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ENHANCING LEARNING EXPERIENCES WITH AR AND VR TECHNOLOGY

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BACHELOR'S THESIS | ABSTRACT

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ENHANCING LEARNING EXPERIENCES WITH AR AND VR TECHNOLOGY

As the virtual and augmented reality technology is becoming more accessible than ever before, the interest of integration of such technologies into modern learning environments is growing among educational institutions. Virtual and augmented reality technologies allow students to experience immersive educational content in any subject, improving their concentration power and allowing for detailed exploration of various learning topics.

The aim of this thesis was to examine what virtual and augmented reality technology offer for enhancing the quality of learning and to give insight into the practices of virtual and augmented reality application development.

The thesis explains the basic guidelines, tools and principles behind virtual and augmented reality application design and development. The thesis also tells about the development practices of an augmented reality application, designed to enhance navigation activities in Yli-Maaria School (Moisio Unit) together with a Helsinki based company Zoan Oy and Turku University of Applied Sciences as part of the Smart Learning Environments for the Future project, which is funded by European Regional Development Fund (ERDF). The project was built on Unity game engine and utilized Vuforia augmented reality software development kit.

The test results of the application suggest that both virtual and augmented reality technologies have great potential in the educational field by having a substantial positive impact on the quality of learning.

KEYWORDS:

augmented reality, virtual reality, technology, education, learning environments, learning experience

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KOULUTUSKOKEMUSTEN PARANTAMINEN AR- JA VR-TEKNOLOGIALLA

Virtuaalisen ja lisätyn todellisuuden tekniikan saatavuus on kasvanut ja on suurempi kuin koskaan ennen, minkä vuoksi oppilaitokisissa on kasvanut kiinnostusta integroida tätä tekniikkaa nykyaikaisiin oppimisympäristöihin. Virtuaali- ja lisätyn todellisuuden tekniikat antavat opiskelijoille mahdollisuuden kokea minkä tahansa aiheen opetussisältöä parantaen keskittymiskykyä ja mahdollistaa erilaisten opintoaiheiden yksityiskohtien tutkimista. Näiden tekniikoiden sovellusten suunnittelussa ja kehittämisessä käytetyillä menetelmillä on monia samankaltaisuuksia pelien suunnittelun ja kehittämisen menetelmien kanssa.

Opinnäytetyön tavoitteena oli selvittää, mitä virtuaalinen ja lisätyn todellisuuden tekniikka tarjoaa oppimisen laadun parantamiseksi, ja antaa tietoa virtuaali- ja laajennetun todellisuuden sovellusten kehittämisen käytännöistä.

Opinnäytetyö selittää virtuaalisen ja laajennetun todellisuuden sovellusten suunnittelun ja kehittämisen suuntaviivat, työkalut ja periaatteet. Opinnäytetyö myös kertoo laajennetun todellisuuden AR Adventure -sovelluksen kehittämisestä. Sovellus on suunniteltu suunnistusaktiviteettien parantamiseen Yli-Maarian koulussa (Moision-yksikkö) yhdessä Helsingissä toimivan Zoan Oy:n ja Turun ammattikorkeakoulun kanssa osana Tulevaisuuden älykkäät oppimisympäristöt -hanketta, jota rahoittaa Euroopan aluekehitysrahasto (EAKR). Projekti rakennettiin Unity-pelimoottorilla ja työssä hyödynnettiin Vuforian laajennetun todellisuuden ohjelmistokehityspakettia.

Sovelluksen testituloksien perusteella on päädytty siihen, että sekä virtuaalisella että lisätyn todellisuuden tekniikoilla on suuri potentiaali koulutusalalla sillä on huomattava positiivinen vaikutus oppimisen laatuun.

ASIASANAT:

lisätty todellisuus, virtuaalitodellisuus, tekniikka, koulutus, oppimisympäristöt, oppimiskokemus

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LIST OF ABBREVIATIONS (OR) SYMBOLS

VR	Virtual reality
AR	Augmented reality
GPS	Global Positioning System
2D	Two-dimensional
3D	Three-dimensional
HMD	Head mounted display
RF	Radio frequency
UI	User interface
UX	User experience
API	Application programming interface
SDK	Software development kit
PC	Personal computer

1 INTRODUCTION

Augmented reality (AR) and virtual reality (VR) are technologies that are attracting attention among companies of various fields. Both technologies have brought new ways of experiencing media content, which can bring benefit to various processes. The education industry plays a major role in bringing innovative ideas and products to learning processes. The applications using these technologies typically run on game engines, which makes various levels and areas of knowledge of game development a great benefit in developing or maintaining applications or games for such platforms. This thesis aims to provide a detailed look at AR, VR and game-engine based technologies and their possibilities in education. The study will examine the current examples of AR and VR technology usage for learning and analyze the process of AR and VR application development. The thesis will discuss different approaches of the design of learning applications in detail.

The developed application that backs up this study is AR Adventure, which is a gamified mobile application played on tablet computers that is based on augmented reality technology. AR Adventure was designed to add an interactive layer to school children navigation activities using augmented reality technology and location-based game mechanics. The application was developed based on feedback from children in Yli-Maaria School (Moisio Unit) together with a AR and VR specialized and Helsinki based company Zoan Oy. The project was developed in Turku Game Lab, a joint working environment of University of Turku and Turku University of Applied Sciences. The developed application was part of the Smart Learning Environments for the Future project, which is funded by European Regional Development Fund (ERDF).

The author’s role in the project was to figure out what was necessary to develop the game and to utilize any skills that would be needed for the development. The author led the development team as a project manager and programmed the core functionality of the application. The flow of this thesis begins by explaining what AR and VR technology is, and proceeds by giving a brief introduction how the technology is currently used in the education field by giving insight into real usage cases and statistics. It will then cover the basic guidelines, tools, concepts and principles behind virtual and augmented reality application design and development. The thesis will use the acquired feedback of the practical testing to conclude the effect of the application on the learning experience.

2 AR TECHNOLOGY

Augmented reality adds virtual elements such as 3D objects or multimedia content onto real-world images, providing new possibilities to interact with the user. There are many ways digital information can be connected to the real world. One of the most typical ones is using a special tracker or marker, that has unique elements such as clear shapes and colors. There are other methods as well, such as GPS (Global Positioning System) location pinpointing. Augmentation happens in real time in the real environment. In some cases, augmented reality uses cameras and sensors, collecting data about the user's interactions within the session and sends that data for processing (Volna, 2019).

There are many ways to experience AR technology. This experience relies both on the hardware and the different ways of how AR technology can be utilized through software. According to International Data Corporation (IDC) (2019), the main types of devices that run AR applications are handheld consumer devices such as smartphones or tablets. It is possible to experience AR through an AR headset device, although they are largely enterprise focused, as most consumers already own smartphones or tablets for the basic AR experience.

Figure 1. Popular AR game Pokémon GO (Jansen, 2019)

AR can be used in many ways, such as enhancing learning experiences or problem solving in medicine. Marker-based AR has been used used in factories to help instructing

workers with various workflow guidelines, for example. Some museums take advantage of marker-based AR by teaching history and bringing historical art to life (Pärnänen, 2019). The augmented reality technology that is used on smartphones and tablets can be separated into categories. There are several types of methods of utilizing AR technology in mobile games and applications: marker-based AR, markerless AR, location-based AR, projection-based AR and superimposition-based AR (Poetker, 2019).

2.1 Web-based AR

Web-based AR, or WebAR, is a method of displaying AR content without the need of installing an application on an AR capable device. Web-based AR only needs a camera and a web browser to function. This also means that there is no need to send software updates to the end-user, as all the functionality and data is stored on a separate server. The main benefit of web-based AR solutions is that the content can be viewed much quicker and easier, making it a great marketing and advertisement tool. Web-based solutions can be divided into self-contained computing and computing outsourcing. In a self-contained method, the computing is done on the user's device, where as in cloud computing, everything is done over the cloud servers. It means that cloud computing requires more data transfer compared to the self-contained method. The advantage of cloud computing however, is that it makes the user device computing performance less relevant, since all of the computing is done on the server. Some AR applications, such as the popular game Pokémon Go, uses a method, where both back-end and the user device are working together, in order to bring positional data from the cloud and placing the Pokémons on the map (Pärnänen, 2019).

2.2 Marker-based AR

Marker-based augmented reality is the most advertised AR technology. Marker-based AR utilizes special markers, sometimes with unique patterns, such as a QR (Quick Response) code, in order to project 3D objects. These objects are then 'tied' to that real-world special marker and are positioned relative to it (Poetker, 2019). Marker-based AR is often also known as ID-based (Identifier-based) AR. The identifier or marker data is always given to the AR device prior to usage (Pärnänen, 2019). This AR method is used in the AR Adventure application.

Figure 2. Marker-based AR application (Volna, 2019)

2.3 Markerless AR

Markerless augmented reality is essentially the usage of location-based or position-based tracking, that utilizes GPS, a compass, a gyroscope, or an accelerometer to then provide that data for AR processing. The data determines what AR content you find in a certain area. It is more versatile, in the sense that it allows the user to decide the placement of the AR object which is to be displayed. This allows the user to experience the content completely digitally in almost any type of environment. This method is typically used in various mobile applications for smartphones or tablet computers, although the lack of important components like GPS on some tablets can affect the position acquisition, which leads to poor performance of AR projection. Most often markerless augmented reality is used for purely business info, but it can sometimes also be used for games depending on the design and objectives of those games (Poetker, 2019).

Figure 3. IKEA augmented reality application (Volna, 2019)

2.4 Location-based AR

Location based augmented reality tends to tie the content and experience to the location of the user or a specific place. The locations of the objects that could be mapped out in a way that when the user reaches a mapped destination, the application would display any related information to the location, for example (Poetker, 2019).

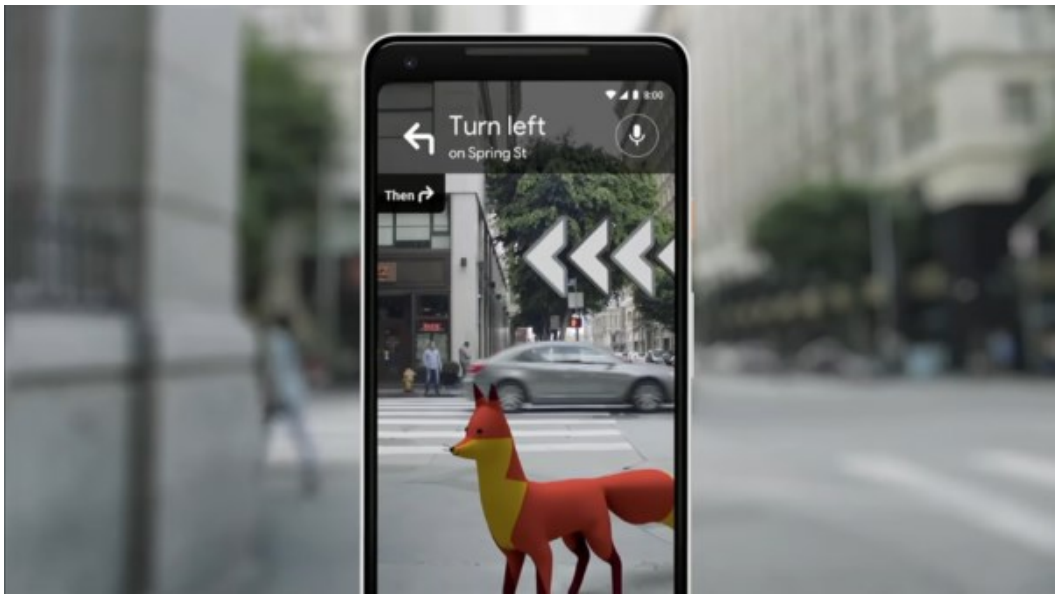

Figure 4. Google Maps can display data on top of the real world (Volna, 2019)

2.5 Superimposition AR

Superimposition AR attempts to recognize an object in the physical world and basically duplicate it. This allows the user to place or rotate the duplicated virtual copy of a real object in the real world. This type of AR could be useful for space management for example. The user could take a real object that isn't modelled in a special 3D software to see if the surrounding area would be enough to place more objects of the same dimensions (Poetker, 2019).

2.6 Projection-based AR

Projection-based AR differs from the other types of AR in a way, where a mobile device would not be needed, and instead the information would be projected with light on any type of surface. This type of AR would create an interactive experience essentially using holograms (Poetker, 2019).

Figure 5. 3D objects are displayed by projecting light on a table (Poetker, 2019)

2.7 AR mobile games

As mobile phone ownership has grown to an enormous extent, mobile phone manufacturers figured that mobile devices could be more than communication tools. More and more of these devices included extra apps, like calculator or notes, and slowly even games had emerged on mobile devices. Entertainment companies started developing specialized devices for gaming. Such devices had special controls for the specific functions for games. Today, almost every type of consumer aimed mobile device has the capability of running games. This includes mobile game consoles, smartphones, tablet devices and surprisingly, even smartwatches. AR is a technology that is most used on handheld mobile devices, thanks to the low hardware requirements of this technology. This creates great possibilities for mobile games to use this technology, creating interesting and immersive gaming experiences. Usually these games use the camera of a mobile device to scan the environment around the player to display data or interactive 3D objects on the display.

2.8 AR Glasses

In September 16, 2020, Facebook announced that it is working on a pair of glasses, that add a 3D layer of contextually-relevant information on top of the real world. According to Facebook, this type of device, generally known as AR glasses, can become a very helpful tool that allows us to perform everyday tasks better. While the product itself may be still in the works, Facebook has developed a research tool to help understand how to build the needed software and hardware for the actual AR glasses. The tool is called ”Project Aria”, which is a pair of glasses with built in sensors, which capture video and audio data from the wearer’s point of view, and send that data to Facebook engineers and programmers to give feedback on how the AR can work in practice. The device does not have any kind of display technology at this point (Facebook, Inc., 2020).

Protecting people’s privacy is a priority for Facebook in developing AR glasses. Facebook claims that researchers who wear Project Aria, instructing them where they should and where they should not be collecting video and audio data. Facebook also says that recording this data will be done transparently, meaning the people wearing the device will need to wear clothing that identifies them as participants of the research study.

Figure 6. Project Aria (Facebook, Inc., 2020)

In Apple's fiscal first-quarter earnings call in 2020, Apple CEO Tim Cook stated that augmented reality is gaining traction in both enterprise and consumers. For years, Tim Cook has been saying that augmented reality will play an important role in our future, hinting at Apple's involvement of developing a rumored AR glasses device (Eadicicco, 2020).

3 VR TECHNOLOGY

An article by Martín-Gutiérrez et al. (2016) explains Virtual Reality (VR) technology to be a simulated reality that is built using computer systems. Visualizing such alternate reality would require powerful hardware and software to display a realistic and immersive experience to the user. The hardware that is used to visualize this immersive experience is commonly a combination of a head mounted display device and input devices. Head mounted display (HMD) (Figure 7) can usually be a virtual reality headset with integral displays for each eye, either as an extension for a desktop PC (Personal Computer), or as a standalone device with it's own processing power. It can also be a smartphone with a special mount to wear it as a headset to simulate virtual reality using sensors on the smartphone.

Figure 7. Popular Head Mounted Displays (Extraordinary Technology, 2020)

The most popular input devices for VR currently are usually a pair of controllers (Figure 8), which use dedicated Lighthouses, beacon devices that emit infrared light to the HMD and controllers. The HMD and controllers have built-in sensors that receive these signals for determining the position and rotation of the HMD and both controllers (Malventano, 2016).

Figure 8. Example of VR controllers (VRrOOm Ltd., 2016)

Input devices play a crucial role in creating an intuitive VR experience. Many companies are actively working on extending and improving the range of interactivity to make the experience both, more precise and easier to use. One of such companies is Leap Motion, which developed an alternative way of interacting with the virtual world, where the user does not require a physical controller, and can instead use hand and finger movement to do actions in VR. Another example is Valve's new Index controller, which is a hybrid between gesture tracking and a physical controller. The Index controllers allow the user to get into more in-depth usability, while having precise hand tracking using more usual VR base stations.

Tracking is an essential part of the VR experience. VR technology is constantly advacing, standalone head mounted display technology is improving, sensor technology gets more accurate and other quality of life features are becoming reality, such as wireless data transfer between the computer and HMD (Figure 9). An example of a wireless VR setup

would be a setup, where the HMD and the controllers receive radio frequency (RF) signals from two or more Lighthouses.

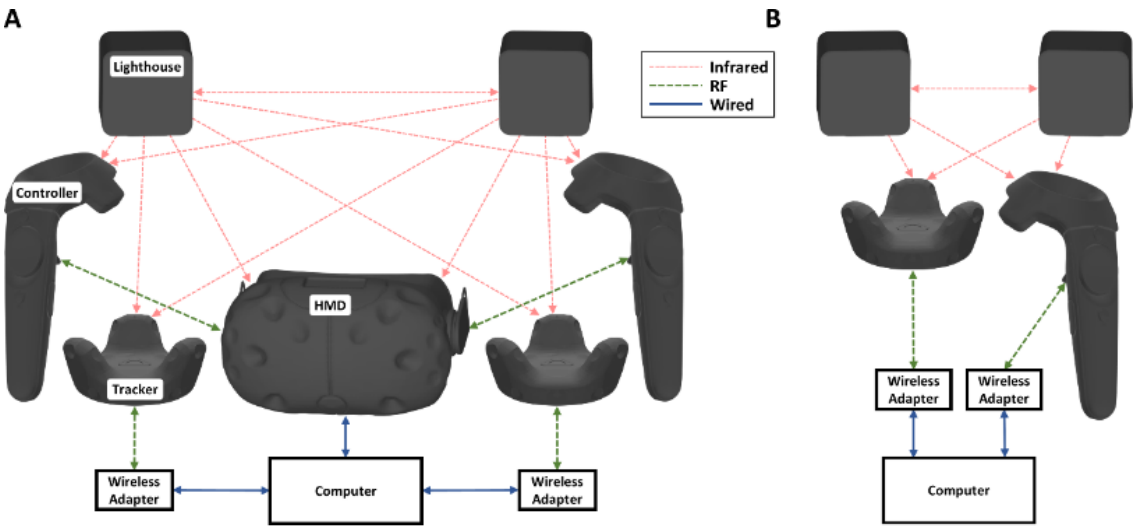

Figure 9. Example of a wireless VR setup (Clinel et al., 2018)

Tech companies actively work on ways of improving the tracking precision and technology. In May 21, 2019, Oculus released its standalone VR headset Oculus Quest (Murphy, 2019). The headset featured technology called ‘Oculus Insight’, which provided inside-out tracking using ultra-wide angle sensors and computer vision algorithms. This technology provided room-scale VR experience and did not require any external sensors, making the setup process much easier (Oculus VR, 2018).

4 USAGE OF AR AND VR IN EDUCATION

4.1 AR/VR Market and Accessibility

A study by Huang et al. (2019) stated that devices with AR and VR support are becoming more accessible than ever before with the wide adaptation of smartphones around the world and the introduction of low-cost consumer VR headsets such as Samsung Gear VR, Google Cardboard, Google Daydream, Oculus Quest and Oculus Quest 2. The study not only concludes that there is a huge potential in portable and cost-effective AR and VR technologies, which are provided by smartphone-based mobile applications, essentially providing students with a whole new educational reality, but also hints at weaknesses that are to be considered when dealing with the integration of such technologies to learning environments.

According to an article by Markopoulos et al. (2019) the virtual reality market seems to be growing rapidly in Europe. The article states that in 2018, virtual reality market was expected to grow to a value of $12.1 billion, and into $95 billion market by 2025. Even though education is currently the smallest share of the VR/AR market share (Figure 1), both virtual and augmented reality technologies seem to be promising technology in general.

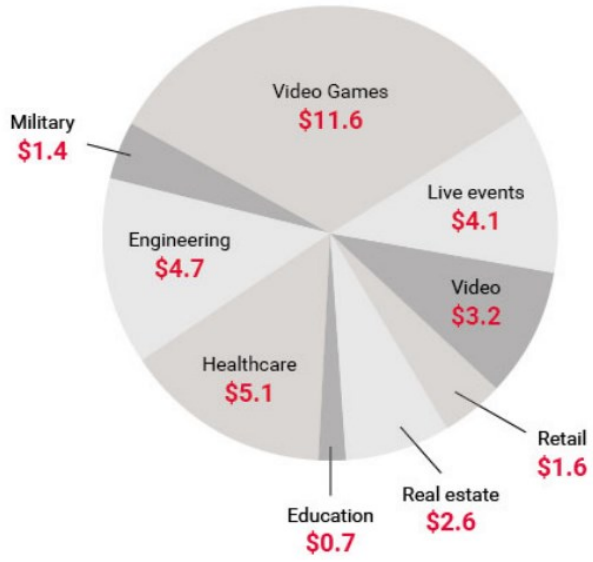

Figure 10. Expectation of 2025 AR/VR Market share (Cobos, 2017)

AR and VR can both be experienced on many types of devices. While AR can be easily experienced on popular consumer devices such as smartphones or tablets, advanced VR can be more complex and may require special hardware such as a headset with built in sensors for tracking. According to a report by International Data Corporation (IDC) (2019), the shipments of VR headsets are expected to reach 36.7 million units in 2023, and AR headset shipments to reach 31.9 million units also in 2023.

4.2 Growing interest in AR/VR in education

Transferring knowledge to next generations requires brand new methods and approaches. An article by Rawal (2018) stated that augmented reality app development is a trend that is being followed by the education industry. Schools and colleges are interested in changing the traditional ways of teaching. Rawal (2018) states that virtual and augmented reality technologies would revolutionize the methods of teaching and learning, and that visualizing a subject is more effective than explaining or reading about it. Visualizing topics help students understand the details and insights of the topic, offering interactive experiences. Augmented reality allows students to stay interested and excited in the topic. Just as AR, VR can also heavily affect the world of education. VR allows students to see educational content immersive in any subject. It improves their concentration power and allows for detailed exploration of the learning topic provided by teachers. VR provides a complete sensory experience and content, that students can experience virtually with touch, see, and hear. AR and VR are very similar in their educational potential. The main difference is that AR is still somewhat more accessible to schools and other educational institutions, since AR can be used on already existing school mobile devices, such as tablet computers (Rawal, 2018).

4.3 Current usage of AR and VR in education

Currently there are many applications or games that utilize AR technology for learning purposes around the world.

A good example of **Augmented Reality** usage in learning is Quiver Education, a mobile application that uses coloring pages as markers, which activate augmented reality content when scanning the markers. This makes the application to well suit younger age groups. These coloring pages are first printed, then colored and scanned by the

application to form a 3D visualization of the colored painting using augmented reality. This improves users motor and hand-eye coordination skills (QuiverVision, 2019). Visualizing education material makes it an effective way to communicate ideas to the learner. It aids the learner to understanding a concept or a problem. Such application lets the learner not only see a 3D visualization of a likely unseen concept or a problem, but also brings the immersion to a new level by animating the concept or a problem, and placing the visualization in the learner's local space (Shatr & Buza, 2017). Because of these benefits, the AR element of the application helps the students to get better results in understanding the subject because of the higher student engagement and interest that AR creates (Chalimov, 2020).

Arloon is also a great example of how AR can be used for education. Arloon is a company that focuses on delivering AR apps that help the user to understand a variety of pedagogical topics. The Arloon Geometry app for example uses AR to display simple shapes on any real surface, which is aimed to improve spatial visualization by interacting with the figures. The user is able to view geometric shapes from every angle, and study the properties of prisms, polyhedras, bodies of revolution and pyramids (Arloon Geometry, n.d.). Arloon Plants is another app which uses AR to give the user a deeper insight into the life cycles and different species of plants. This app allows the user to choose a seed, which will eventually grow into a plant, that has to be taken care of in AR. The app is designed for primary education, tailored to students of age 8 or more. Arloon Plants is designed to develop skills such as learning the terminology of plant science, the biology of plants, as well as some linguistics for extending the vocabulary for different languages. The app practices AR usage to a great extent (Arloon Plants, n.d.).

There are some great points to why AR benefits education. According to ViewSonic (2019), Standford researchers have stated that AR inspires empathy in an individual, and that emotion, interactivity and engagement enhances the ability of students to remember learned information, which ultimately leads to faster learning. Augmented reality applications allow students to experiment in safer environments. For example, handling chemicals in real life would be less safe than experimenting with chemicals virtually. Financially, AR helps to save budget on expensive equipment for various pedagogical experiments. AR is a very cost effective tool to ground school children with knowledge (ViewSonic, 2019).

According to a systematic review of AR trends in education, Bacca-Acosta et al. (2014) have stated that AR has been applied mostly in higher education settings, with the intention to motivate students. The review concluded the following advantages of augmented reality in education:

- learning gains
- motivation
- interaction
- collaboration
- student engagement
- better learning performance
- positive emotions

The limitations of AR technology were following:

- difficulties maintaining superimposed information
- paying too much attention to virtual information
- consideration of AR as an intrusive technology

Bacca-Acosta et al. (2014) have provided data on which these conclusions are based on, by listing how many reported advantages around the world there are about the usage of AR in educational settings to back up each conclusion.

Table 1. Advantages of AR in educational settings (Bacca-Acosta et al., 2014)

Sub-category	Number of Studies	Percentage (%)
Learning gains	14	43.75
Motivation	10	31.25
Facilitate Interaction	5	15.63
Collaboration	6	18.75
Low cost	4	12.50
Increase the experience	4	12.50
Just-In-time Information	4	12.50
Situated Learning	3	9.38
Student-centred	3	9.38
Students' attention	3	9.38
Enjoyment	3	9.38
Exploration	4	12.50
Increase capacity of innovation	2	6.25
Create positive attitudes	2	6.25
Awereness	1	3.13
Anticipation	1	3.13
Authenticity	1	3.13
Novelty of the technology	0	0.00

Table 2. Effectiveness of AR in educational settings (Bacca-Acosta et al., 2014)

Sub-category	Number of Studies	Percentage (%)
Better learning experience	17	53.13
Learning motivation	9	28.13
Improve perceived enjoyment	4	12.50
Decrease the education cost	0	0.00
Positive attitudes	4	12.50
Student engagement	5	15.63

As for **Virtual Reality**, Floreo is a company that uses VR to teach social and communication skills to individuals with Autism Spectrum Disorder (ASD) (Floreo, 2019). Floreo is using VR to create immersive and repeatable experience that tends to be supervised by parents or therapists in order to guide the progression of the learner. Floreo states that virtual reality technology is cheap enough to provide therapy

supplement that is accessible and teaching ready. Researchers underline that VR can be considered an advanced imaginal system, that is effective as reality in inducing experiences and emotions. In comparison to reality, virtual reality allows for a more predictable and controllable level of self-reflectiveness (Riva et al., 2018). Floreo's learning tool contains multiple virtual scenarios, where the individual can enter a safari park to engage in social interactions or be in a school classroom to perform social actions such as choosing the seatmates, shifting attention during lessons and raising hand to answer questions.

Another similar example that is focused on learning in the health care field is an immersive training platform based on VR technology provided by Embodied Labs (Embodied Labs, 2019). The intent of the platform is to provide immersive training to care professionals. According to Embodied Labs, about half million employees provide personal assistance with activities in US. Train care professionals with required skills for such activities is hardly trainable in a classroom, which is where virtual reality technology comes in. Embodied Labs is developing a platform that contains a library of simulations of problems and situations facing older adults and caregivers. Embodied Labs VR training gives the user an understanding of what is it like to be in these situations and have such problems. The training is designed to improve the communication and teamwork between patients and care providers.

An article by Lin, Chen, & Cheng (2018) concluded that developing a VR game that aims to improve the quality of life of people with chronic diseases has had a gratifying impact on physically limited people by allowing them to perform simple physical actions such as jumping or running in a virtual environment. The article states that many sick and disabled people tend to have depression or other psychological disorders, virtual environments that temporary take the user away from the physical world can sighnificantly improve their mood. At the same time, such games teach specific lessons about managing chronic illnesses.

5 DESIGN OF AN AR APPLICATION FOR LEARNING

In the following, practical methods of designing a basic AR application will be explained. These methods were applied in the AR Adventure project.

5.1 Design process

A great way to start designing an AR application is to first get familiar with the VR/AR experience (Evans, n.d.). The design team should have a good understanding of the target device of the application. The controls of the application should feel comfortable and instantly intuitive from the beginning of usage. It is important to remind the user where they are in the. In a VR application for example, the presence of the location, status and content is an important part of the experience, which affect the chances of students getting lost because of too repetitive scene design of the virtual environment of the application (Rasheed, 2019).

5.2 Brainstorming

Brainstorming is a term that refers to a method of idea generation in order to solve a particular problem in a project. Brainstorming usually involves a group, where individuals share ideas to each other. In such a process, idea that is shared by one individual can inspire another individual to come up with another idea. Capturing as many ideas as possible is a good brainstorming practice, no matter how unusable they may sound at first. In brainstorming, collecting vast amount of ideas comes first and evaluation of ideas comes later, as even bad ideas may be the ones that will inspire the good ideas. Brainstorming is a great way to filter out ideas that may be useful in designing any type of applications, including applications designed for learning (Interaction Design Foundation, n.d.).

5.3 Serious games

A serious game is a type of game that aims to do more than just entertainment. Most often, serious games relate to a type of educational game, which have a careful and

thought-out educational purpose. In some cases, the term may be applied for interactive applications, such as a computer simulation, which may not necessarily involve any pedagogical purpose. The main purpose of serious games, however, is most often explained as education and training. Other examples of serious gaming are advertising, political propaganda, health or military games. Serious games do not represent serious situations. Unlike normal games, serious games apply successful gaming mechanisms to increase the involvement to bring gains in knowledge and competencies. Serious games can sometimes be referred as game-based learning, or educational games (EduTech Wiki, 2019).

Examples of features a serious game may include:

- Clear learning goals
- Broad experiences
- Practice opportunities
- Encouragment of inquiry
- Monitoring of progress
- Contextual bridging

5.4 Playful design

Playful design implies using game aesthetics and limited usability, which is based on game elements for non-game contexts. Some examples would be Twitter's ”Fail Whale”, a web page that is designed in a way that draws users attention by displaying a drawing of birds trying to lift a whale, instead of a page that displays a standard error message (Borges et al., 2014).

5.5 Gamification

The concept of “Gamification” is explained by Deterding et al. (2011) as “the use of game design elements in non-game contexts”. According to the article, gamification is the process of taking something that exists, and integrating game mechanics into it. There is a long tradition of using game input devices for non-gaming purposes. In fact, there is a range of graphic engines and authoring tools of video games that are used for non-entertainment purposes, from scientific visualizations and 3D environments to fan art.

Gamified products typically include reward mechanics, such as points, badges and leaderboards, and usually have some type of progression. They are structured with explicit rules, and the primary intention is to increase the motivation of the player. Typically, they are most successful when they are extrinsic, and when they lead to user engagement. Often these types of games are cheaper and easier to produce, compared to interactive entertainment focused games.

There are other similarly related concepts that touch the subject of education and gaming, such as serious games and playful design (Figure 3). “Gamification” essentially adds game elements as parts, which is a process rather than being a product. In application development, ”gamification” differs from these concepts by being a design that tends to incorporate game elements to non-gaming applications by definition, rather than being a game that is used in non-game contexts (serious games) or being an application that tends to add playful interaction (playful design) (Deterding et al., 2011).

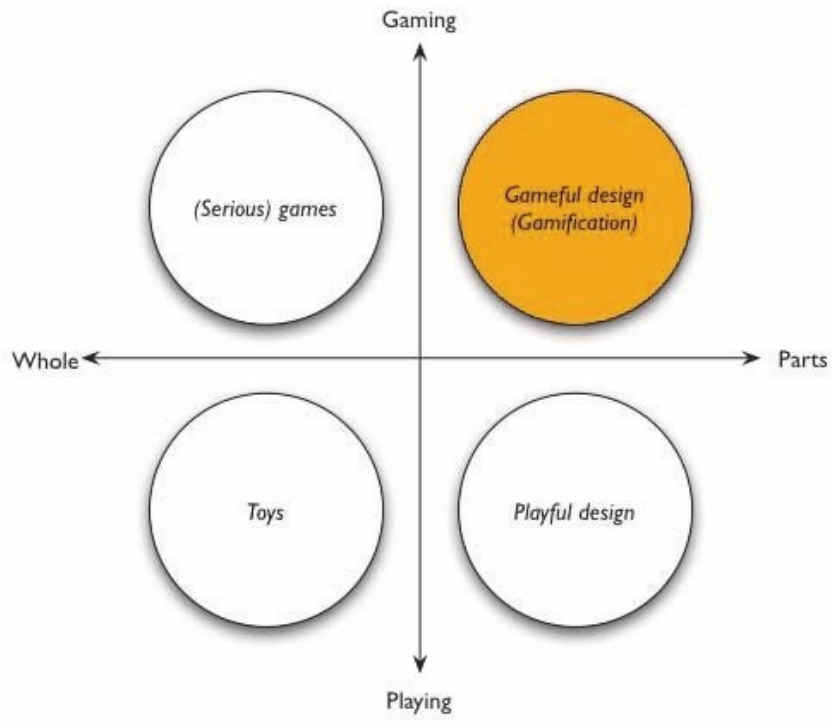

Figure 11. Terminology comparison (Deterding et al., 2011)

5.6 Defining the target group

As with many applications, there is always a target group that should be considered when designing an application of any kind. In designing applications that are meant to enhance

a certain type of learning topic, selecting a target group can be very straight forward. In many consumer centric applications, narrowing or increasing the audience range can have a great impact on the marketing budget. Given this, in education the age group can vary greatly, but depending on the purpose and scale of the application, there could also be a very narrow target group (Yesbeck, n.d.).

5.7 Agile methods

The agile methodology is an approach to software development which is centered around adaptive planning, short delivery times and self-organization. Agile methodology is meant to be an alternative way of product development, which aims to replace the primitive plan, design, build, test, deliver process by abandoning the risk of spending huge amounts of time on processes that can ultimately fail. The methodology relies on trusting the employees and teams to have a great understanding of the goals by working directly with the customer. Therefore, communication plays a big part in an agile business project, as it keeps all teams related to the business ensured that the process stays on track. The methodology is meant to be simple and fast, which works great in software development, since it is easy to communicate feedback and change the software without having to take any large risks. Agile methodology aims to fulfill the first additions of a software in a matter of weeks, where the entire software would be done in a couple weeks. Some example methodologies are Scrum, eXtreme Programming (XP), Feature Driven Development (FDD), Crystal and Lean Software Development (LSD) (Stackify, 2017).

5.8 Rapid prototyping

Often the problem is that dedicating many hours to the development of a fully functioning prototype can come costly. This is where rapid prototyping comes in. In general, rapid prototyping includes technologies and techniques that let engineers and designers to create a basic version of their design usually to test form fit functions. In the context of application development, the idea is to build an early version of the application using special prototyping tools, to test and validate the product in an early phase. This process includes practices like gathering user feedback. Rapid prototyping enables teams to

have more time on feedback, discussion, iteration and re-testing of the prototype (Concise Software, 2019).

In AR Adventure, the customer and the end user were engaged in prototyping the application from the beginning. As stated by Ravyse et al. (2019), the project began with defining the requirements, such as the main idea of the application, must-have features of the application and the user experience flow for a MVP (Minimum Viable Product) during initial workshop sessions that were held at Yli-Maaria school together with the teachers and children.

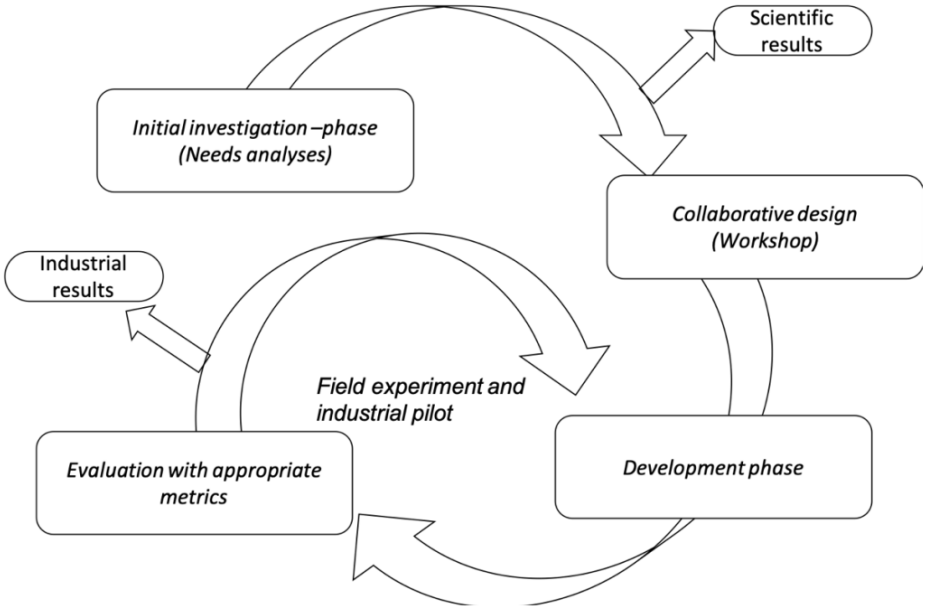

Figure 12. The research approach of AR Adventure. (Ravyse et al., 2019)

AR and VR applications have their unique features, but for both technologies to work effectively, it is important to have a properly functioning user interface (UI). UI design is one of the examples where rapid prototyping can be implemented in AR and VR application development. There is a great selection of applications that are focused on mobile application UI and UX (user experience) prototyping, which can be used in AR and VR application prototyping as well. For example:

- Axure (2D)
- Sketch (2D)
- InVision (2D)
- Wiarframe (3D)

5.9 User-centric design

User-centered design process (UCD) or human-centered design is a design process which focuses on the goals of usability, user characteristics, environment, tasks, and workflow in the design of an interface (W3C, n.d.). It is a suite of methods that emphasizes on understanding the needs of the end user instead of the technology that is used in the application. It is an iterative process in which the developer focuses on the user in each phase of the design process. The design should make it easier for the developer to determine what actions are available to the user at any moment, make things more visible to the user and to make it easy to understand the current state of the system (Tesiman, 2019).

5.10 Working with usability

Usability is defined as the extent to which a system, product or a service can be used by a specific user, to achieve specific goals with the effectiveness, efficiency and satisfaction (Usability.de, n.d.). It is about the ease of use and it is dependent on the user context. A well usable product should be easily learnable and memorable. The user should be able to easily understand and maintain that understanding for a long period. Maximizing the effectiveness, efficiency and satisfaction are also part of usability. It is important to ensure that the player will not struggle with problems that could make the experience less fun.

When it comes to games and usability, it is worth to note, that usability for games might be even more important than usability in other fields. This is because gaming is a voluntary, and often, a continuous action. Some games also provide competitive aspects, which makes usability even more vital in some situations. High usability risks can occur in controls, reward mechanics, feedback system and the user interface of a game or gamified application.

6 DEVELOPMENT TOOLS

Before the actual development can begin, the developer will need to get familiar with the development tools. In AR and VR application development, the developer will most likely have to deal with a game engine as the basis of the application in order to deploy the application on a AR or VR supported device. This is because most modern AR and VR devices have limitations in computing power and rely on software optimization. Game engines offer great tools for managing and developing projects that deal with quick rendering of 3D (three-dimensional) graphics for both AR and VR. To create a basic functioning AR or VR application, the optimal requirement of tools would be following:

- An existing game engine
- Project management tools
- Programming software
- External modeling software
- External texturing software

6.1 Game engines

There are plenty of game engines available on the market in 2019, with many of them being free and easy to pick up, although only a portion of them support AR and VR technology. There are many engines that are specifically made for 2D game development as well. When it comes to AR and VR application development, game developers either choose their own engine or go with an engine available on the market.

Unity is a game engine that is easy to pick up and learn. Unity is an all-in-one editor that features a range of tools to enable rapid editing and iteration for both 2D (two-dimensional) and 3D game development (Unity, 2019). Unity is an excellent tool to get familiar with AR and VR application development, as the engine features like Play mode, where the application can be previewed and tested in-engine in real-time.

Unity's main competitor, Unreal Engine 4, is a suite of development tools developed by Epic Games. Unreal Engine 4 is suitable for developing high-quality games for PC, console, mobile, AR and VR platforms, and features accessible workflows for developers to experiment results without writing lines of code using the Blueprints visual

programming tool. Unreal Engine 4 is designed to be built for performance without sacrificing quality, stating that high framerates are crucial for immersive and believable AR and VR experiences. Unreal Engine 4 uses both Apple's ARKit and Google's ARCore SDKs for iOS and Android AR application development, respectively (Epic Games, 2019).

6.1.1 Comparing Unity and Unreal Engine

Both Unreal Engine and Unity are easy to learn for beginners and pack variety of features with great documentations. It is good to be aware of the functionality that the game engine possesses and what are the needs that are to be required in the developed project. Therefore, a comparison of the two popular game engines is going to be helpful to better understand what each engine gets to offer for AR and VR development.

Table 3. Comparison between Unreal Engine and Unity (Abrar & Ali, 2016)

Feature	Unreal Engine 4	Unity
Programming Language	C++	C#, Java Script
Asset store	Good variety and amount of assets	Great variety and great amount of assets, more than Unreal Engine
Price	Free, 5% of share paid if revenue exceeds $3000 per Quarter	Free until revenue is more than $100000 per year
Platforms	Windows PC, Mac OS X, iOS, Android, VR, Linux, SteamOS, HTML5, Xbox One, and PS4	Windows PC, Mac OS X, Linux, Web Player, WebGL, VR (including Hololens), SteamOS, iOS, Android, Windows Phone 8, Tizen, Android TV and Samsung SMART TV, as well as Xbox One & 360, PS4, Playstation Vita, and Wii U
Documentation	Good amount of documented material	Great amount of documented material, more than Unreal Engine

Graphics	Powerful graphical capabilities, more powerful than Unity	Good graphical capabilites
Usage (2016)	13% of game developers	47% of game developers

The table shows that the vast majority of game developers are using Unity engine for game development, which can be attributed to the larger documentation and pricing, making Unity a great choice for AR application development for smaller game development companies or less experienced developers, for example.

6.2 Project management

The consistency of application development relies on how well the project is managed. It is important to keep a stable pace of development and report the steps of each development subprocess assigned to developers. Project development tools that deal with IT projects are meant to do that, where some of them are aimed more on version control, others focus on monitoring and reporting.

GitHub is a project management platform made for business or open source projects (GitHub Inc., 2019). Its focus is on version control. The tool enables the developer to store each modification of the application to a repository, in order to make things easier for project collaboration (Brown, 2019). Each developer can see the changes made to each modification by each member of the development team, which significantly improves the overall visibility of the progress made to the whole team. These changes can be downloaded for testing or merging the progress made by another team member. Each software project usually has its own repository with a unique URL. To create a project that is based on another project that already exists, the developer can use the ”fork” function, in order to then ”pull” (download) the project onto a work station. As the development progresses, the developer can use the ”commit” function to store the changes made to the project on a local repository, and publish the change to a common cloud repository to make the changes visible and available to other team members.

As an alternative to GitHub, Bitbucket by Atlassian is another similar tool that offers practically the same functionality, along with compatibility to use GitHub repositories in the Bitbucket client (Atlassian, 2019).

6.3 AR SDKs

Unity offers powerful tools to develop engaging AR experiences for mobile platforms. There are two main SDKs available for AR application development for Unity, ARKit for Apple's iOS platform and ARCore for Google's Android platform. Unity allows the developer to create AR applications for both platforms using the AR Foundation API. AR Foundation makes it relatively easy to implement features like automatic surface detection, world feature point identification, real world object tracking, lighting adjustment based on real world estimation and image tracking (Buckley, 2019). ARCore and ARKit have their pros and cons. Compared to Apple's ARkit, Google's ARCore SDK tracks more feature points and expands mapped areas more quickly. ARKit, on the other hand, detects horizontal and vertical surfaces more accurately, then ARCore (Manin, 2019). As an alternative to Unity's AR Foundation, Unity integrates another remarkably similar software platform for AR application development — the Vuforia Engine.

6.4 Location data platforms for Unity

Mapbox is a great tool for AR applications that use location-based AR. Mapbox is an open-source platform which allows application developers to easily create applications that have navigation features, such as a map that can be panned around on a screen and displaying device location and rotation on the map. Mapbox provides tools to customize the visual style of the map that can be used in a mobile application. Mapbox can display live location data to a mobile device to show points of interest, such as the locations of real-world businesses and landmarks. Mapbox also gives the choice of displaying buildings in 3D, although some buildings might not be rendered. Some applications use AR and Mapbox together to create fully functional location-based AR applications, where the user can swap between the AR experience and the interactive map (Mapbox, 2020).

Google's Maps SDK for Unity is another location data platform for Unity, which can be used in achieving interactive map functionality in an AR mobile application. The SDK provides high quality geo data from Google Maps, which can be retrieved on runtime. Google's Maps SDK has a strong focus on quality of the map visuals. It can render geographic features like buildings, monuments or roads in 3D (Google, 2020).

7 DEVELOPMENT OF AN EDUCATIONAL AR GAME

This chapter will explain the methods and decisions in the AR Adventure project.

7.1 The idea behind AR Adventure

AR Adventure was a gamified application with the intent to provide an additional interactive layer to a navigation activity in Yli-Maaria school (Moisio unit). The idea was to use augmented reality technology in a forest, where children could seek for special printed markers around the forest. These markers would be scanned using the camera on a tablet computer, which would activate unique questionnaires and other tasks that use augmented reality to display 3D objects on top of the real world. The game needed a scoring system to add a competitive element, along with an in-game store with custom player characters which could be unlocked using the credits gained from the scoring of each task.

7.2 Initialization with Unity -game engine

In the initial stage of the development process, pre-production involves several decision-making components. In AR Adventure, it was clear that the game is oriented for school usage to improve the navigation activities, thus making the main audience to be the school children.

The development team chose to use the Unity -game engine, because it was a game engine that the development team knew well and had used in many previous projects with similar features. Aside from that, the Unity -game engine had great amount of 3rd party plugins available that were well suited for the project, such as Mapbox and Vuforia.

The resourcing of the project was managed mostly by the developers themselves, as the work was very adaptive for development during studies. As most developers of the development team were still students, it was essential to have a free, fluid workflow that does not interfere with studies. Despite that, the project included very strict deadlines.

7.3 Integrating AR functionality

The very first version of the game included basic Vuforia functionality. The development team chose Vuforia instead of AR Foundation because of previous experience of working with Vuforia by team members. The main objective of the prototype version of the game was to test the AR functionality, mainly to see and determine how accurately and swiftly the device (iPad) would track the markers, which were designed by the development team. The development team made several prototypes, the later versions included GPS positioning testing and quiz system testing.

One of the main objectives was to create a system that would manage all the special AR tasks. The point of having special AR tasks on each marker location was to make the gameplay engaging, thus it is considered to be core functionality of the game. Each AR task creates unique challenge to the player. The development of AR tasks started with implementing a flexible quiz system, which would allow easy task management and creation.

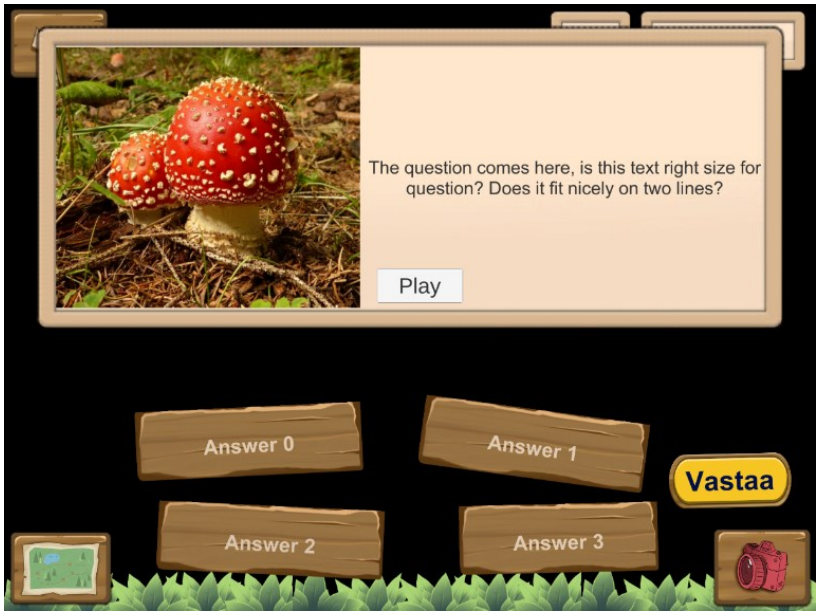

Figure 13. First prototype of the UI for the quiz system

7.4 Integrating location tracking functionality

To use proper GPS positioning in the game, the development team decided to use the Mapbox Live Location Platform addon for Unity. Mapbox offered great amount of

documentation for easy implementation of the addon. It was necessary to understand the basics of the tool as soon as the project started, because the deadlines were strict and location-based features had to be prototyped as soon as possible. The first tests for GPS positioning utilized the Mapbox Location Based Game example, to test the accuracy of the position tracking and to make sure it works.

Soon after the first tests of Mapbox GPS positioning, there had been issues with maintaining a viable enough positioning accuracy indoors and in forests. The development team investigated the code and the methods of how Mapbox provided the position data, and found out that accuracy couldn't be improved from the software side without developing position prediction functionality, which would most likely utilize device gyroscopes or other similar tools. Such development would require much more resources and experience in coding. It was later decided that further development of an interactive map that would use live location data wouldn't be viable anymore, and the development team started with an entirely new interactive map scene, which would instead have the draggable Mapbox map with the character following the points of interests according to the last AR task the player interacted with. Later, however, the team decided to remove the Mapbox map completely from the project, as it still required a stable internet connection for map chunk loading, which was not available for the devices particularly used by the school.

The new map used a basic bitmap for displaying the map, which did not load any map data dynamically, and instead remained as just a static, unchanged image, thus giving the name "Static Map". The map did not differ much visually from the previous version, although there was discussion whether if the end-user (Moisio school) could customize the map to resemble a terrain map with contour lines. This idea was kept as a potential task for the development team, but map customization functionality, such as uploading custom images as maps did not make it to the final build.

If not the issues with live GPS positioning, customizing the map to reseble a terrain map with contour lines could have also been done with Mapbox map customization tools.

Figure 14. AR Adventure static map

Figure 15. Player character movement on the map

7.5 Acquiring feedback

The project made use of multiple workshop sessions organized by Moisio school. The development team received a great amount of feedback from the end user during these sessions. The developers had great discussions with both teachers and school children on possible features, which could be added, as well as the features that could be changed to make the gameplay more fitting for the activities of the school.

The test process consisted of two individual test sessions in the school and school forest, as well as a questionnaire for each testing group. When the very first playable build of the game was shared with the representative of Zoan, the game was ready to be installed on school tabled devices (iPad). The first real test was conducted in an indoor area along with the end-user (school children). Before the test, there was a short briefing and introduction to the controls and features of the game. As the deadlines were very tight, some technical problems were noticed right before the testing session. Main concern of the test had to do with the data storage of the game. It was known that due to poor AR marker design, some of the markers initiated the wrong tasks during the gameplay, locking them from initiating again on scanning the correct marker. The feedback, however, in general, was positive. By the end of the project, the teachers proposed an interesting idea for the potential development of an admin version of the game for mapping future task locations and task creation itself.

The feedback gathering made done quantitively by Zoan. The children were asked to answer several simple questions on the same iPad tablet devices that had the game installed on. The answers were mostly matching the initial impressions received in the beginning of the second test, although it appears that not all users answered the questions from the kindergarten group. To test the gamified application, the word “application” was substituted for the word “game” to make it simpler for the children to understand.

7.6 Relevant agree-disagree results

Table 4. Statement “I would like to play this game very often”

Answer	Number of answers	Percentage (%)
I strongly agree	14	31.1
I somewhat agree	23	51.1
I don’t agree or disagree	3	6.7
I somewhat disagree	4	8.9
I strongly disagree	1	2.2

According to the feedback statistics, over 80% of the school children expressed their desire to use the app regularly.

Table 5. Statement “I found the game easy to play”

Answer	Number of answers	Percentage (%)
I strongly agree	32	71.1
I somewhat agree	10	22.2
I don’t agree or disagree	3	6.7
I somewhat disagree	0	0.0
I strongly disagree	0	0.0

The simplicity of the app was rated good or great by over 90%, which is a sign that the UI and UX of the application is working very well.

Table 6. Statement “I need someone to help me play the game”

Answer	Number of answers	Percentage (%)
I strongly agree	3	6.7
I somewhat agree	8	17.8
I don’t agree or disagree	2	4.4
I somewhat disagree	7	15.6
I strongly disagree	26	57.8

Around 70% of the children had no need for external help to be able to navigate the application.

Table 7. Statement “I think the features of the game were easy to find”

Answer	Number of answers	Percentage (%)
I strongly agree	25	53.4
I somewhat agree	15	33.3
I don’t agree or disagree	4	8.9
I somewhat disagree	1	2.2
I strongly disagree	1	2.2

Most children had no issues navigating the menus and finding app features, although there could be some improvement on that according to the 46.6% of the children.

Table 8. Statement “I think there were enough tasks in the game”

Answer	Number of answers	Percentage (%)
I strongly agree	7	15.6
I somewhat agree	16	35.6
I don’t agree or disagree	7	15.6
I somewhat disagree	11	24.4
I strongly disagree	5	11.1

The amount of content is somewhat disputed by the results. The application had 4 different types of tasks in total.

8 CONCLUSION

The aim of this thesis was to determine what augmented and virtual technology offers for enhancing the quality of learning and to give insight into the practices of virtual and augmented reality application development. The thesis provided theory on the concepts of augmented and virtual reality technology, listing examples of their types and technologies, and provided knowledge of application design and development that is focused on creating applications for education purposes, going through concepts such as brainstorming, agile methodology, rapid prototyping, gamification, development tools and user-centric design. The research suggests that there are many great examples of the usage of AR or VR in learning purposes. AR and VR technology can be used to train the skills hardly teachable in a classroom to professional workers in different types of fields, as well as help people with diseases or disabilities to experience what normally cannot be experienced.

The acquired feedback has shown interesting results, which can be applied in the study. According to the gathered data from testing AR Adventure, the vast majority school children were very engaged in using the app. This points that the gamification of the app had helped it to be more engaging but does not completely prove that AR was the reason to that. Data from other sources, however, suggests that both AR and VR do positively affect the engagement level of an application or a game. The high engagement level of AR Adventure could very likely come from the increased immersion that augmented reality provides. The usability of AR Adventure was also very good according to the feedback, which suggests that even for younger ages, AR can be considered easy to use.

Most of the theory and concepts of this study were carefully adopted in the development of AR Adventure. The theory suggests plenty of recommendations. Excluding the obvious, the key factors such as brainstorming, gamification, target group defining, rapid prototyping and usability theory were applied. According to feedback, usability of the application has been received very well by the target group. The usability of AR Adventure was done alongside the usability theory of this thesis, proving the theory to be useful. Same can be said about gamification. The developed product was meant to become an application which was to include game elements for a non-game context. This goal was met, and the result was positive according to the feedback. The project

management has been flawless thanks to the utilization of the tools described in the concepts of the thesis. GitHub has provided services that have allowed the development team to share work without significant issues that could have slowed the development process down, and using agile methods, the development team had achieved a very consistent workflow for acquiring feedback from teachers and applying the feedback in application design decisions.

What could have been differently, is that the feedback questions could have been more centered around AR. The feedback did not necessarily tell how much AR alone improved the learning experience of AR Adventure, but it gave hints whether it affected the learning experience as part of gamification. As for the application itself, the feedback does raise some suggestions on improving the usability, but not to a very large extent. The technologies that were used in the application are still relevant for AR app development, so there is not much that could have been done differently in the development process.

The accuracy of the GPS positioning was a big problem during the development of AR Adventure. Finding a good solution to accurately display the location of the user was not easy. The team ended up removing Mapbox from the project to display the location of the user more accurately using simpler methods, without using live GPS positioning at all. Implementing an accurate GPS positioning that works in a forest requires at least good knowledge of how location data is calculated and translated to the device. There is some potential in creating algorithms that do location prediction better. There also could potentially be a hybrid solution, where the last scanned AR marker could be tied to a coordinate on the map, making positional prediction more accurate between the next and the previous and the next AR marker coordinates.

The developed project was commissioned by Zoan Oy and provided information that can be useful in developing similar gamified AR applications for learning purposes. The thesis went through many concepts that are applied in the development of various gamified applications. The thesis explains the different phases in the development of AR Adventure, from prototyping to testing, but perhaps there could have been some room to explain the design of the 3D characters or UI as well. The thesis focused on the developed functionality of the application where the author had taken part in. The questionnaires were designed together with Zoan and applied by the author in the study.

In general, AR and VR are technologies that are rapidly growing and offer great potential in the education field. AR is already getting a lot of attention in many fields due to the

ease of adaptation using existing smartphones and tablets. New technology such as AR glasses may very likely increase the interest of AR even more. Education remains to be expected to be the smallest VR/AR market share in 2025, but it seems that this might change as the market will continue to generally grow and the overall interest in these technologies is growing (Cobos, 2017). It is believed that the global pandemic of 2020 had an impact on the growth of AR, some experts believe that AR and VR market will grow because of the COVID-19 virus by $125.19 billion during 2020-2024 (Business Wire, 2020).

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AR Adventure Feedback Questionnaire (Translated)

Next, read the various claims about the nearby forest adventure game.

Think about which option best matches your own opinion and select it by clicking the box next to the option.

The options are:

- I strongly agree
- I somewhat agree
- I don’t agree or disagree
- I somewhat disagree
- I strongly disagree

The survey is anonymous, meaning the names of the students are not asked and are not combined with the answers.

The answers to the questionnaire are used in the development of the learning environment and in the thesis.

Participation in the survey is voluntary, and the survey can be suspended if you wish.

Thank you for your answers!

1. Class

   ☐ Kindergarten
   ☐ 1
   ☐ 2
   ☐ 3
   ☐ 4
   ☐ 5
   ☐ 6
   ☐ 7
   ☐ 8
   ☐ 9

2. I would like to play this game very often

   ☐ I strongly agree
   ☐ I somewhat agree
   ☐ I don’t agree or disagree
   ☐ I somewhat disagree
   ☐ I strongly disagree

3. I think the game is unnecessarily complicated

   ☐ I strongly agree
   ☐ I somewhat agree
   ☐ I don’t agree or disagree
   ☐ I somewhat disagree
   ☐ I strongly disagree

4. I found the game easy to play

   ☐ I strongly agree
   ☐ I somewhat agree
   ☐ I don’t agree or disagree
   ☐ I somewhat disagree
   ☐ I strongly disagree

5. I need someone to help me play the game

   ☐ I strongly agree
   ☐ I somewhat agree
   ☐ I don’t agree or disagree
   ☐ I somewhat disagree
   ☐ I strongly disagree

6. I think the features of the game were easy to find

   ☐ I strongly agree
   ☐ I somewhat agree
   ☐ I don’t agree or disagree
   ☐ I somewhat disagree
   ☐ I strongly disagree

7. I don’t think playing the game was consistent

   ☐ I strongly agree
   ☐ I somewhat agree
   ☐ I don’t agree or disagree
   ☐ I somewhat disagree
   ☐ I strongly disagree

8. I think most people will learn to use this game easily

☐ I strongly agree
☐ I somewhat agree
☐ I don’t agree or disagree
☐ I somewhat disagree
☐ I strongly disagree

9. I found the game uncomfortable to use

☐ I strongly agree
☐ I somewhat agree
☐ I don’t agree or disagree
☐ I somewhat disagree
☐ I strongly disagree

10. I felt confident when I used the game

☐ I strongly agree
☐ I somewhat agree
☐ I don’t agree or disagree
☐ I somewhat disagree
☐ I strongly disagree

11. I had to learn a lot of things before I learned to use the game properly

☐ I strongly agree
☐ I somewhat agree
☐ I don’t agree or disagree
☐ I somewhat disagree
☐ I strongly disagree

12. I think there were enough tasks in the game

☐ I strongly agree
☐ I somewhat agree
☐ I don’t agree or disagree
☐ I somewhat disagree
☐ I strongly disagree

13. I liked the graphics in the game

☐ I strongly agree
☐ I somewhat agree
☐ I don’t agree or disagree
☐ I somewhat disagree
☐ I strongly disagree

14. I liked the music in the game

☐ I strongly agree
☐ I somewhat agree
☐ I don’t agree or disagree
☐ I somewhat disagree
☐ I strongly disagree