses wireless communication between the different devices and tries to accommodate typical interactions humans do in the real world. Skills humans usually are very good at in the real world often turns out to be cumbersome and time consuming while interacting with a GUI using mouse and keyboard. Skills like sifting, sorting and manipulating a large number of objects. This is something that is typically done in the traditional GUIs by clicking and dragging objects. Often leading to a long string of sequential interactions has to be done to reach the goal. While doing the same in the real world would be done very flexible and efficiently. Siftables tries to take advantage of this by using what is called direct manipulation. The Siftables are small objects with LCD screens, accelerometer, 4 infrared transceivers and an RF radio. This means that the Siftables can pick up gestures, proximity and so on. As new technologies evolve new ways of interacting also develops. However these are not entirely new ways of interacting, rather the interactions mimics the skills people already know from the physical world. The Siftables are physical, so they can be easily grasped and everyday gestures can be applied to data [24]. Very few instructions have to be given to the users as well. A word game was introduced, and all the instruction that would have to be given was "make words", and they would know exactly what to do.

2.3 Cognitive and Developmental Theories

Section 2.3.1 introduces theories by Piaget on how people develop and assimilate knowledge. Section 2.3.2 introduces the concept of the zone of proximal development, which will act as motivation for using collaboration in education.

2.3.1 Assimilation, Accommodation and Equilibration

Much research has been done in the field of pedagogy. Researchers such has Jean Piaget and Lev Vygotsky developed fundamental theories concerning cognition and development. Piaget [4] makes a distinction between development and learning, other theories has stated that learning trigger development. Piaget states that learning is subordinated to development. Piaget states that there are three fundamental processes in learning. These are assimilation, accommodation and equilibration. Assimilation is when new stimulus is introduced. Accommodation is the process of fitting this into the existing cognitive structures. The last, and most important according to Piaget is equilibration, where there is a balancing between the two previous processes.

> A stimulus is a stimulus only to the extent that it is significant and it becomes significant only to the extent that these is a structure which permits its' assimilation [25, p. 24].

This is to clarify that learning is a developmental process. Meaning it is impossible to learn something of a higher level unless the basic knowledge is already in place. One of the problems with todays teaching is that a large portion of it is simply done by conveying new information to pupils. According to Piaget to reach the equilibrium state active discovery is needed.

> The presentation I propose puts the emphasis on the idea of self-regulation, on assimilation. All emphasis is put on the activity of the subject himself, and I think without this activity there is no didactic or pedagogy which significantly transforms the subject [25, p. 26].

The idea is that AR and tangible user interfaces can provide meaningful activities for the pupils. As reading and writing might not be enough to reach the transformation Piaget mentions, alternative activities can be provided by AR applications. This is something that is already done in schools, especially primary schools, as physical activities often play an important role in the education. However not every subject can easily be visualized, and an AR system can make a new array of activities possible.

2.3.2 The Zone of Proximal Development

Vygotsky's theories supports the belief of the positive effect collaboration has in education. Vygotsky introduced the zone of proximal development [26]. He distinguishes between the actual developmental level, which is determined by independent problem solving, and level of potential development, which can be determined through guidance or collaboration with more capable peers. The zone of proximal development is the distance between the actual developmental level, which is what is what the child can achieve based on independent problem solving, and the potential development. This is determined by what can be solved under guidance from someone more capable [26, p. 86]. According to his theory, encouraging collaboration has a positive effect. The teacher acts as a person that brings the pupils into the zone of proximal development, however as this is one person usually divided among a larger group of people, taking advantage of the effect of collaboration among the pupils to increase the learning opportunities is preferable.

> Children can imitate a variety of actions that go weIl beyond the limits of their own capabilities. Using imitation, children are capable of doing much more in collective activity or under the guidance of adults [26, p. 88].

It is suggested that the zone of proximal development should be an essential part of learning. Because when cooperating with other children such proximal development might happen. When doing interactions the processes are internalized, and become part of the independent development. This is similar to Piaget's theories and can be seen as an extension.

2.4 Learning styles

Intuitively it makes sense that people learn in different ways. People have different preferences, some learn from reading, while others benefit from practical exercises. Many models and theories about learning styles have been developed over the years. However it is a complex research field, and little reliable empirical findings exists [27, p. 1]. Thus, this way of categorizing how people learn is not accepted by everyone. In [27], 13 of the most influential models are reviewed. The most known are Kolbs learning style inventory and the Myers-Briggs type identifier. The focus for this thesis is the model introduced by Felder and Silverman [28]. The Myers-Briggs Type Indicator is similar to the Felder-Silverman model. Both operate with the notions of bipolar preferences of learning [27, p. 46-47]. The Felder-Silverman model initially proposed 5 different groupings, where each group has two opposite preferences of learning styles. This was later modified into four groupings. The four groupings were initially proposed in the context of engineering education, but has been heavily cited within many different fields since the article was published.

Sensing and intuitive learners Sensing learners like facts, data and experimentation. intuitive learners like principles and theories. Sensing learners also like to solve things in using standard methods, while the intuitive learners like innovation and do not like repeating things. There are more characteristics, but in this context it is enough to say that the corresponding learning styles that are preferred for these learners are concrete and abstract respectively. The former prefers data and facts, and the latter likes more of an overview, such as models.

Visual and verbal learners Visual learners prefer images, diagrams and symbols. Verbal learners likes words and sounds. There is also a third called kinesthetic learners, these prefer senses such as taste, touch and smell. An extensive body of research, cited by Felder [28, p. 676], has shown that most people learn best with one of these three. Information is often missed or ignored in the two other. This means that visual learners remember best what they have seen, and so on. It is mentioned that the kinesthetic part is mostly covered in the active learners group introduced next.

Active and reflective learners Active learners need to do some experimentation, such as testing the information or discussing it in the external world. Reflective examines and manipulates the information introspectively. This means that active learners work better in groups, while reflective learners tend to like theory and time to think about it.

Sequential and Global learners Sequential learners follow a linear reasoning process when solving problems. They can work with material that they understand only partially or superficially. Global learners have problems with partially described material. Global learners learn in a more unpredictable manner, but when they first grasp the problems they tend to have a very good understanding of the whole concept.

The fact that there exists such a substantial number of models concerning learning styles indicates that they are useful for categorizing how people learn. However as mentioned not everyone accepts these models and theories, but they still give useful indications of principles that should be taken into consideration in the context of learning. This thesis use them as motivation for developing learning applications based on AR technology. Being aware of the fact that people learn in different ways was useful when planning applications for learning. Reading and writing is a large part of a normal school day, this however only accommodates for parts of the learning styles. Applications that fit into the other learning styles will be advantageous to learners that have other preferences than verbal and reflective learning. In the same article introducing the Felder-Silverman model, a quote that contradicts the notion of learning styles is given.

> ...students retain 10 percent of what they read, 26 percent of what they hear, 30 percent of what they see, 50 percent of what they see and hear, 70 percent of what they say, and 90 percent of what they say as they do something [28, p. 677].

This statement diminishes the importance of the concept of learning styles. Visual learners prefers images and verbal learners prefer reading or hearing. The statement suggest that seeing something is more effective no matter, and therefore would make the notion of learning styles less important. The problem is that these numbers have no substance in research, even though they have been cited many times and are well known. Several people have tried to hunt down the original numbers that this statement, and similar statements are based on, but the numbers are not to be found [29, 30]. The numbers have often been connected with Dales learning pyramid. Dales learning pyramid was intended as an aid for describing the different learning material. It has often been misinterpreted to give certain classifications a higher rank or value. The pyramid has later been coupled with the numbers of how much is retained after certain activities [31]. If these numbers were correct, they would weaken the importance of the theories of learning styles. However as the numbers are not credible, it actually strengthens the the importance of learning styles as this opposing theory is not substantiated by peer reviewed research.

2.5 Collaborative Aspects

A study by Johnson et al. [32] compared cooperative against individualized learning. Thirty 5th graders were involved in a study concerning language arts. The results suggested that working cooperatively has a positive effect on three levels when compared to individual work. First, group work promotes altruistic behavior. Second, the results suggest that cooperation increases intrinsic motivation, while working individually increases the extrinsic motivation. Third, concerning achievement there were found no differences between cooperative and individualized conditions when a review test was given individually. However when the review test was taken cooperatively by the pupils who worked in groups, compared to the ones who worked individually the cooperative groups scored higher on the test.

Further studies by Johnson. et al. [33] concerning cooperative, competitive and individualistic goal structures on computer-assisted instruction states that an individualistic assumption dominates much of the instructional use of computers. Educational software also reflects this individualistic approach. In the study a problem solving task was given to the different groupings that were cooperative, competitive or individualistically focused.

> The results of this study clearly indicate that when computer-assisted cooperative, competitive, and individualistic learning were compared, computer-assisted cooperative learning promoted higher quantity and quality of daily achievement, greater mastery of factual information, greater ability to apply one's factual knowledge, and greater ability to use factual information to answer problem-solving questions. Students in the cooperative condition were far

> more successful in problem solving than were students in the competitive and individualistic conditions. Cooperation also promoted greater motivation to persist in striving to accomplish learning goals than did competitive and individualistic efforts [33, p. 674-675].

In addition to this it was observed that the pupils in the cooperative learning situation also had relatively frequent discussion related to the task given. The authors also mention that a number of researchers has concluded that this kind of cognitive process is necessary for deeper understanding and long term memory [33, p. 675].

Charles Crook looked at children as collaborative learners [34]. He argues that younger children might have problems collaborating, because they do not have the socio-cognitive skills needed for learning in collaborative environments. This is also consistent with Piaget's theories, since the needed structures might not be present at a young age. Therefore collaboration is not as effective. Crook describes specifically two needed mediations when concerning collaboration among children. The first is to have an array of visible and manipulable things. The second is narrative. He states that much of the material represented in school is abstract, such as mathematics. As they are abstract it might be difficult to represent them using these two mediations. The author states that computers can solve the problems of making visible and manipulable representations. If it in addition is provided in a narrative way it should accommodate for collaboration even among children.

It is stated that when people collaborate face to face they share information that is located at a common space, often a table [35]. Objects can be used as props for discussions and new ideas can be developed together. Computers often inhibit these properties of collaboration, and are often not used when the goal is collaboration. Kruger et al. have looked into the role the orientation of objects has in collaboration. Their conclusion was that orientation have mainly three roles. These are comprehension, coordination and communication. For comprehension it was used for *ease of reading*, *ease of task*, where they were oriented for more easily solving a specific task. Last in comprehension was *alternative perspective*, for helping the users' understanding. Coordination is concerned with *establishment of spaces*. Observations show the establishment of personal spaces and group spaces. In the personal space objects are typically placed close to the person it belongs to, as well as the orientation of the objects corresponding to the owner. Group spaces are typically centralized on the work space. Their orientation is often the opposite of the person who established the group space. Several group spaces can also exist at the same time. Coordination is also concerned with *ownership of objects*. If objects are not aligned with a personal space or the orientation does not match, it means the object is free and can be picked up. The last role is communication. The process of orienting objects creates *Intentional communication*. This orientation change can be either towards another person or to a group space, and signal communication to the other collaborators. *Independence of orientation* suggest that people rarely explained or made any additional gestures when rotating an object. Questions about rotations where also rarely asked, meaning that rotating something is a natural, intuitive and quick activity [35, p. 371-375].

Five design implications are given for supporting these subtle but important parts of collaboration on a shared work space [35, p. 376].

1. Free Rotation: people are allowed to rotate objects at any angle
2. Lightweight rotation techniques: rotations can be done easily and quickly
3. Orientation of positioned objects must be maintained: a system should not reorient items
4. Rotation actions must be clear: it should be easy for the other participants to understand when a rotation is happening
5. Automatic support for rotation and orientation must be handled carefully and allow easy user override

Multiple sources showing learning benefits from collaboration in the classroom [34, 32, 33]. Crook [34] described the importance of providing visibly manipulable objects as well as narratives when children collaborate. The results of Johnson et al. [32, 33] suggested that working in groups the intrinsic motivation for solving problems is higher than when working individually, and also suggests that people will do more work on solving a problem before giving up. Groups that have being collaborating are able to apply their knowledge more successfully. However in individual review tests no difference was found between individual work and collaboration. This suggests collaboration does not have any effect on recall of information, however for practical problem solving work it has a positive effect. Lastly Kruger et al. [35] discussed the importance of small cues when collaborating face to face, and also suggested five design implications for supporting this kind of collaboration.

3 Contact With School

Contact with Gjøvik Skole was made at an early stage of this project. Nina Kristoffersen, a 6th grade teacher was the main contact person during the project. Her class consisted of 49 pupils. Where seven of these pupils would start with computer assisted learning because of learning disabilities. During an initial meeting she made statements that supported the need for exploring using alternative technologies in teaching. Parts of this interview was transcribed and can be seen in Appendix A. It was mentioned that especially one pupil in the class had problems visualizing concepts, and that AR would be a good fit for this particular pupil. However Nina also thought this was something that also would be suitable for other pupils as well. Her statements supports the belief in learning styles, and the need for adapting teaching styles to a broader range of students. During this first meeting, Nina suggested using European geography as the theme for the AR applications. This was part of their curriculum and suitable for development. Further meetings with Nina and a colleague was conducted at the start of the development period of the thesis. Chapter 4 describes the applications on a conceptual level. Earlier versions of what will be introduced in that chapter was shown to them. They gave feedback and thoughts about the suggested ideas. This was taken into consideration and the early ideas evolved into the current concepts.

3.1 Videotaped Session

Information about typical activities done in a regular school day was given early on by Nina. In addition to this a camera was rigged up for observing a typical day. The idea was that this would give information that confirmed and also supplemented that Nina had already explained. The camera was put on a tripod and left alone for observing. Manually handling the camera would have given better images and could provide more focus on taping the activities. However, this had the potential to create distraction for the pupils. Leaving the camera unmanned was chosen. When reviewing the video later also seemed to be the correct choice, as the camera itself caused quite a lot of interest and distraction to many of the pupils. The video and audio was analyzed qualitatively. Approximately three hours of video was recorded. The key activities were identified, from watching through the video. These are listed below, the full list of observations can be found in Appendix B.

1. Gatherings in the front of classroom were common. Information was given, texts and material were being presented during these.
2. Smaller groups worked together on tasks.
3. Tasks could involve a physical aspect, not just sitting together working. The video showed a "treasure hunt", where the pupils had to search for the questions that were hidden around school.

4. When there was an element of competition in the group work, there seemed to be excitement around this.

The observations were made to get some cues about what should be considered when developing a prototype. Both concerning what the pupils might find enjoyable, and also so that it does not disturb general teaching. Also potential applications should not introduce activities that diverge too much from the existing activities. The observations from the video seemed coherent with most of what the teacher had said about the typical school day. However also having the video showed the small subtle things. Such as the competitive aspect was not mentioned by the teacher. Meaning the video and the teachers statements supplement each other well.

3.2 Questionnaires for Teachers and Pupils

Two sets of questionnaires were developed as part of the thesis. A 15 questions questionnaire was made for the teachers at the end of thesis. The questions were designed to see if the teachers seemed to agree on the theories reviewed in Chapter 2. The questionnaire can be seen in Appendix C. In addition to this a questionnaire was created for the pupils. This was a questionnaire that was intended to be conducted after the pupils had done a user test of the applications. The questionnaire made was based on a game experience questionnaire. Several statements are given, and these are rated using a 5 point scale. The different statements can be divided into seven components. These are immersion, flow, competence, tension, challenge, positive effects and negative effects. This questionnaire is intended to assess the human experience when playing games [36]. It consists of 42 questions, not all are relevant for the AR applications, so a selection of these were made. The full set of questions can be seen in Appendix D.

Both of the questionnaires were set up using an online system called Limesurvey[1]. Limesurvey is an open source survey applications and is free to use. It is built using PHP, and was easily set up on a personal web server. This was done as it would save time, as no transcribing from paper forms would be needed. Limesurvey could export the data into several flexible formats that could easily be worked with.

[1] http://www.limesurvey.org/

4 Application Descriptions

In this chapter three conceptual applications that use augmented reality will be introduced. The setup of the workspace, which is common for all is given in section 4.1. The three applications are described in sections 4.2, 4.3 and 4.4. Section 4.5 gives a stepwise use case of how the use of such an application would typically happen. In section 4.6 the expected advantages and disadvantages of an AR approach is discussed. The discussion is based on the conceptual framework introduced in 2.2.1.

4.1 Initial Setup of Workspace

All the three applications will take place at a set workspace. A choice of having a public workspace was taken. In Section 2.5 the importance of orientation of objects in collaboration was introduced. Supplying a table coupled with the AR technology as a public work space supports the design implications introduced. A marker can easily be rotated at any angle, and the rotation of the object attached to a marker is relative to the marker, so the orientation is stored. The markers are tangible and square, and the virtual objects follows the markers in realtime, meaning it is easy to know when objects are being rotated. The applications does not have any functions that automatically reorientate objects, so the users have full control of this. This supports the notion that this is a suitable setup for collaboration. The setup is a quite simple one, as the use is intended to be in schools, it uses equipment that is often already available. The setup consists of a camera, a computer workstation, a projector, calibration markers and the additional markers or marker cubes, that are needed for the different applications. The camera is mounted such that it faces the students. The AR process, illustrated in Figure 2, is computed, and the result is projected onto a screen in front of the work desk. The students can then see themselves with the virtual objects superimposed in the video. This is often called a magic mirror effect in the literature[37, p. 3-4]. The calibration markers are positioned at each corner of the workspace. The calibration only has to be done once before using the system. The markers will be tracked by the system and a relative coordinate system based on the markers placement on the workspace will be used rather than a coordinate system based on the position of the camera. After the calibration is done, the calibration markers can be removed. This can be done as the camera will be static and not moved while the system is used. If the system allowed the camera to move, the calibration markers would have to be visible all the time, or the coordinate system would come out of synchronization with the real world. A conceptual illustration of a sample setup can be seen in Figure 6.

4.2 Country Puzzle

The first application is called a country puzzle. It works in the same manner as a regular puzzle game would. The different countries of Europe acts as the pieces of the puzzle. In an early version of this game all the countries of Europe would start out as scattered around the workspace.

Figure 6: Illustration of sample workspace

Where they then had to be reattached to their neighboring countries, also based on the attaching them at the right angle. The idea of all the countries being scattered from the start however would lead to a messy and unwieldy workspace. As the workspace will be calibrated a certain area will have a virtual box, filled with the different countries. When a marker is brought close to the box, a random country is picked up from the box, and attached to that marker. Several markers can be used meaning that several different countries can be attached to different markers. The countries will follow the markers movement, and will give a feeling of directly controlling the countries. When two countries are being brought close to each other they will snap together to form a new group, this only happens if they are neighboring countries and are being brought together at the right angle. Trying to put Norway next to Italy will therefore have no effect. There will also be no effect if Sweden is being brought close to Norway on Norway's west side, however if on the east side they will join together and make a new group. Groups can be further joined with other countries or other groupings of countries. After a country, or group, is attached to a marker they can be de-attached by covering the marker for three seconds. This will drop the country where it was when the marker was covered up. It can be attached again by moving a marker close to it. The goal is to rebuild the European map. A “help” marker is also provided for this game. When it is brought into the sight of the camera useful hints will be given to the players, such as showing the names of the countries. If a country is attached to a marker subtle hints of where two countries might be attached can also be given. A score is given when the map is rebuilt. The score is based on how many times the help marker is used, as well as how much time was used for reaching the goal.

4.3 Monument Placement

The second application is similar to the country puzzle game. In this application the theme is European monuments. Here the European map is represented already built, but with some hints of where different monuments belong. Monuments can be picked up from a pre-defined area of the workspace. This happens the same way as in the puzzle, and the de-attachment is also done in the same way. Further they can be placed around the European map. In this application cube markers should be used, so that the monuments can be observed in detail more easily. Flat markers will still work, but will not give as much flexibility as the cubes. When a monument is successfully placed at the correct location an animation is triggered which zooms in to the country and the monument, where additional information about it is given. The information is given in textual form as well as auditor form. When the presentation is finished the users are returned to the game. Everything is zoomed out again, and further placement can be made. Also In this game the help marker can be used. It can give either visual or textual hints about in which country a certain monument belongs. As this application is more a exploratory and presentational game, the score is only based on how many times the help marker was used, and the accuracy of their placement. With accuracy it is meant if they have misplaced a monument a lower score is given. The time factor does not matter in the game, as this would rush the players through the presentations of the monuments, which would be against the purpose of the application.

4.4 Population Game

As in the monument placement application the whole map is provided for the users. The objective here is to successfully place the correct number of people in the different countries. This is done using a bucket metaphor. An area of the workspace is used for filling the bucket with the desired population. When the bucket is held in the area of the workspace that is used for filling it, it will be filled with people. It will be clearly shown how many people a bucket contains. A cube marker will represent the bucket. The bucket can be moved over the different countries of Europe, the country that is currently being hovered will be clearly marked so it is easy to know where the people will be poured out. When the desired country is hovered the bucket can be tipped over. This will pour out the population in the bucket into the current country. When the pupils are satisfied with their distribution of the population a finished marker can be brought in to stop the game and give them feedback on their distribution of the population. It should also be mentioned that a finite number of people are provided, so it is a matter of distributing it correctly. A score is given based on how close the population in the different countries are to the number that have been distributed by the players.

4.5 Sample Use Case

Use cases are often used in interaction design, it focuses on the interaction between a user and a system, with the focus being on the users perspective. The focus is on the users goal, and the path of interactions that are needed to reach this goal [6, p. 510-513]. A sample use case based on the country puzzle concept, introduced in Section 4.2, is provided to give a better understanding of how a finished application will work.

1. Application starts
2. Pupils pick up markers
3. Student A brings marker close to the country box
4. Spain is attached to the marker
5. Student B brings marker close to the country box
6. Germany is attached to the marker
7. Student A de-attaches Spain from the marker by covering it for 3 seconds. Spain is loosely placed in the workspace.
8. Student A gets a new country attached, this time it is France.
9. Student A recalls that France is located north-east of Spain.
10. Student A brings France close to the north-east part of Spain.
11. A new group consisting of France and Spain is now attached to a marker
12. Student B realizes that Germany also borders to France.
13. Student B asks to borrow the other marker, and brings Germany close to the east side of France.
14. A group consisting of all three countries are located at one marker.
15. Poland is attached to a marker
16. Student A and B discusses which country the new one actually is, but neither seems to recognize the shape of Poland.
17. The help marker is brought onto the workspace, when visible the names of all the countries are shown in textual form on top of the country.
18. They both realize that Poland is neighboring Germany.
19. The help marker is removed from the workspace.
20. Even though they know Poland is next to Germany, they are not certain if it is at the west or east side.

21. Poland is tried being attached to the west side of Germany, no grouping is made, but a feedback showing a thick red border at the east side of Germany is given. In addition a subtle green-yellow color is shown at the east border of the Germany where Poland should be placed.
22. Poland is now being attached to Germany at the correct side.

This use-case shown in Enumeration 4.5 illustrates how some typical use of the country puzzle application might be conducted. There will be variations of how this can be done, and this only serves as an example of a single scenario. An alternative course on step 21, could also be if a country that is not a neighbor with another country is tried being attached to each other. Then a purely negative feedback showing a thick red border around the whole country would appear. Other scenarios might involve the students grabbing a large number of countries and scattering them around the workspace, and then working from there.

4.6 Possible Advantages and Disadvantages

This section gives a review of the negative and positive aspects of the conceptual applications. This is based on the framework introduced in subsection 2.2.1 as well as theories from Chapter 2. General points about the applications will be considered, however some applications support some concepts better than others. The observations based on the framework from subsection 2.2.1 are presented in table 1. The observations state that if the conceptual applications are realized with these concepts in mind, it will follow principles that according to the authors of the framework are good practice for TUIs.

The concepts have also been considered in the context of the theories that were introduced in Section 2.3. Firstly the zone of proximal development can be considered. The idea is that more capable students might help others onto a higher level. The concepts of non-fragmented reality, externalization, performative action and multiple access points supports this. These are all properties that support being able to help others. Being able to directly manipulate objects, and simultaneously do actions together, or physically show how to do something are all positive aspects that is supported. The same scenario on a PC would involve people to first observe and remember all the actions being taken, and finally try to replicate the actions that were just demonstrated. Often leading to focusing purely on remembering the steps, rather than understanding the actions.

It was also stated that collaboration gives more intrinsic motivation, and also that group work in general was more efficient if it was part of the regular work method. Pupils who worked collaboratively applied their knowledge more effectively than individual workers. In addition the zone of proximal development supports the claims that collaboration should be an important part of learning. Crook [34] stated that younger children might have problems collaborating efficiently, due to the lack of developed structures. It is suggested that providing physical manipulable objects as well as narratives will support collaboration among children. The former is supported, and was one of the main reasons for choosing the AR technology. Presenting concepts in a narrative way is not covered much by these applications, except from the monument placement application introduced in Section 4.3. Where a presentation of the monument is given when it is correctly placed.

This chapter has explored the main ideas and concepts that an educational augmented reality system should consider. Three applications has been suggested based on best-practice reviewed in the related work, as well as ideas and tips from the involved teachers. This process has clarified the requirements that need to be implemented. Chapter 5 builds on the concepts introduced here and is concerned with the actual implementation of an application.

Table 1: Concepts supported in conceptual applications

Concept	Description
TM 1: Lightweight Interactions	In all the proposed applications a public workspace is provided. Everyone involved will always have the same view and be given the same information. The tracking of markers happens in realtime, this gives continuous feedback to the user. As soon as a marker is moved, the object attached also moves. All interactions are also done tangibly and stepwise. This means that it is always clear what is happening.
TM 2: Isomorph Effect	For all applications the interactions that are available are simple, and there is a clear connection between the action and effect. There are clear interaction metaphors for all applications. Such as a puzzle metaphor and a bucket metaphor. Pieces of a puzzle have to be connected to the correct neighboring piece, as well as on the right side of this piece. This is a concept most young children are very familiar with. The same goes for the bucket metaphor, it can be filled up, and if it is tipped around the content will fall out. By having these familiar and simple interactions schemes, the actions and their effects are clear.

SI 1: Inhabited Space	There is a set and limited workspace for all applications. In this space any virtual object that is needed can be provided. The content of the workspace is therefore highly customizable and meaningful for the actual use of the applications. Examples of this are the virtual box provided in the country puzzle and the filling zone in the population game.
SI 2: Configurable Material	For all the applications the materials, or in this case the virtual objects in the real world play an important role. It is the manipulation and rearrangement of these that are the goal in all of them. Such as putting the countries together, placing a monument and also distributing the virtual population onto the European map. While working with a regular puzzle it is common to work on different parts of the puzzle, which later can be merged together. This means a group of country can be put down and then later be attached to another group when it is more clear where it belongs.
SI 3: Non-fragmented Visibility	As mentioned several times earlier the workspace is a public workspace. Everyone sees the same, and the display is visible to all participants at any time.
SI 4: Full-body Interaction	Already known skills are taken advantage of, by providing metaphors that are commonly known. Negative aspects is also apparent here. There are very limited ways of interacting with the system. The extent of skills that could be used in the applications is something that needs more exploring. As the users get more proficient in using it they would probably demand more advanced ways of interacting.
SI 5: Performative Action	By providing tangible objects it is possible to both verbally express something while doing actions, as well as demonstrate concepts by action. Rearrangement of objects in such a way that was discussed in Section 2.5 is also supported by having the public workspace coupled with tangible and visible objects. The country puzzle application is the one that best fits this area.

EF 1: Embodied Constraints	The constraints of the markers and cubes are limited. Since these are not built specially for representing one object they do not have any constraints that makes certain interactions more easy or more difficult. Constraints would have to purely be done using virtual cues, this is not optimal, but AR markers does not have the same capabilities as self-contained tangible objects, such as the Siftables for example.
EF 2: Multiple Access Points	One of the goals of this project was to see if using AR can encourage collaboration among students. One of the shortcomings of using a PC workstation are the limited input devices, while great for individual work it is does not encourage collaboration. AR provides several to many markers. The markers does the interactions with the system, meaning that there is a high degree of distributed control. Actions are space-multiplexed rather than time-multiplexed. Allowing more than just sequential interactions.
EF 3: Tailored Representation	The virtual representation that will be attached to the markers will take advantage of previous experiences they might have. However when starting out with blank markers it is very likely that the users will not know how to use them to interact. Some initial instruction will be needed unless the users already have experience from this.
ER 1: Representational Significance	The representational significance for all three applications are good. The markers can contain any virtual object. For the country puzzle it is easy to know that there is country attached, and that it should be attached to another country. As long as the user knows the shape of the specific country it is easy to know what it represents. The same goes for the monuments. They can dynamically change to represent different states as well. The negatives are however that the users are actually holding a flat marker, or a cube with different patterns, and it is only in the virtual world the objects actually exists.
ER 2: Externalization	In the country puzzle game several countries can be laid out on the workspace to get an overview, and by looking at the shapes of the countries find out where they belong. The other applications does not take advantage of this fact.
ER 3: Perceived Coupling	The digital objects have a very close connection to what is happening in the real world, because of the tracking that is used in AR. This means that there is a close relationship between everything that is done in the real world, and this will in most cases, as long as tracking is working properly, be mapped directly to the virtual world.

5 Development

This chapter is concerned with the implementation of one of the conceptual designs introduced, the country puzzle was selected. It was based on fairly simple interactions, and would also lay the foundation for further development by introducing the most important interaction schemes. Section 5.1 introduces the frameworks and libraries used for the development. Section 5.2 discusses the choice between using head-mounted displays versus a public display. Section 5.3 discusses the process of generating markers for the thesis, as well as the cube maker. Section 5.4 introduces some of the problems solved during the development. Lastly Section 5.5 shows a demonstration of what has been implemented.

5.1 Technologies

C++ was chosen as the main programming language for development of the applications. In addition two frameworks have been used in the development. The first one was ARToolKit [38]. This is a software library that tracks square fiducial markers. It tracks this in real-time and gives information about marker position and rotation. This information can be used for drawing 3D objects that corresponds with the position and rotation with the tracked marker. This means that the user gets the feeling of interacting directly with the object through the marker. The version used for the project is 2.72.1.

The second framework used was OpenSceneGraph [39]. This is an open source 3D graphics toolkit. The sample code provided for ARToolKit only uses OpenGL for drawing 3D objects, which is quite low level coding. OpenSceneGraph provided many features for working with 3D objects. Scenegraphs could be made, which makes organizing 3D objects easier. In addition it had the capability to load many types of 3D formats through the use of supplied plug-ins. The version used was 2.8.2.

ARToolKit did provide one of the most important features needed for the project, tracking of the markers. However only working with OpenGL for making the more visible parts of the system was not feasible. Since OpenSceneGraph provided many of these features it seemed like a good solution to use the capabilities of these two for developing the applications. An existing framework called osgART [40] existed, it combines the two mentioned frameworks. This was used for an initial prototype done in a pre-project for for this master thesis. Some flaws were uncovered during this period. Jayson Mackie, who has 10 years of academic and commercial AR experience, developed most of the initial prototype, which used osgART. He stated that using the osgART hides too much of the information available from the two other toolkits. This meant that changing the functionality provided by osgART would be difficult. In addition the documentation available for osgART was very poor. He suggested not using osgART, and rather combine ARToolKit and OpenSceneGraph manually. His advice was followed and further development was done without using osgART.

ARToolKit is released under the GNU General Public License. This requires that the software can be used for any purpose, can be changed as it suits the needs and changes to the software can be freely distributed. OpenSceneGraph is released under the lesser GPL. The main difference here is that the former one only allows the use for free programs, while the lesser GPL permits its use in proprietary programs. Since these are toolkits that are open source and freely available for use, it makes them ideal for use in this project, as it had no budget available. Both toolkits was mentioned in articles having developed similar applications [17, 18, 14]. Since similar applications used the same toolkits it seemed like an appropriate and good choice for the development. In addition Hornecker and Psik used ARToolKit for building tangible prototypes [41]. They mention that AR can mimic many of the same capabilities as the typical and specialized technologies that are usually used in TUIs. Advantages were that it did not need the specialized technology, meaning a lower cost, necessary for this thesis. The disadvantages on the other hand were the known issues with AR, such as the tracking stability in poor lightning condition, obscuring of markers and so on. Even though it has some limitations the choice of frameworks should support tangible interactions well.

5.1.1 Connection Between ARToolKit and OpenSceneGraph

As osgART provided too little control and also would be time consuming to customize for the needs of this thesis, a connection was done manually between ARToolKit and OpenSceneGraph. What was needed was to migrate the video feed provided from ARToolKit, as well as the transformation matrices of tracked markers over to OpenSceneGraph. A textured quad was created in OpenScenegraph. This was textured using the dynamic video stream, which was accessed from the memory of the computer. The quads projection was set to orthographic, giving a two-dimensional representation in a set location. This resulted in a dynamic background based on the video feed. Further objects were then rendered on top the quad, effectively linking the two frameworks.

The simple combination of camera stream to textured quad was extremely slow. Eventually the cause was discovered to be a resizing happening every frame. The main problem was that OpenGL requires that textures have lengths in powers of two. Very few cameras provide images with powers of 2 sizes, the typical is 640x480. This required that for every frame a resizing of the texture was performed, which slowed down the application significantly. This was solved by providing a texture using a power of 2 size, which prevented the resizing from happening every frame. The final step was to get the projection style correct. Transformation matrices from ARToolKit are used for getting the placement and rotation of objects attached to markers correct. If the projection style used in the OpenSceneGraph project does not match the one used in ARToolKit objects would not be placed correctly according to the marker positions. Experimentation with a perspective projection was done to get the results close to what was used in ARToolKit.

5.2 HMD vs Single Projection

Very often when using AR the output is through a head-mounted display (HMD). This option was rejected because of the need to build an inexpensive application for use in an educational situation. In addition the plan is to make a system that supports collaboration among pupils. This would mean that several HMDs would have to be provided. Lastly the users of the applications are 6th graders, and putting expensive equipment in the hands of 11-12 year olds is too risky. One last display technique that could have been used is handheld devices. How this would work would be similar to HMDs, except they are handheld, such as mobile phones. These would have to be synchronized with a centralized work-station. A public display should encourage collaboration more than having individual "looking glasses" into the AR world. A single projection was the most feasible solution for this project. Mentioned previous work reviewed also supports the concept a public display and work space will better support collaboration.

5.3 Fiducial Markers

This project uses fiducial markers for tracking. Alternative methods were introduced in Section 2.1.3, but the chosen software library, ARToolKit, use marker tracking. It is a robust software library that has been around for a while and has been heavily used. Using markers also provides the tangible user interface that is wanted. Work has been done on using natural hand gestures for interacting with 3D objects [42], but is not supported in any software libraries at this point. In addition having an actual physical object to interact with might also be more intuitive to use. In addition this thesis focuses on collaboration, meaning several people will do interactions at the same time. Tracking many hands would most likely cause problems.

5.3.1 Marker Generation

Generating markers that are easily tracked were also part of the project. The default markers provided with ARToolKit were not especially suitable for pattern differentiation. Two examples of markers can be seen in Figure 7 The default marker consists of a quite thin and complex pattern.

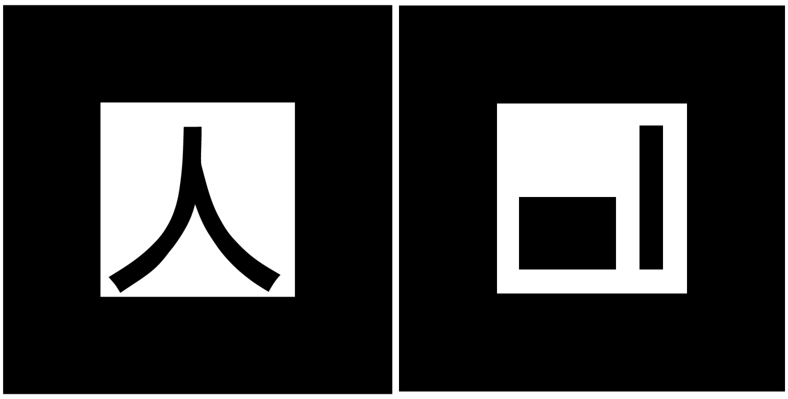

Figure 7: Left: Kanji marker standard for ARToolKit Right: generated marker for project

This gets easily lost when tracking the markers. The generated marker consists of only straight lines and an easily recognizable pattern. A pattern is stored as 16x16 pixel information. This means that if the pattern provided is too complex a lot of information is lost, as there is limited how much information 16x16 pixels can hold. If a very complex pattern is being registered using a camera it will be normalized to fit into 16x16 matrix. This is why a blocky pattern is a more suitable choice. Designing the markers so that they are rotationally invariant was also important. Meaning they have to be unique no matter how it is rotated. If two sides look the same the tracker will be confused and will not be able to track the marker correctly, risking that the rotation of an object might not be displayed correctly.

In Figure 8 the template used for generating markers is shown. Here it is divided into a 8x8 grid. The outer border is not used, so the basically it is a 6x6 grid that is used for designing the markers. On the right side, in column six and seven, there are two stripes, these are either on or off. This means that with only these there are 2^2 possibilities. The second part goes from column two to five. Where there are 2^4 different variations. In theory this means this pattern system is able to generate 64 different patterns for the markers. The actual amount is a little less, since a completely white and a completely black marker are not rotationally invariant. Also some of the pattern combinations might produce identical patterns. However the number of patterns that can be generated from this template provides a sufficient amount for this project. The markers that has been generated was made using PPM [1]. This proved an easy way to generate the markers without the need of any program except from a text editor. Below is an example of such a file.

```
P1 16 16
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 1 1 1 1 0 0 0 0 0 0 1 1 0 0
0 0 1 1 1 1 0 0 0 0 0 0 1 1 0 0
0 0 1 1 1 1 0 0 0 0 0 0 1 1 0 0
0 0 1 1 1 1 0 0 0 0 0 0 1 1 0 0
0 0 1 1 1 1 0 0 0 0 0 0 1 1 0 0
0 0 1 1 1 1 0 0 0 0 0 0 1 1 0 0
0 0 1 1 1 1 1 1 1 1 0 0 1 1 0 0
0 0 1 1 1 1 1 1 1 1 0 0 1 1 0 0
0 0 1 1 1 1 1 1 1 1 0 0 1 1 0 0
0 0 1 1 1 1 1 1 1 1 0 0 1 1 0 0
0 0 1 1 1 1 1 1 1 1 0 0 1 1 0 0
0 0 1 1 1 1 1 1 1 1 0 0 1 1 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
```

P1 defines that it is a bitmap format, and the two values of 16 says that it is the size of 16 by 16 pixels. Each pixel can then be defined, where 0 is white and 1 is black. Other formats for grayscale and color can also be used [43].

[1] Portable Pixamap Format

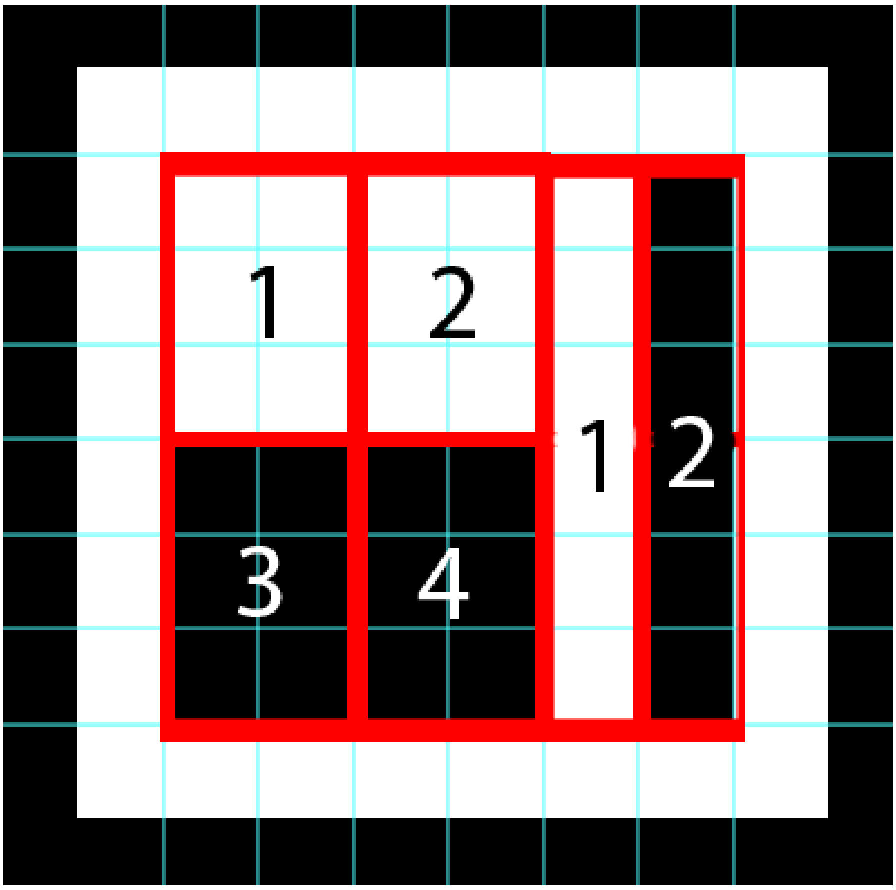

Figure 8: Pattern for designing markers

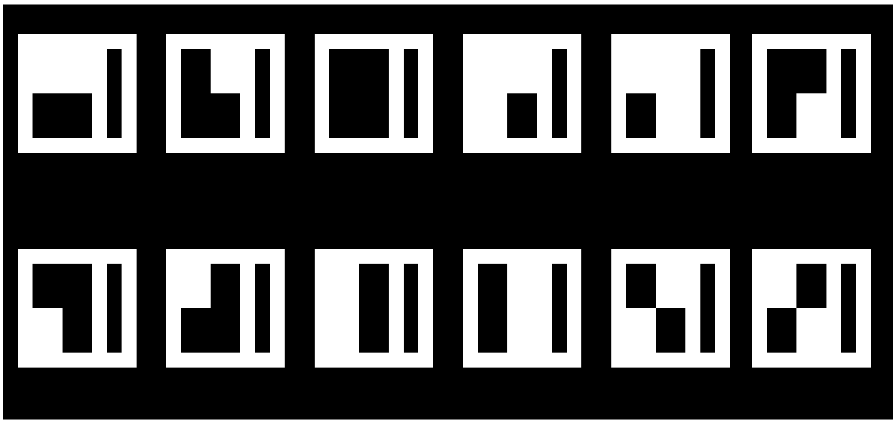

Figure 9: Sample patterns from template

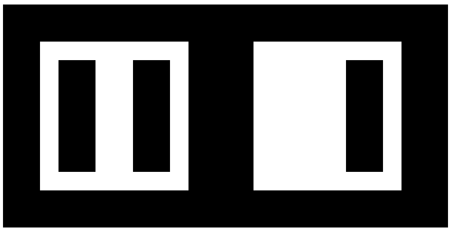

Figure 10: Patterns generated from template that are not suitable

The first marker shown in Figure 10 is not rotationally invariant. It is impossible for the tracker to know which edge is right or left, and also which edge is top or bottom. The tracker will try its best, but will be confused. The second pattern is not used because by filling only 1 and 2 in the binary area gives a pattern that can also be interpreted as the same pattern given when only filling 1 and 3 in the quad area. This could be solved by only using one pattern like this, but it is chosen not to be used at all. Since which pattern a marker corresponds to might be ambiguous if both are used.

The information stored in a pattern file is shown as a graphical representation in Figure 11. It can also be seen that in the marker information there is stored information in three channels. These are red, green and blue. For example when a marker with a red pattern is shown that has the same pattern as a stored black pattern with the same shape, the application will track the colored marker as well [44]. Because black is a mixture of all these channels. This means that colored markers could be used as well. By introducing colors a very large number of markers can be generated based on the pattern template introduced.

Cube Marker

As part of the pre-project for the master thesis a cube marker was developed. Work on this was done by Jayson Mackie and Øyvind Nygård. It is a six sided cube that has different marker patterns on each side. Each side is defined as top, bottom, left, right, front and back. These names are inspired by the conventions in 3D graphics, an overview can be seen in Figure 12. Where each side has a unique pattern that identifies which side it represents. An image of two marker cubes constructed with the standard AR markers is shown in Figure 13. Having only one marker makes it easy for it not being tracked, since only occluding part of the frame of a marker is enough for it not being tracked. Initially in the pre-project it was hoped that having a cube with many markers would decrease the problem of markers often being occluded by users. However from an early test it was clear that a cube marker did not solve these problem. Occlusion still happened on a regular basis. Issues concerning flat markers has been addressed in an earlier master thesis [45, p. 60-61]. It is stated that users who had no experience with AR did not relate the marker to the 3D object. So they tried to grab the 3D object instead. Also in the system tested, the marker was not always visible, because it was a flat marker that was covered by the 3D object. Using a cube marker might solve some of this problems, and should be an advantage when working with

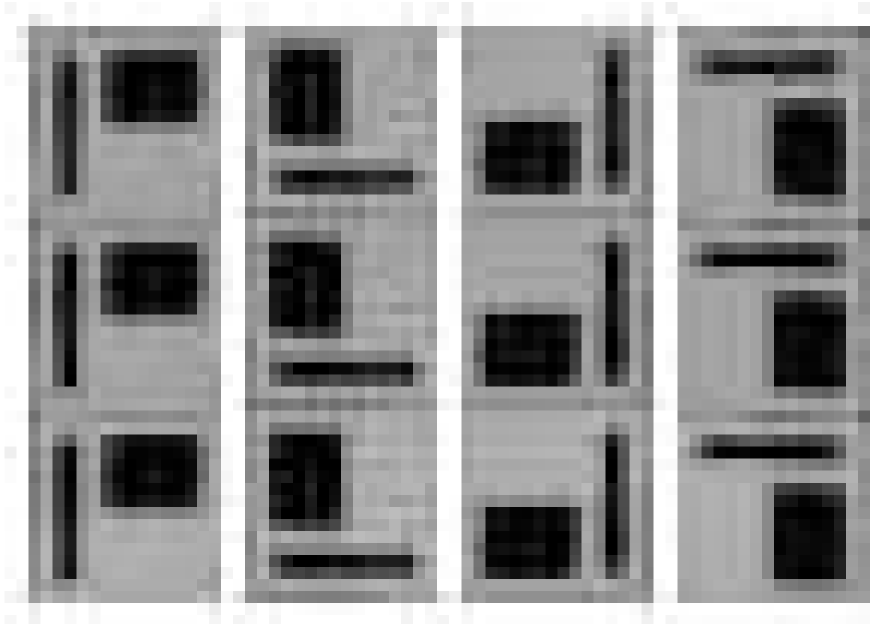

Figure 11: Information stored about marker patterns

children.

Another advantage in using cube markers is that it is possible to explore a 3D object from virtually any viewpoint. When using a flat makers there is a limitation first of all how much the marker can be turned before the system loses track of it. Another obvious short-coming of a flat marker is that it is never possible to view and object from below, as this would involve flipping the marker over. Using the cube marker however makes it simple to view from all possible angles.

5.4 Implementations

This section introduces some of the problems that were solved during the development period. Such as tracking problems, implementing functionality that was not offered by the framework being used and converting KML data into 3D objects that could be used by the application.

5.4.1 Tracking problems

One of the problems that became obvious when tracking markers, where that even if the marker was in the same position, the 3D object attached to it tended 'jitter". This was caused mainly by lighting conditions, which made the tracking unstable and caused the shaking movement. Several solutions for this problem were suggested. The first was to simply take into account several frames, and average the position of the 3D object based on this. The second suggestion was to use multiple thresholding when detecting the markers, this however did not behave the way that was expected when trying to implement it. The third and chosen solution is similar to the first, the four previous frames were taken into consideration, the marker position of these are averaged and the euclidean distance between these are calculated. If this value exceeds a

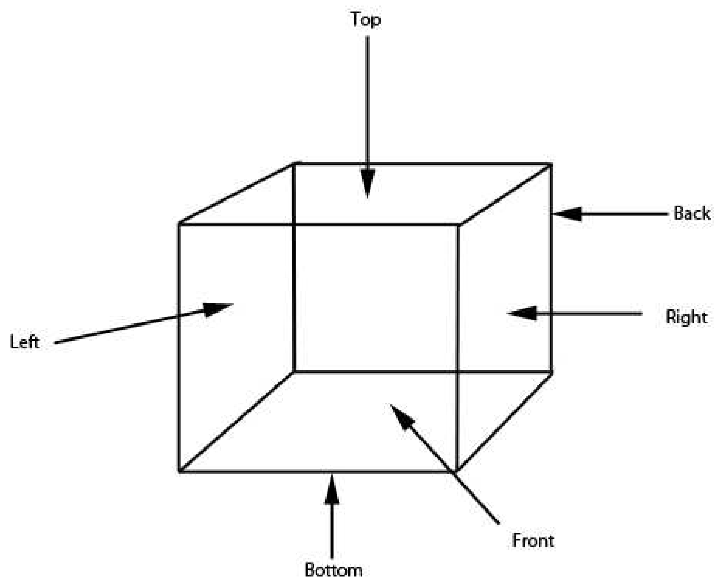

Figure 12: Cube Overview

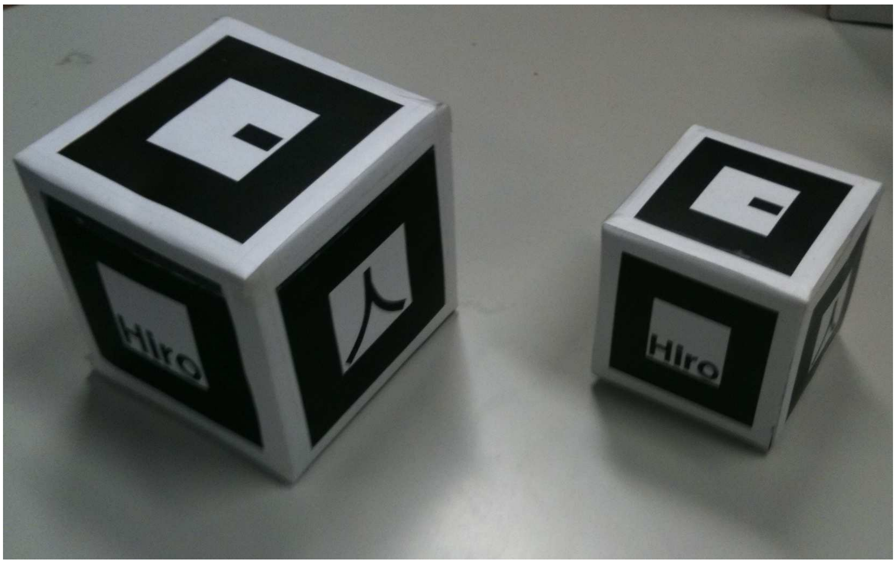

Figure 13: Constructed Cube Markers

set value, the 3D object is re-drawn in the new position. However if the distance is smaller than the set value, no update on the 3D objects position is done. Testing showed that small variations in the positions was picked up by the tracker. Testing with different thresholds on the allowed distance solved the jittering problem.

5.4.2 Independent 3D objects

Most of the examples provided by ARToolKit is made such that a 3D object always was attached to a marker. The developed application required having independent 3D objects. Meaning that they needed to exist in the workspace independently of any marker and its' position. By default ARToolKit works in a way such that an object belongs to a single marker, if the marker is covered up the object disappears. Providing independent 3D objects meant that objects would still be drawn if they were attached to a marker or not, or a marker with an object was covered up. This was necessary also because of the requirements of being able to attach an object to a marker, so that this certain object follows the markers movement. Providing a feeling that the object is attached to the marker. If the user do not want the object to follow the marker, being able to de-attach the object from the marker was also needed.

Two classes were written for solving these problems. A "Marker" class and a class called "OSGObject", where the former was used for storing information about the position of a marker, a timer function and information stating if it currently holds any object. A simplified UML class diagram containing the two classes variables and methods can be seen in Figure 14. Constructors and method parameters have been left out for simplifying it. The latter holds information about a 3D objects position, which marker it is attached to, if any. It also has information about the 3D object attached to it, as well as what countries are neighboring countries. These two classes works closely, and the the Marker class updates the OSGObjects position if it is attached. The information provided by these classes makes it possible to have control over the relationship between markers and objects and their position, and therefore provides the functionality that was described. In addition if a marker was covered up, and then reappears the 3D objects starts moving at a constant speed towards the marker again to catch up. This was done by finding a vector by subtracting the current position with the previous position. The vectors magnitude was then divided by a set value for maximum movement allowed in one step. This gave a result of how many steps an object needed for catching up with its marker. This meant that the update of the objects position was updated incrementally, and appearing to catch up with the marker. This was implemented because it is more clear what is happening, rather than the 3D object suddenly jumping to the new position of the marker. However if the marker is covered for more than 3 seconds the object is de-attached from the marker, leaving the object in the position it was when the marker was covered. It can easily be attached again by moving it close to the object again. Proximity of a marker to an object is simply checked by the euclidean distance between them in three dimensions. If the value is under a set threshold, the object can be attached, provided no object is already attached to that marker.

All classes and functions written as part of this thesis has been commented using JavaDoc style. This is a special way of commenting that can be used for auto-generating documentation. Running the actual code through a program such as Doxygen will then generate this document-

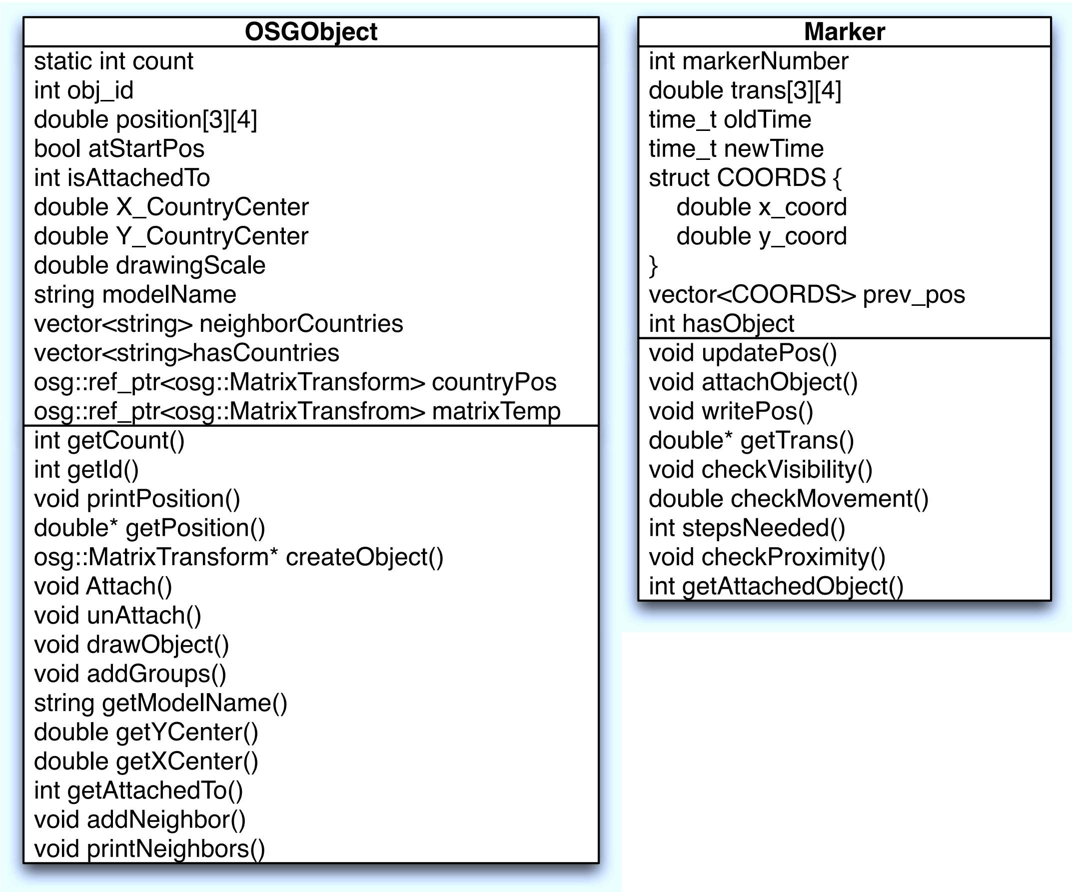

Figure 14: Simplified UML class diagram

ation. This was done as it would make it easier to extend and further develop the code.

5.4.3 Getting country data

As this projects theme is European geography, data for the different countries were needed. As geographical data is vastly available in many different geographical formats, it seemed like a good idea to utilize this. This should save much time rather than manually model the needed countries using some 3D modeling tool. Simon McCallum discovered that there existed a KML file that had data for the borders of every country in the world [46]. This was made by users in the Google Earth Community. KML is an XML based file format for storing geographical data. I.e it is used on Google Earth and Google Maps [47]. Using this data was something that would be useful for this project. The file had large quantities of data, so a script for extracting the data had to be made. This data would then need to be input in OpenSceneGraph so it could use it for drawing the country shapes. A simple PHP script was made, it generates the code needed for drawing polygons with the shape of countries. When these polygons where drawn it was further saved into the native .osg format OpenSceneGraph uses. This meant a country now could easily be loaded by a single command in future development. Following is a very small portion of the KML data of Sweden. As can be seen it mainly consists of vectors in three dimensions that maps to world coordinates. It also contains other information, but not of relevance for the needs of the thesis. As mentioned each country was represented by huge quantities of these vectors. After running the PHP script on Sweden's KML data it would be represented as shown in Figure 15.

```
[...]
<Placemark>
   <name>Sweden</name>
   [...]
   <MultiGeometry>
      <Polygon>
         <outerBoundaryIs>
            <LinearRing>
               <coordinates>
                  11.46500015258789,58.06610107421875,0
                  11.40110969543457,58.1302604675293,0
                  11.57610988616943,58.22526931762696,0
                  11.65528011322022,58.23138046264648,0
                  11.67164039611816,58.27621078491211,0
                  [...]
               </coordinates>
            </LinearRing>
         </outerBoundaryIs>
      </Polygon>
   </MultiGemometry>
</PlaceMark>
[...]
```

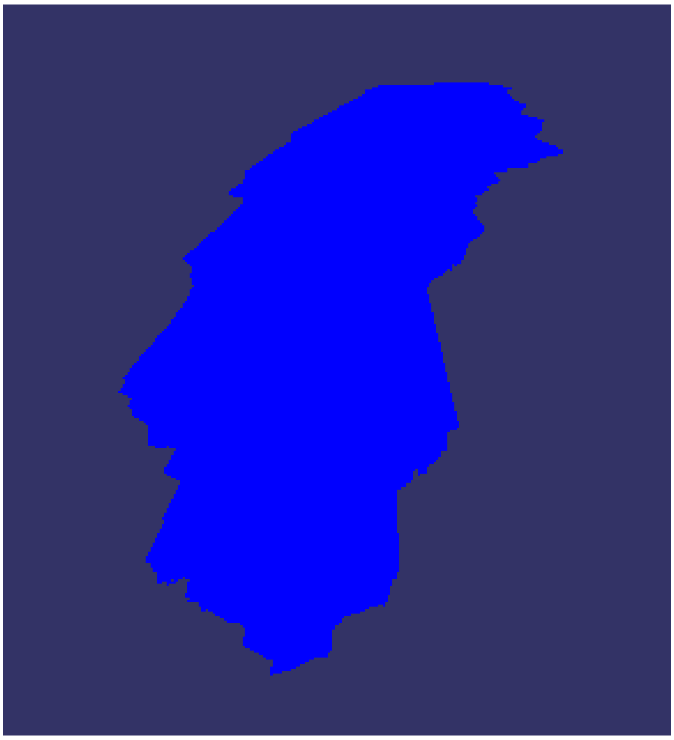

Figure 15: KML converted to polygon in OpenSceneGraph

5.4.4 Country Puzzle Scenegraph

As mentioned the merging of OpenSceneGraph and ARToolKit was done manually, rather than using the osgART framework that existed. For linking the video feed from ARToolKit to OpenSceneGraph a new osg::camera was added, which was set to do a pre-render. This was done so that the video feed will be used as a texture for a simple quad that is added in geom, osg::geometry. This is pre-rendered so that it will function as a background, and the countries that will be drawn later will appear on top of video feed. Further in the scene graph. A group was added to hold the different countries. A country model is a child of a matrix transform, which again is a child of another matrix transform. Lastly they are added to the desk group, which is a child of root. The first matrix transform, countryPosition, sat the transform of where the country is located in the frame, meaning if it was moved around this was where the transform was done. The second matrix transform, centerTransform, was simply done to center a country in its local geometry. This has to be done because the countries have been extracted from a KML file. Meaning that the countries initially were not centered, but were drawn according to their original world coordinates. The center of the country, which was also supplied in the KML file, was simply subtracted in this transform, so the countries are being centered instead of using the world coordinates. An illustration of the scenegraph can be seen in Figure 16.

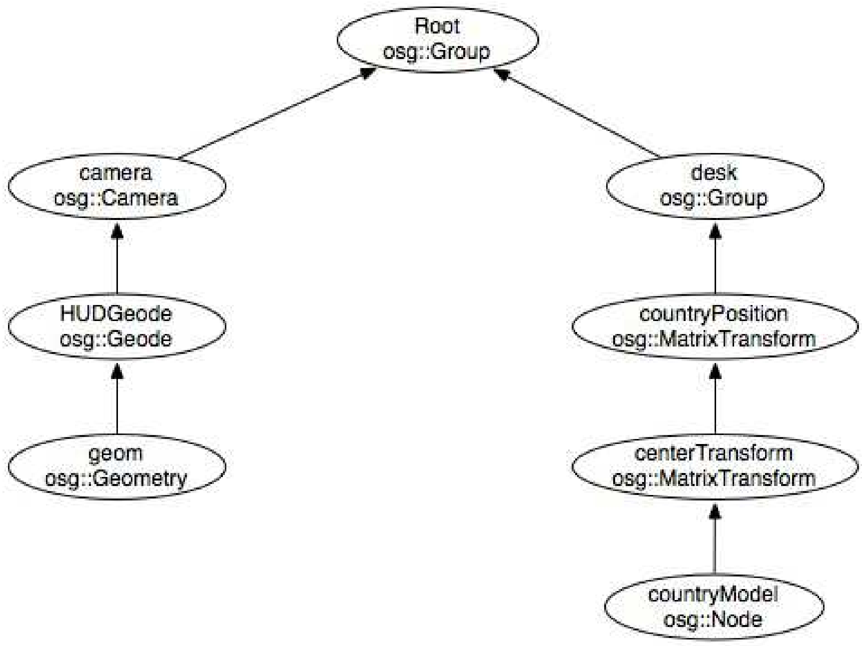

Figure 16: Scenegraph of country puzzle

5.4.5 Logging of Events and High-scores

A logging function for the application was made as this would provide additional data that could make debugging easier, as it could show what was done before it crashed. In addition cues to how the application was used could be extracted from such a log. Events such as applications start, application end, object attached and so on was being logged as separate lines in a log file. A database was created for further development. The log grew rapidly, and having the query functions of a database would make working with the data easier. The database was made using MySQL and an overview can be seen in Figure 17. This overview also has a high score table. In further development this would be used to store the score of the users, as the application work in a game-like manner. Implementation of the database functions was planned solved using ODBC in C++. The logging functions was implemented using a class, and a parameter decided if it would write to a file or to a database. All code for writing to a file is implemented, and the ODBC can easily be implemented later. As mentioned logging could be useful when looking at data from test sessions. As it would reveal crashes and what kind of events happened before the crash. I.e if a session has has a "Start Application" event, but no "End Application" can be found, this is implies that the application did not end properly. Analyzing the events happening before would make debugging easier.

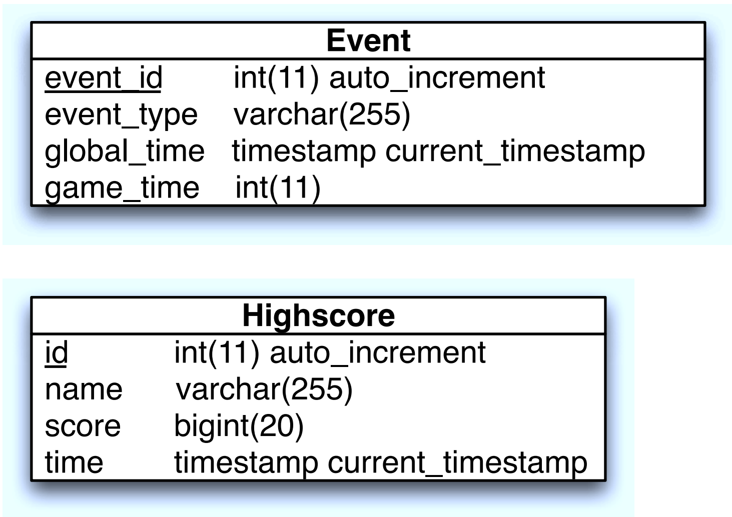

Figure 17: Overview of Database

5.5 Demonstration of Implementation

This section will demonstrate the functionality that has been implemented in the prototype. Screenshots from the application are shown and explained. In Figure 18 and Figure 19 an example with five countries, Norway, Sweden, Finland, Denmark and Germany are shown. The figure shows (1) Countries are scattered around, and are not attached to any marker. (2) Sweden is attached to a cube marker. (3) and (4) Norway is attached to a flat marker. (5) Norway and Sweden has been joined as a group on the cube marker, and Finland is now attached to the flat marker. (6) Finland joins the Norway and Sweden group. (7) Cube marker is covered for 3 seconds, and the group is now de attached from the cube marker. (8) Germany is attached to the now free cube marker, and Denmark attached to flat marker. (9) Germany and Denmark joins as a new group.

As can be seen the basic dynamics of the puzzle game is implemented. However at this point no calibrated workspace is used, and neighboring countries can be attached at any side. Meaning Sweden can be attached to Norway even if it is brought close Norway on the west side. The framework is working, and more development on refining and adding more interaction types are the most important parts remaining. At this point a number of 3D formats can also easily be placed on a marker, meaning new content can be added flexibly.

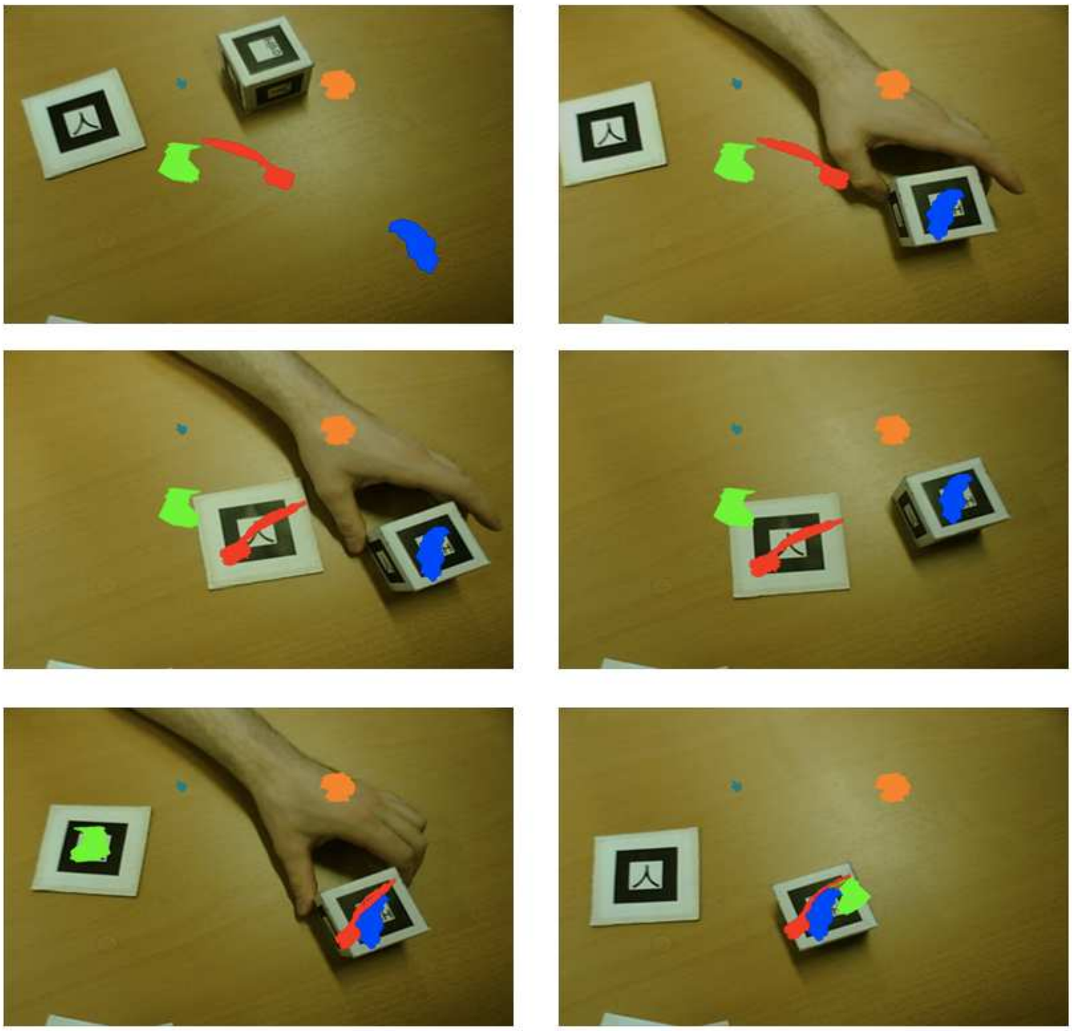

Figure 18: Screenshots from application

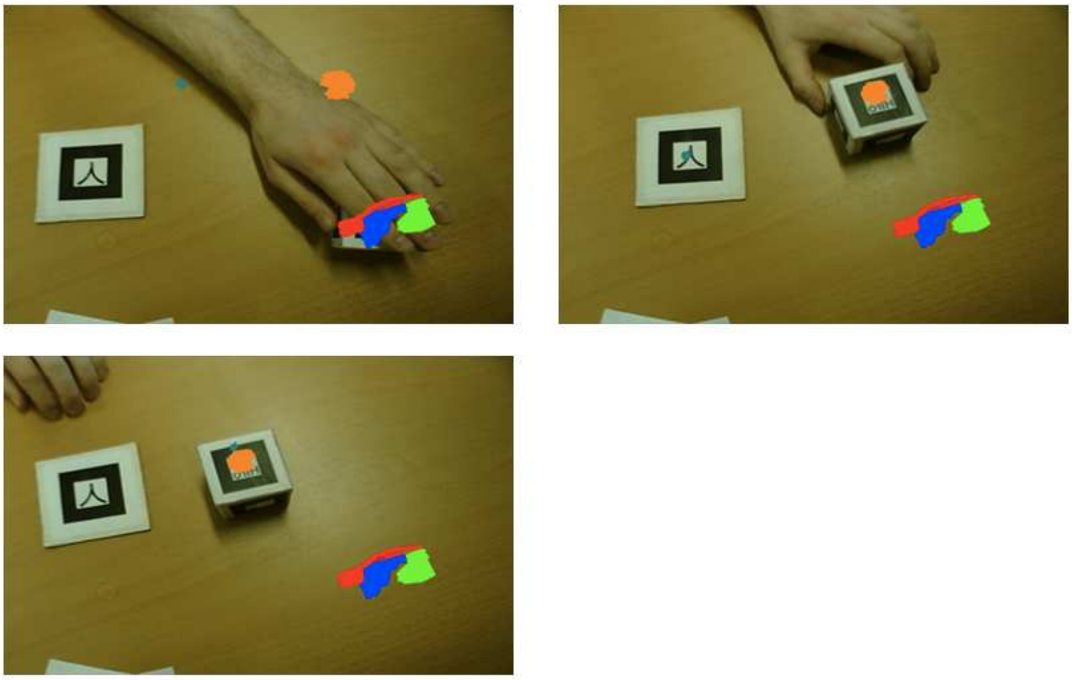

Figure 19: Screenshots from application

6 Results

6.1 Prototype Test

A pre-project test was conducted the 14th of December. This was a simple test to try out the setup, and see how the pupils would react to the AR technology.

Four groups consisting of two students each were tested in this initial design. A MacBook was set up for showing a simple 3D model of the Eiffel Tower. The students initially did short interactions with this to. The next thing that was done was to test out the prototype using a flat marker for showing some different 3D models. At testing time there were four models to show, a cookie, the statue of liberty, an elephant and a model of a cathedral. After some interaction with the flat marker it was changed with the cube markers.

Initially a form with five questions had been created. However at testing time the questions were not that relevant, so a more informal approach was taken. Questions were asked as they were suitable and notes were taken. What was done with all groups was asking them to compare the three different approaches and how easy they were to use.

6.1.1 Observations made

Three of four groups ranked using the lap top and a mouse to look at the 3D models the worst, flat marker slightly better, and the cube best. One group did not like using the flat marker and also reckoned it was just as good navigating with a regular mouse as using the cube. The first group had a nice comment, they said they would like "a bit more action". All groups mentioned that they would like the models to be able to move around. So animation might be an important point concerning further development. At the moment only static models are loaded. Further one group stated that it might be fun to create things using the system. So that they could place objects around, get a new one and place that one. The other groups showed indications of wanting to be able to interact more, not just show models. For example group one was looking at the elephant model and wanted to be able to cut it in two, so they could see what was inside it. Most of the pupils indicated that they used computers frequently, and were fairly competent in doing this. When talking about using the cubes they said it was really easy, and something anyone would be able to do. They also seemed to enjoy being able to actually hold and directly interacting with the objects. One of the pupils said that it is much easier to learn when something is fun to do. Of the negative things was that the tracking of the cubes were not very stable , so some jittering, or shaking of the model was present. At this point it was hoped that the cube markers might result in the markers not being obscured as often. However as mentioned earlier this test revealed that this was not the case, even with more markers to track the markers got regularly obscured so the 3D models disappeared. These were important observations that was considered and fixed in the later development stage. The prototype was a simple application for showing 3D models on cube markers or flat markers. No interactions were implemented at this point. So it was expected that some comments around this would be given. Some points on improving the work space setup also became apparent. Introducing an additional light source for the work area would be important, because the lighting conditions in the room the prototype was set up was not good enough, which lead to poorer marker tracking than usual. In addition for this setup the camera was placed quite high and only focused down at the workspace, meaning that the magic mirror effect being described earlier was not present. Providing that setup would map the interactions with the cubes and marker more directly to the projection, making it easier to interact.

6.2 Results from Questionnaires

Unfortunately no further user testing on the 6th graders could be conducted because of time issues. This reason for this will be further discussed in Section 7.1. The questionnaire made for the teachers was also sent by mail to the involved teachers, and was made available online through the Limesurvey system. Several mails was sent for encouraging answers, however no answers were ever registered in the system.

7 Discussion and Conclusions

Section 7.1 gives a short discussion of the experiences made during the thesis. In Section 7.2 the research questions will be answered and conclusions will be made.

7.1 Discussion

This thesis is built on a solid theoretical fundament. Development of the application was hoped to be swifter than what it turned out to be. The two frameworks used were documented, however not sufficiently, as many parts were lacking documentation properly explaining how functions and classes should be used. This slowed down the development speed, as much time had to be used for figuring out how the frameworks should be properly used, rather than making progress on the application. In addition the manual connection between ARToolKit and OpenSceneGraph took more time than expected. As the early prototype was discarded, it also took time to get back to same functionality that was offered by this. Important parts and interactions have been implemented, and it has enough functionality to actually be tested. However it had flaws that would greatly decrease the user experience of the application. Because of this it was decided to skip this test, as the data it would produce would be of low quality. Having this data could confirm or deny the theories introduced in Section 2. Because of the lack of empirical data, the conclusions made are based on the related work, observations from the initial test, as well as the experience from the development period.

Most of the previous work that has implemented has concluded with that the users generally enjoyed using their systems. However as these studies have not been conducted over a longer period of time, what is called the measurement and observer effect as well as the Hawthorne effect should be taken into consideration. The behavior of the people involved might change due to the fact that they are being observed. The Hawthorne effect showed that people improved their productivity, because of the interest shown in them. No matter what adjustments were made, the results seemed to improve. However when the study was concluded the results went back to normal again [48, 49]. This is not mentioned for implying that the results given in the previous work is faulty or wrong, however it is something that should be kept in mind when testing and working with novel technologies.

The next section starts answering the research questions and concluding them, before giving a more general conclusion.

7.2 Research Questions and Conclusions

1. What are the possible advantages of collaboration in learning?

The first advantage that has been pointed out is that when people of different developmental levels collaborate, people at a higher independent level can help others to solve tasks that are usually at a higher level than what their independent problem solving usually allows them to. This was reviewed in Section 2.3 and are considered as reliable and classic theories. As the size of classes grow, it means that the teachers attention has to be divided among a large number of pupils. The teachers will traditionally assist the pupils into solving problems that are at higher level than what can currently solve. However other students should also be used as resources, as there will always be a natural distribution of the students current level. Meaning that students might be equally suitable in bringing fellow students to the next level.

Section 2.5 argued that collaboration tend to give students higher intrinsic motivation for solving goals. This leads them to strive harder to solve the goals before giving up compared with working individually or competitively. When individual review tests where given there were no difference between students who had worked individually or had been cooperating. However the students who had worked in a cooperative fashion tended to be more successful in applying their knowledge in problem solving. Taking advantage of collaboration seems to lead to a better practical understanding of subjects, in addition since the resources, in form of teachers, nowadays are being spread thin across a larger group of students, collaboration has the potential to develop students without relying solely on the input from the teacher. As the tested application worked with one input device at a time the collaborative aspects was not captured in these results. In addition if the more advanced application had been tested it would still be difficult to prove effect of collaboration from the empirical results. This means the conclusion is based on the related work.

2. Can augmented reality applications encourage collaboration among students?

Section 2.5 stated that children might not have the necessary skills for collaborating efficiently. Supplying manipulable objects are important for children's collaboration. It is also stated that presenting abstract concepts in a narrative way is useful for children. Augmented reality provides the manipulable objects that children need for efficient collaboration. Abstract concepts can also be presented using AR. Presenting something in a narrative way is not something that is typical for the AR technology, but nonetheless is no problem implementing in an application. Previous work using AR was presented in Section 2.1.4 and introduced applications that had a more narrative focus. In addition the monument placement application introduced in Section 4.3, suggested presenting a narrative when correctly placing a monument.

One of the positive aspects of AR is the low threshold for being able to do interactions. Objects can be directly manipulated without any intermediate interface. Section 6.1.1 stated that the children involved in the early test phase seemed to agree that interacting with the 3D objects through either a flat marker or a cube was easy, and something anyone could do without the need of training. This is positive in the context of collaboration, as it is able to involve anyone. Students should not be left out of the collaboration activity because they lack the technical skills for doing this. [35] also expressed the importance of providing lightweight interactions so that interactions can be done without much effort. This allows the students to concentrate on the activities and trigger discussion and collaboration rather than having to concentrate on interacting correctly with the system. Based on the early feedback AR seems to offer many of these capabilities, if implemented using best practice.

3. Can an AR application take into consideration several learning styles?

Supporting all of the different learning styles at the same time is a difficult task. Augmented reality however is a flexible technology, based on how an application is implemented almost any learning style can be supported. Some applications might support visual learners more than verbal learners, and opposite. It is however important to note that some work methods are used more than others in a school day, so the main objective should be to make applications that supports the learning styles that are not that common in the daily school work.

Based on the observations from the test the involved students made some statements that supports the belief that AR is suitable across several learning styles. For example one group wanted to open up the elephant model and look at its' inside. While another group expressed the desire to placing objects and building something. A solar system was also mentioned and wanting to explore this. These different suggestions seem to fit into a variety of the learning styles introduced in Section 2.4. The students were being provided with the same technology, but seemed to suggest quite different actions they wanted to do with it. This suggest that augmented reality can form the basis for a wide array of actions taking into consideration the different learning styles.

4. Does having a public display and work space support discussion and collaboration?

It has been expressed that one of the problems with collaboration on a personal computer is that it is meant for personal use. The input devices provided are one of the biggest problems. Natural ways of collaborating and discussing often uses coherent interactions, the interactions are done parallel and overlapping. However it is not enough to simply have a distributed control system. Important aspects were mentioned in Section 2.2.1. Concepts such as *non-fragmented reality*, *lightweight interactions*, *configurable material* and *externalization* are important to consider in collaboration. It is important that everyone sees the same and that any interactions that are done gives an immediate feedback so it is easy to understand what is going on. In addition being able to manipulate and re-order objects, and also making this visible and easy to understand are key aspects. By following these guidelines coherent interactions are supported in a way that is familiar to the way it is done in the real world and will encourage the users to do it as well.

Section 2.5 introduced the fact that when people do face to face collaboration in a common space objects are used a props in discussions and for demonstration. There are many subtle aspects that are used in this context. Some aspects make things more convenient for a single person, while others establish personal and public work spaces within the work area. The placement and orientation of objects play a large role. The design implications being suggested also supports that this is not typically supported by a desktop computer. However AR technology offers a tangible way of interacting which inherently supports most of the design implications. The work on the importance of orientation mentions that little communications related to rotating or positioning of objects were done. This however does not imply that other communication is done. As can be seen a public display and work space offers many more possibilities than what individual devices could offer. In addition since the handles of the actions are space-multiplexed rather than time-multiplexed everyone involved has equal opportunities to do interactions and the sequential aspect is removed.

7.2.1 Conclusion

The answered research questions suggest that using AR in a learning situation can yield positive results. However it depends on how it is implemented, and implementation should be based on suggested design principles. The thesis is heavily supported by the related work and their theories. Little data was produced during the thesis' development period, due to time consuming programming. However the little data was obtained from the initial test supports the beliefs of the thesis. AR is an emerging technology that has started to rapidly evolve in to the commercial market and it is likely that we will a growth in the amount of applications using AR, also in education. AR has great potential and can offer effective and novel ways of learning if used with care.

8 Future Work

This chapter introduces further work that can be done to extend what has already been done in the thesis.

8.1 User Testing

The most important further work is to finish all the necessary implementations and refinements so that a user test on a fully functional system can be conducted. The introduced game experience questionnaire is to be conducted after the participants have tried the application. The user testing should be videotaped, and later analyzed to see if there are signs of of collaboration, cooperation, coordinated problem solving, and reflection. Getting reliable empirical results is therefore suggested as the most important extension of this work.

8.2 Content Generation

One of the positive things with providing a quite simple interactions scheme, is that it can be re-used for many topics. Organizing and putting different parts of information together is very common. Providing a GUI application that teachers can use to make their own material for the applications was discussed during the project as a possible extension. The puzzle metaphor has been focused on during the thesis, and this is something that could quite easily be implemented. For example if a teacher provides an image of something, the image can be divided into different pieces by a drawing mechanism. The different pieces can then easily be converted into polygons textured with the image. This could easily make virtually any picture into a puzzle.

8.3 Expressive Applications

In this thesis the focus has been mainly on explorative applications rather than expressive applications [50]. Looking into more expressive applications is something that should be done. Especially since the focus has been on collaboration, and expressive applications can be used for producing and building different representations. For example architectural design where direct manipulation can be used is some of the potential TUIs and AR can provide [51, 52].

It has been mentioned earlier that importing geographical data from a KML file could quite easily be imported to OpenSceneGraph and further be placed on markers. This shows that augmented reality can be useful outside just a learning situation. Research has looked at making 3D environments more attractive for non-experts by providing a more tangible approach. This can also be used in a learning situation, but has potential in many other situations as well.

8.4 Adding Physics

Because of the suggested calibrated workspace a next step that would improve the applications would be to add physics. At this point the different objects float statically around in the air, which is not the way real world objects behave. A first step would be to make objects that have been put in the air would actually start falling down until they hit the workspace surface. Open Dynamics Engine (ODE) offers capabilities such as this `http://www.ode.org/`.

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A Initial Interview with Nina

1:40
Nina: I have a student, pupil, he is eleven, he really needs this visual thing to imagine and to learn. So that is why I was eager to be in this. To get some ideas how to do things differently for him to learn more.
12.00
Nina: That would be nice for every pupil to see , not only for the very visual kid and the other with special needs. I always look for ways for them to learn more. They were my idea, to go into this project, my pupils with special needs. But this would be so nice for everyone.
Simon: Well yeah, and working with kids with special needs is a good area for this. Because it provides a different interface.than the computer.
Nina: And thats what we always are looking for, how can I attack this in another way than I usually do.
Simon: Certainly the tangible, touch something to make stuff interact is something that some of those kids will work better with.
19.10
Nina: This one kid, we had him tested, and they said that we really need to visualize. Because what we just speak about, if he has no pictures, he can't imagine himself what we talk about. That's also something that every pupil need...
Simon: might benefit from.
Nina: We tend to speak and speak, I have my images in my head about everything, because I'm a grown up, I've seen this and learned about for years. This is new to them, and sometimes we shoot over their heads. Demanding they can imagine things they are not qualified to imagine at all. To visualize is a good thing in teaching. Generally, not only for the kids with special needs.

B Observations from video

Tape 1: Part1
(At this point there are only 10 pupils present, they are divided in groups)
07:10 Teacher informs about camera
07:50 Tells about the plans for the day
08:50 about Religion, Islam, she will go through a text, they will be divided in groups, and there are 5 envelopes hidden around with 3 questions each, and the groups will try to answer the questions
11:30 They have a plan with goals of what they should have learned at the end of the day
14:00 Goes through the text
18:30 Delivers out the same text to the pupils in paper form, two versions, one short version as well
19:20 Goes through another text
21:30 Delivers out another text
22:10 The pupils are divided into three groups
23:00 Groups collaborate on the delivered texts, before the "treasure hunt" starts
25:00 Groups will be scored on the result from the "treasure hunt", winner is promised a prize
31:00 hints on where the envelopes with questions are hidden are given
33:00 Groups have to deliver back the texts they were given
34:00 Treasure hunt starts
35:00 groups are going around searching for and answering questions
42:00 Hints about locations are given underway when they have problems finding them
Note: seems to be some excitement about the competitive aspect
54:00 Treasure hunt ends, teacher goes through the questions, pupils answer, scores are given to the groups as they go through
01:00:00 Scores are given
01:01:00 Break
Tape 1: Part2
New group seems to follow the same treasure hunt as the previous.
Also this group seems to like competing against each other
Nothing new going on with this group
Tape 2: Part1
(Whole class is present)
00:00 - 12:00 The children are sitting individually and working at their desks, very silent, people are whispering
12:00 One teacher gives some task about reading parts of a newspaper, they are reading for themselves
19:30 The whole class is gathering in front of the classroom

21:00 Giving information about class tomorrow, and talking about how to write an interview
28:00 Seems to go through the tasks they have to do in the different courses
32:00 gives instruction about the pupils to work on their own with the newspaper booklet for 25 minutes
33:00 Pupils start working
58:00 New gathering in front of classroom, asking the pupils what they have been working with the last 25 minutes
01:00:00 Questions from teacher, pupils answer
01:08:30 Physical activities, pupils can choose between playing football or go for a walk
01:11:00 Everyone goes out
Tape 2: Part2
Nothing happening, pupils are outside

C Questions for Teachers

Introduction

This is a questionnaire given concerning what activities are done in a typical school day. As well some thoughts if some methods used in teaching have an especially positive or negative effect. All the questions are answered in free text form, any thoughts are valuable. There are 15 questions in this survey

Part 1

1. How much attention is given to presenting material focused on different learning styles?

2. What kind of activities happens during a normal school day?

3. How important do you think student motivation and enjoyment is to successful learning? How do you feel this influences the student learning?

4. For the more abstract concepts, how much time is spent on visualizing the concepts, and how useful is this for the students?

5. As a follow up to the previous question, how are physical (tangible) objects used to represent concepts?

Part 2

6. Are games used in teaching? In that case, what kind of games?

7. Is group work and collaboration among students often used? What are your impression of the positive and negative aspects around this?

8. Motivation is important when learning. Are there anything special that seems to give pupils more motivation than other activities?

9. What is your impression of how pupils gains the best understanding of a topic? Do some activities seem more effective than others?

10. What is your impression of explorative learning versus specific problem solving tasks?

Part 3

11. When talking about group work again, are there something that you think are important for encouraging pupils to work together?

12. Are computers used in a typical school day? What are they used for?

13. Does the school have access to digital learning material? Is this something that is used, and what is your impression of the availability of this material?

14. Are computers used when pupils are collaborating? How does this work?

15. Do you have any other thoughts that might be related to the topics brought up?

D Game Experience Questionnaire

Immersion
1. I was interested in the game's story
2. It was aesthetically pleasing
3. I felt imaginative
4. I felt that I could explore things
5. I found it impressive
6. It felt like a rich experience

Flow
7. I felt completely absorbed
8. I forgot everything around me
9. I lost track of time
10. I was deeply concentrated in the game
11. I lost connection with the outside world
12. I was fully occupied with the game

Competence
13. I felt skillful
14. I felt strong
15. I was good at it
16. I felt successful
17. I was fast at reaching the game's targets
18. I felt competent

Tension
19. I felt tense
20. I felt restless
21. I felt annoyed
22. I felt irritated
23. I felt frustrated
24. I felt pressured

Challenge
25. I felt that I was learning
26. I thought that it was hard
27. I felt stimulated
28. I felt challenged

29. i had to put a lot of effort in to it
30. I felt time pressure

Positive Affect
31. I felt content
32. I could laugh about it
33. I felt happy
34. I felt good
35. I enjoyed it
36. I thought it was fun

Negative Affect
37. I thought about other things
38. I found it tiresome
39. I felt bored
40. I was distracted
41. I was bored by the story
42. It gave me a bad mood