SCHOOL OF COMPUTATION, INFORMATION AND TECHNOLOGY - INFORMATICS

TECHNICAL UNIVERSITY OF MUNICH

Bachelor's Thesis in Informatics: Games Engineering

A Physics-Based Serious Game about Magnetism in Augmented Reality

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Ein physikbasiertes Serious Game über Magnetismus in Augmented Reality

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I confirm that this bachelor's thesis in informatics: games engineering is my own work and I have documented all sources and material used.

Munich, 15.10.2023 Tim Gerhard Winter

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Abstract

Magnetism is a force all around us. It is also commonly taught in school, yet students sometimes struggle to understand certain concepts such as field lines and polarization. Therefore, this thesis is going to propose a serious game in order to educate players about said topics. To enhance the player experience, augmented reality was also used.

First, the relevant background information regarding this topic will be explained. Then related works are examined to find common issues and best practices. Afterwards, the game concept will be presented and how serious game as well as augmented reality principles are included. Following that, the implementation and it's inner working will be explained. Then, to judge the effectiveness of the game, an evaluation via a user study will follow. The results of this evaluation are analysed and discussed afterwards, to see to what extent the research goals have been fulfilled. Lastly, a look at possible future work will be done and the results of this thesis will be summarized.

Overall, the game was successful at teaching players about magnetism related topics and moderately motivated them to learn more about magnets.

Kurzfassung

Magnetismus ist eine Kraft, die uns überall umgibt. Es wird auch häufig in der Schule gelehrt, jedoch haben Schüler manchmal Schwierigkeit bestimmte Konzepte wie Feldlinien oder Polarisation zu verstehen. Daher wird in dieser Arbeit ein Serious Game vorgestellt, um den Spielern die genannten Themen beizubringen. Um das Spielerlebnis zu verbessern, wurde auch Augmented Reality eingesetzt.

Als erstes, werden relevante Hintergrundinformationen zu diesem Thema erklärt. Daraufhin werden ähnliche Arbeiten untersucht, um häufige Fehler und optimale Vorgehensweisen zu finden. Anschließend wird das Spielkonzept vorgestellt und es wird erläutert, wie Serious Game- und Augmented Reality Prinzipien einbezogen werden. Danach werden die Implementierung und dessen inneren Funktionsweisen erklärt. Um die Effektivität des Spiels zu beurteilen, wird eine Evaluation mittels einer Benutzerstudie durchgeführt. Die Ergebnisse dieser Evaluation werden anschließend analysiert und diskutiert, um zu sehen, inwiefern die Forschungsziele erfüllt wurden. Abschließend wird ein Ausblick auf mögliche zukünftige Verbesserungsmöglichkeiten gegeben und die Ergebnisse der Arbeit werden zusammengefasst.

Insgesamt war das Spiel erfolgreich darin den Spielern Themen rund um Magnetismus zu vermitteln und sie wurden auch ein wenig motiviert mehr über Magnete zu lernen.

Contents

1. Introduction

One of the fundamental aspects of physics is electromagnetism, a field concerning itself with the attraction and repulsion between same and opposite electric charges. A key component of this area is the magnetic force or magnetism for short [12]. It plays an important role in various facets of our lives, such as in machinery, compasses, and even in everyday items like fridge magnets. Despite their widespread usage, a research review from the Institute of Physics [19] has shown that many students struggle with magnetism in school, having particular difficulty with topics such as predicting the direction of electromagnetic forces or being unable to accurately represent magnetic fields. To address this issue, this thesis proposes the development and implementation of an educational game. Specifically, this game will make use of serious game and augmented reality techniques with the aim of creating an engaging and effective learning experience for students.

The term "Serious Game" (SG) was originally coined by Carl C. Abt in 1970 and gained wider recognition when it was popularized by Ben Sawyer in 2002 [33]. It is characterized as a game with the intention to entertain as well as at least one additional goal, such as facilitating learning or promoting better health [10]. This thesis is centered on educational SGs which can be used to teach facts, develop skills, and foster sustained learning [10]. However, according to De Gloria et al. [9] while recent studies have demonstrated the effectiveness of SGs, their full potential for instruction, knowledge development, skill acquisition and accurate progress tracking are still far from being fulfilled. Therefore, SGs warrant further research to gain more insights on this topic and to further enhance their educational value.

In conjunction with SG concepts, the game is also going to make use of augmented reality technology. Augmented reality or AR can be defined as a system that a.) combines the real and virtual b.) is interactive in real time and c.) is registered in a 3D scene [4]. Not only has AR shown promising signs to aid students education, but it has also become more accessible than ever. Due to the technological advancements of the last few years, even smartphones are now able to run AR applications [14]. Given its widespread availability and positive effect on learning, it is intriguing to further explore the potential of AR and how it synergises with SGs.

1.1. Research Question

The goal of this thesis is to implement a SG in AR about magnetism. Afterwards, an evaluation is conducted to measure it's efficiency as a SG, the usefulness of AR features and if the game is successful in teaching new information about magnetism.

With these goals in mind, this thesis is going to address the following research questions:

1. How effective is the game at relaying information about magnetism?
2. How well does it motivate players to learn more about the topic?
3. How do serious game and augmented reality methods aid the educational experience?

1.2. Thesis Outline

- **Ch. 2 Background Information:** In this section, the research topic and the most relevant information is going to be explained more thoroughly. First, a closer look will be taken at what SG and AR games are. This includes design principles that should be followed when implementing SGs in AR. Finally, some more background information about magnets and other game related terminology will be presented.
- **Ch. 3 Related Work:** This chapter examines three papers and games related to the topic. All of these papers have also developed and evaluated an AR physics related game. These case studies will be compared to find similarities and differences in order to determine common issues and best practices.
- **Ch. 4 Game Concept:** In this segment, the game concept of the project is going to be described. It will cover elements such as description of the gameplay, how the design principles were included, art direction, accessibility and how magnetism is going to be taught.
- **Ch. 5 Implementation:** Here the specifics of the app implementation are going to be illustrated, explaining how the program works on a fundamental level. Additionally, a closer look at the individual game stages will be taken. Lastly, the tools, assets and accessibility techniques used will be explained.
- **Ch. 6 Evaluation:** This chapter goes through the evaluation process of the game, including the methods used and how it was conducted. Afterwards, the data that was gathered is presented.
- **Ch. 7 Discussion:** For this section, the results of the evaluation will then be discussed with the aim to answer the proposed research questions.
- **Ch. 8 Future Work:** This chapter will go through some possible refinements and alternative approaches which could be done in the future.
- **Ch. 9 Conclusion:** Here all findings are going to be summarized and some closing remarks will be made.

2. Background Information

In this chapter the necessary background information to understand the research topic will be explained. First of all, the theory behind SGs and AR will be further elaborated on, exploring some of their advantages as well as disadvantages. Moreover, some implementation guidelines will be presented. Following that, key terms related to game design are going to be defined.

2.1. Serious Games

Digital games can possess the ability to generate intrinsic motivation. They could even put users into the mental state of flow, which causes players to feel immersed and totally absorbed by a task. SGs try to make use of this characteristic by for example, getting learners to be fully focused on a learning activity. But what exactly are SGs? As was mentioned in the introduction, SGs are defined as digital games with the intention to entertain and to achieve at least one additional goal, these additional goals are called characterizing goals. Characterizing goals can be split into competence domains such as cognition and perception, emotion and volition, sensory-motor control, learning and many more. In this thesis however, the focus is going to be on the characterizing goal of learning, more specifically informal learning (as opposed to educational games for formal learning in educational facilities). [10]

So what are some of the benefits of using SGs? Dörner et al. [10] have identified six reasons for employing a SGs, in short:

1. It provides players with a fun experience and makes software enjoyable to use.
2. SGs can help increase user motivation. An entertaining experience could stimulate a player's curiosity about a presented topic.
3. They could potentially reach users on an emotional level, encouraging their active engagement.
4. The feeling of achievement in SGs can be higher than with other means, promoting sustained learning.
5. SGs have immediate feedback and adaptability, allowing players to quickly assess their progress.
6. It can be a smart tool to accomplish certain goals which have no equivalent alternatives.

While SGs potentially offer many advantages, there are also some issues which need to be taken into consideration. Some of the challenges one faces when implementing SGs involves ensuring the game's entertainment value, fostering player engagement on an emotional level, evaluating its motivational aspects, and comparing its appeal to other leisure activities [10]. In order to deal with such challenges and avoid mistakes, a useful approach is to follow best practices and design principles.

One set of such design principles has been proposed by Gunther et al. [15]. They have developed an overall structure for SGs based on the instructional theory of Gagne's Nine Events of Instruction. Firstly, the game should have a strong hook describing the essence of the game. Second, the subject matter to be taught should be clearly defined. Third, provide references to external sources for the pedagogic content in the game. Fourth, have some form of game progression (e.g. levels, modes etc.). Fifth, define the critical path for gameplay (the main challenges the player encounters to progress through the game) and the didatic resolution (how the educational content will be incorporated within the game's framework). Sixth, specify the educational components and strategies that will be integrated into the learning experience. Seventh, describe how feedback will be given to players. Lastly, encourage the player to replay the game, in order to assist in retention. How these principles will be included in the game is described in the game concept section.

2.2. Augmented Reality

AR aids a player's vision and engagement with the physical world. Virtual objects are placed in the environment which either convey information or help the user perform some task [4], in the case of this thesis a virtual playing field will be displayed on a surface of the user's choosing. AR has also been found to have several advantages such as helping to engage students in the learning process, enhancing users visualizations abilities, aiding teachers in explaining certain concepts via virtual annotations and offering a further learning platform outside of school [29].

There are a wide variety of techniques and features used to employ AR, such as image tracking, object recognition or ground plane detection. Image tracking uses a picture or designated marker such that an application knows where to place the object in the screen, relative to the real world. Similarly, object recognition often tries to find close looking models in the real world so they can be augmented with extra information on the screen. Lastly, with ground plane detection you try to find a flat horizontal surface such as the floor or a table, to then place objects on top of them. [27]

However, when using AR one has to be aware of the registration problem. Objects in the physical and virtual world need to be properly aligned, so that the illusion of both worlds coexisting can be maintained. Such a conflict could potentially cause motion sickness and should therefore be avoided. [4]

Similarly to SGs, to avoid problems and follow best practices design principles for AR implementations will be used. Ko et al. [21] have analyzed existing research to identify some of the most common problems in AR applications as well as offering some best practices to avoid said problems. Such issues include confusion due to inadequate explanations of icons, difficulty operating the application because of small and unfavourably placed buttons or complications caused by duplicate information. Therefore, six guidelines were proposed to avoid the most common problems, these are

1. Avoid duplicate information by expressing hidden info only by operating the camera.
2. Provide additional information about what the users want according to user options.
3. Make icons familiar and consistent with widely used icons and support users with simple explanations about them.
4. There should be an intuitively placed function to expand a players searching range.
5. A help menu should be included with steps to operate the program.
6. The menu and icons should be placed and scaled so that one-handed operation is possible.

As with the SG principles, how these rules will be implemented in this thesis' game will be explained in the game concept chapter.

2.3. Game Design

Now that some terms of SGs and AR have been introduced, some further terminology regarding games design will be explained. A core part of games are their gameplay, game mechanics and rules. Their definitions as stated by Dörner et al. [10] are:

- **Game mechanics** are all about what a player can do in a game, depending on a set of rules and a certain scenario. Examples of game mechanics are throwing a ball or jumping on a box.
- **Gameplay** on the other hand is how a player interacts externally with the game, for example needing to move their arms to control their character or pushing a key to shoot.
- **Rules** are constraints about what a player can and can't do, e.g. if something is already on top of a box, a player cant jump on it anymore.

Furthermore, as was mentioned players can interact with certain scenarios, these are also commonly referred to as levels or scenes.

- **Levels** can be defined as the space in which the game happens. It has initial settings and a series of challenges the player has to overcome, it ends when the player has met a certain termination condition. A level can also guide the relation between gameplay and a game's story while simultaneously setting the aesthetics and mood. [1]

- **Scenes** are the technical implementation of a level, containing the digital objects of a game such as a player avatar or the environment. Alternatively, certain menus can also be considered scenes. [32]

Having explored the ideas and concepts behind SGs, AR and Game Design, the focus will now be shifted to more practical aspects. Namely, the core principles of magnetism will be explored as it it an integral part of this thesis and the game.

2.4. Magnetism

As mentioned in the introduction, magnetism is a force exhibited by magnets which either draw them closer together or push each other apart. This happens due to the movement of electric charges. To explain in further detail, every atom has electrons which carry electric charges. They have a spin and circle the core of an atom, the nucleus. Through this motion, an electric current is generated, causing the electrons to behave like a very small magnet. In most materials, electrons are paired in opposite spins, effectively nullifying their magnetic effects. This accounts for the weak magnetism observed in substances like fabric or paper. However, in certain materials such as iron, cobalt, and nickel, a majority of electrons spin uniformly in one direction. Due to this, atoms of such materials become strongly magnetic, but they aren't magnets yet. To induce magnetization, an already strongly magnetic medium has to enter the magnetic field (a region surrounding the magnets which exerts magnetic force) of the yet-to-be magnet. [17]

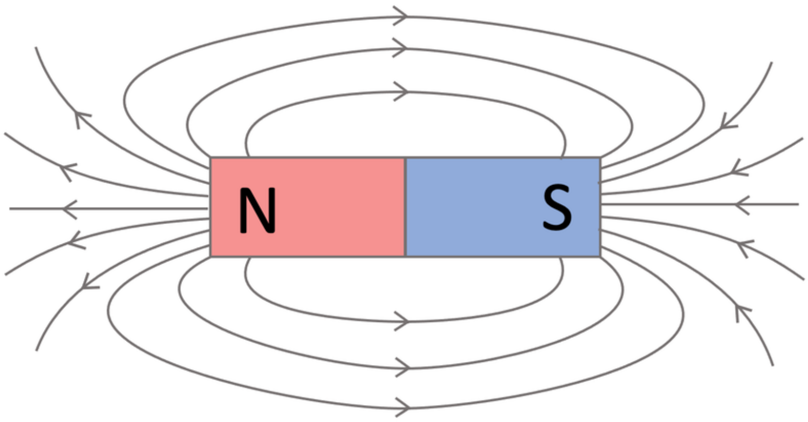

Figure 2.1.: Depiction of a magnet and its magnetic field [13]

As can be seen in Figure 2.1, magnets also have a north and a south pole. Opposite poles attract, whereas similar poles repel one another. If you were to for example rub a piece of iron against a magnet, the north-seeking poles of the iron's atoms align in the same direction. The resultant collective force from these aligned atoms generates a magnetic field causing that piece of iron to become a magnet. [17]

3. Related Work

In this section, three papers related to SGs and AR will be explored. The first paper is about an AR based wave-particle duality learning application called "AROSE", the second paper uses the Hololens for their game "EdAR" to teach about the invisible physics related to audio speakers. Lastly, the third paper is a SG based on an interactive AR world named "Parallel", to educate about electromagnetic fields.

3.1. AROSE

AROSE (Augmented Reality Optical Simulation Experiments) was developed in order to give learners an interactive optical experiment environment, encouraging the development of students' self-efficacy (the amount of confidence in oneself to use their skills to achieve certain work behavior [5]) and conceptions of learning physics. The game was evaluated with a total of 98 high school students aged 16 to 18 which were split up into an experimental and control group. The experimental group had to use AROSE whereas the control group received demonstrations of the same material via a Flash game. [7]

AROSE consists of four experiments. In the first experiment (see left-most picture in Figure 3.1)) the so called macroscopic picture of the photoelectric effect could be seen, a phenomenon often difficult to observe in ordinary classrooms or labs. Experiment 2, the second picture in Figure 3.2, shows a microscopic view of the photoelectric effect. The last two experiments showed similar effects but under different conditions. This lets students directly visualize concepts that would under normal circumstances be too hard or abstract to show. [7]

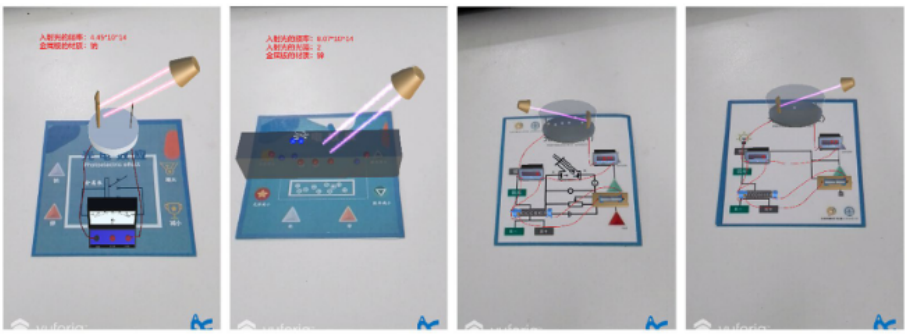

Figure 3.1.: Screenshots from AROSE. The first two pictures depict an experiment to get a macro- and microscopic view of the photoelectric effect. The last two scenes show a similar effect under different circumstances [7]

The implementation was made using Unity, a popular game engine, in addition to the Vuforia SDK (a package to help with AR applications). Players can display the experiments by scanning a recognition card. They could then press on said card to interact with the game. The idea was to provide more experimental opportunities for students, as practical experience is highly related to positive learning experiences. Another goal was to have a high degree of intrinsic connection, by showing the macro and micro views encouraging users to internalize the information in a more meaningful way. [7]

It was found that the experimental group achieved much higher scores than the other group in multiple areas, e.g. in categories such as conceptual understanding, higher-order cognitive skills, practical work and social communication. Also they came to the conclusion that AR technology in a physics classroom can encourage the formation of high-level conceptions of learning and motivate students to further engage with the topic. However, it should also be noted that the AR group performed worse in terms of low-level conceptions such as calculations and testing. [7]

Overall, we can glean from this study that AR is a very effective tool at teaching students about physics related concepts, by providing a practical experience and allowing users to observe different views. Their approach to implementing AR was intriguing, as it involved using different cards to interact with corresponding scenes. However, students did observe that occasionally, pressing on it resulted in decreased sensitivity, requiring them to re-scan the marker in order to restore normal functionality.

3.2. EdAR

EdAR (Educational AR) is an unstructured learning activity designed for the Hololens system (an AR headset, which lets users see digital objects in the real world) to learn about physics topics related audio speakers such as spatial knowledge, the shape of magnetic fields and the relationship between electricity and magnetism. They have decided on an electromagnetic topic as it is one of the most difficult topics to master for students of all ages. [28]

So, in order to investigate the advantages and disadvantages of AR for inquiry-based learning, 14 pairs of participants from a northeastern US university were tested. Their task was to experiment with a sound-producing speaker and to fill out a test before and afterwards. Participants were randomly assigned to four experimental conditions. The first condition was "no Hololens", meaning that participants undertook the task with no virtual guidance. The second condition was the limited usage of a Hololens, which only included simple outlines of major system components. The third group had a so called "AR Scaffolding" which starts similarly to the second condition but progressively provides an increasing amount of information over time, e.g. after a while they could also see the magnetic fields and electric current. The last condition, shows users all of the information from the get go. On the next page in Figure 3.2 the AR guidance and annotations can be seen. [28]

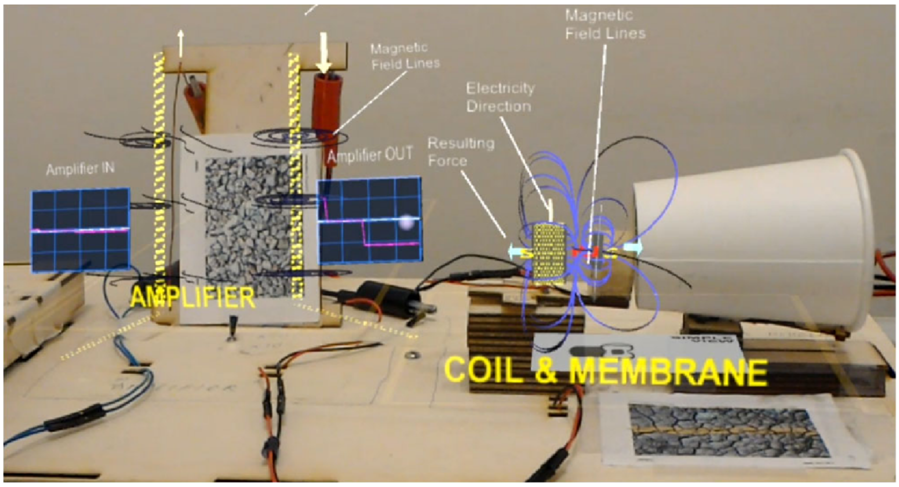

Figure 3.2.: Screenshot from EdAR. Here the components of a speaker are augmented with additional information such as wavelengths, magnetic fields and the acting forces. [28]

Their system consists of an interactive hardware system simulating an audio speaker, which is composed of multiple Hololenses connected together. Interestingly, they have experienced similar AR related issues as AROSE. For example, the system could sometimes not properly track the movement of physical objects e.g. participants connecting wires. Another limitation found were the AR headsets themselves. As the device covers a significant portion of the face, it was harder for participants to make eye contact and communicate with non verbal expressions. [28]

Several interesting results were discovered. Firstly, after the experience both AR and non-AR users had a better attitude towards the subject. However, especially the EdAR group enjoyed the aesthetics of it more and also found the project significantly more worthwhile compared to the other users. Secondly, it was determined that participants in EdAR groups had bigger relative learning gains in contrast to the non-EdAR groups when it came to understanding magnetic field shapes, the relationship between electricity and magnetic fields and how to construct an electromagnet. Lastly, as this experience was conducted in pairs of two, it was also checked how well participants collaborated. In terms of time management the EdAR group was better, however when it came to technical coordination non-EdAR users came out on top. [28]

To summarize, what can taken from this study is that this confirms some of the findings of the AROSE project. They have also used a more experimental approach and have shown that AR helped to get users more engaged with the project. In terms of techniques used, markers as well as object recognition were deployed, an interesting alternative approach to AR. However, they also ran into similar problems with slight tracking issues and hardware getting in the way. Also it must be noted that while the EdAR group performed very successfully, the non-EdAR group also did well. This shows that when it comes to teaching, while AR can be a useful tool, traditional approaches should be considered as well.

3.3. Parallel

Parallel was created with the intention of showcasing the advantages in knowledge acquisition that result from merging educational entertainment and mobile AR solutions. It is a game about showing the behavior of charged particles in an electric and magnetic field. It stems from research about the exploration of new teaching practices of SGs in AR and their impact in a physics class. Similarly to the last two related works, parallel was evaluated by splitting a total of 140 participants into a control group and a Parallel user group. Both groups were tasked with doing a pre-test, but the Parallel group learned the material via the game whereas the control group used more traditional methods e.g. right hand rule. Afterwards the participants were tested again to measure the impact of both methods. [6]

The premise of the game is that the player has found a mysterious sealed chest covered in Sumerian symbols. Alongside the chest, three tablets containing matching inscriptions were discovered. These tablets are also used as markers for the AR tracking and represent three different levels. Upon closer inspection, players can see that the tablets have a magnetic field, this can be seen on the left-most screenshot in Figure 3.3. Attached to this magnetic field is a particle gun which shoots a particle beam. This beam can then be controlled by changing the magnetic field. This is used to figure out hidden clues in the second scene, where the mysterious box is examined (see middle screenshot in Figure 3.3). Once all the clues have been collected, players can use them to open a door in the final scene of the game. [6]

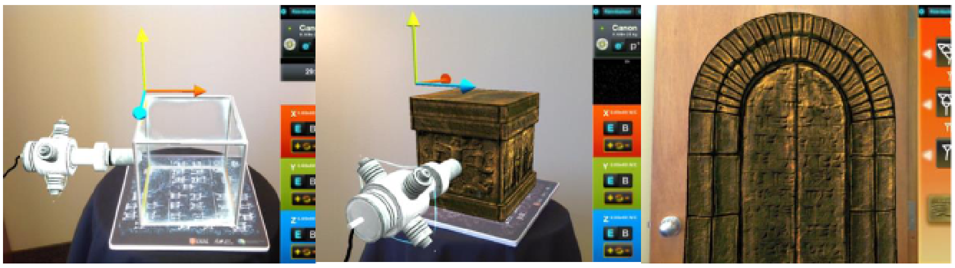

Figure 3.3.: Screenshots from Parallel. The three different levels can be seen. In the first players can experiment with a particle beam, by shooting it through a customize able magnetic field. In the second scene this can be used to find clues in the box. Finally in the third scene, these clues can be used to open the door. [6]

Parallel was made for Apple's iOS platform and is meant to be played with a mobile tablet. While the study does not go deeper into technical explanations of the program, their approach to the study and implementation was thoroughly explained. A methodology called Design-Based Research was used to apply real-world context within a classroom [6]. Design-Based Research is a cycle of 1) analysing a problem and reviewing the current state of the research of the topic 2) developing an intervention 3) testing and evaluating the intervention and 4) repeating the process until an acceptable solution has been found and new knowledge has been gained [11].

This study has adapted this process. First, they defined the problem of combining AR and SGs to teach physics, then they made an intervention (Parallel) and finally evaluated it to see how it could be improved and what can be learned from the experience. [6]

The study revealed that AR helped participants visualize the physics phenomena, aiding in their understanding of the topic. It also provided them with a visual representation of an abstract concept which is otherwise not easily accessible. Furthermore, the AR features improved the interactivity between the players and the setting in comparison to a normal display. All in all, the reception of AR was very positive. However, it was stated that while useful and interesting, it could not replace traditionally teaching a class. In regards to the SG aspects, students liked that it provided a different perspective and way to learn physics. Participants appreciated the fact that they could quickly "confirm their understanding" and test their hypotheses. Most appreciated that the game was of a more challenging nature, however some have found it to be too hard and repetitive. Overall however, it was determined that SGs and AR show promising signs for future use and could lead to new possibilities. [6]

To sum it up, Parallel was another promising example advocating for the use of AR and SGs in an educational setting. Once again, similar techniques were used for the implementation with a simple marker serving as a level. Their explicit explanation of the design based research methodology offered useful guidance for approaching this thesis. It has also provided multiple examples of how specifically AR improved the experience. In terms of gameplay, it is important that players can quickly verify their ideas and that the game is adequately challenging.

3.4. Related Work Conclusion

Now that three related papers have been explained and examined, similarities and differences will be determined to find best practices for this thesis and the implementation to come.

The three papers have a lot of commonalities, such as utilizing image recognition and markers in the form of QR codes or pictures to display information. Given that the AR features were well received in all evaluations, this will also be the main AR interaction method of the game proposed in this paper. However, to offer another point of view the game will also try to implement an alternative method such as using a ground plane instead of markers.

Not only were the AR features positively received, but often the projects as a whole. Participants stated that the games could be useful for learning as it allowed them to visualize abstract concepts and quickly test their ideas in a virtual environment. Therefore, it will be interesting to see whether the evaluation for this thesis' game will reflect a similar sentiment.

One more notable resemblance among the papers, was their approach similar to the Design Based Research explained in the Parallel section. All of the games proposed the problem of teaching abstract physics topics, analyzed current work done, implemented that knowledge in a game and evaluated it with pre- and post-tests afterwards. Therefore, these papers and two other TUM bachelor theses by T. Manherz [22] and L. Marsoner [23] were used as a structural guideline for this thesis to follow common approaches to such research questions.

It should be mentioned that while AR was well received, both AROSE and EdAR reported some technical difficulties using it. Such issues include loss of tracking and wrong positioning. While such issues could be avoided due to the iterative nature of a Design Based Research approach, it is best to avoid said problems in the first place. It will be worth observing whether similar issues arise, in order to better understand what to be careful of when implementing a SG in AR.

Given how the topics of all three papers are closely related there were many similarities to be found, however there were also a few notable differences. First of all, all games targeted different platforms. AROSE was made for mobile phones, EdAR was meant to be used with a Hololens and Parallel was designed for a tablet device. This shows the versatility of AR technology, being able to be implemented across a diverse range of devices. However, as mentioned in the introduction, this thesis will put a focus on smartphones due to their widespread availability.

Another difference were the setting of the games. The first two papers had a more experiment focused approach, with less game aspects. Parallel on the other hand went for a more playful approach, presenting the narrative of opening a sealed Sumerian box. As this thesis is similarly to Parallel also focused on SG aspects, a more game oriented approach will be chosen as well.

Lastly, compared to the other projects EdAR used real physical objects for their experiment. While a nice feature to have, it wont be a priority as less required physical items mean more people can access the software.

4. Game Concept

Now that the background information about SGs, AR and magnetism has been explained, as well as having explored some papers related to the topic, the concept of this thesis' game can be formed. Its goal is to educate players about the mechanics and inner workings of magnets, also helping them visualize the "invisible" force around them via field lines. The game's title is MagnetAR due to magnets and AR being the core elements of this game. It should be said that this game is adapted from work done by Aymane Chaoui, Matthias Mitschele, and Felix Bartossek [3] in which they have developed a pinball style game which can be controlled via a real life magnet in front of a camera.

4.1. Overview

The game is inspired by the mini golf genre of games, in which players have to strike a golf ball into a hole within as few swings as possible. Usually, players control the speed and direction of the ball, however in MagnetAR the ball is restricted to shooting straight ahead, with players only being able to determine the shots power. To influence its movement, magnets have to be placed on the track beforehand. Via either attraction or repulsion the ball can then be guided into the goal. A preview of this can be seen in Figure 4.1, the specific mechanics will be closer explained in the implementation chapter.

The target platform are any AR-capable mobile devices, being controlled mostly by the camera and by placing markers on a surface of the players choosing. The target audience is primarily for students or people that are interested in learning about magnets in general.

Figure 4.1.: Preview of a level. The blue ball must be shot into the windmill to succeed. The magnet can change the trajectory.

4.2. Gameplay

Once a player starts the game, they are greeted with a main menu. In it, they can choose from a selection of "worlds". These so called worlds carry an overall theme and are split into individual levels. These levels aim to educate about details of the theme, for example the overall theme could be the basics of magnetism and a level could address north and south poles. To test the concept, one world with four levels will be included.

Upon selecting a level, an information screen with a lesson associated with the level is displayed. Once the user is finished with reading, the application transitions to an AR scene with the front camera activated. Within this environment, players can then choose any flat surface in a well lit area to place the golf track. Afterwards, users have the freedom to explore the scene in AR allowing them to get a better sense of the golf track.

Now, the aim for the player is to hit the golf ball into a goal. Player can determine the precise force with which they want to strike the ball, however the direction can only be changed via magnetic fields. This gives rise to the central game mechanic of MagnetAR. It revolves around cleverly positioning a magnet onto the field to guide the ball into the goal. This is accomplished by scanning and placing a designated marker, causing a magnet to appear at the marker location. The magnet also comes with a visualization of its magnetic field, allowing players to inspect it closely and use this information to determine its optimal placement on the field. A players wins if they manage to hit the goal, but if the ball leaves the boundaries of the stage the player fails and has to try again.

The lesson in each level is accompanied with unique game mechanics trying to further cement the lesson to be taught. For example, in a level teaching about polarity, gates might appear that change the polarity of the magnets when it passes through. This aims to connect the gameplay with the lesson to be taught.

4.3. Design Principles

Now the implementation and execution of the design principles from the background information section will be explained.

4.3.1. Serious games

Two of the design principles were a strong hook and that the subject matter should be clearly defined. This will be done by showing an information scene before each level which explains what is going to be taught and how it relates to the golf elements of the game. For example, a formula could be displayed and shortly explained, encouraging the player to make use of certain elements to score a hole. Then at the end of the explanation, links to articles discussing the explained topics will be provided. This allows players to further learn and check the information if they are doubtful.

Furthermore, at the end of a level a three star rating will be displayed depending on several factors. First, a star is rewarded if a player successfully completed the level. Second, a collectable coin (placed in a challenging location) has to be picked up. And lastly, lesson specific elements have to be used (e.g. in the polarity example described in core gameplay, if polarity changing gate were used). By encouraging the player to get a better score, this aims to increase the repeatability of a level assisting in the retention of information presented.

4.3.2. Augmented Reality

One of the AR design principles was to provide additional information according to user options. To address this, a variety of configuration options will be included. For example, players can choose to display arrows indicating the magnetic force around a magnet and they can replay the information screen before a level. Furthermore, it should be theoretically possible that users could (via object recognition) use a real horseshoe magnet to interact with the game in addition to markers. Another guideline was to make symbols familiar and consistent with widely used icons, a popular user interface package will be used to create the menus.

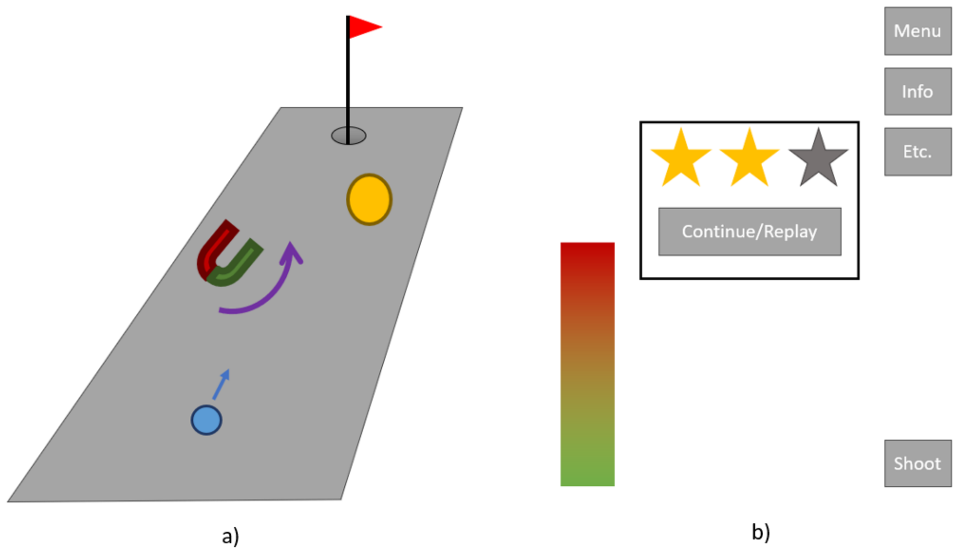

Figure 4.2.: Game Concept Art of a) a Level and b) the in-game user interface. a) depicts a collectable coin how a magnet could be placed on the field. b) displays a colored power bar, the stars rating menu, and other miscellaneous menu items.

Furthermore, to be in accordance with the principle of having an intuitively placed function to expand a players searching range, one of the menu items is going to allow players to reposition a level. One more menu item is going to be a help menu option, explaining how to operate the program as to satisfy another guideline. Lastly, an effort will be made to place and scale the UI such that it conforms with the last principle of one-handed operation.

4.4. Educational content

The game is going to educate players about the basics of magnetism. Levels will therefore focus on subjects such as polarization, magnetic fields and the magnetic properties of various materials. Also more advanced topics will be touched upon such as the concept of field lines and the role of electron spin. In the future, these topics listed could become their own "world" accompanied with explanations in far more detail.

4.5. Artstyle

The art style used for this game is so called "low poly", which is making use of models with very few polygons. Some advantages of using low poly are less required computational power, faster rendering and also allowing for easy loading, viewing and editing. This makes it a very suitable option for working with real-time engines and AR. [26]

4.6. Accessibility

In order to make the game more accessible to a wider range of people, possible accessibility options have to considered. Firstly, as one-handedness is a key design principle, to ensure an optimal experience the user interface should be able to be flipped depending on a users dominant hand. Other possible actions to make a game more accessible were identified by Yuan et al. [34]. They have conducted a survey illustrating various game accessibility problems and their solutions. For example, for visually impaired players elements such as high-contrast color-schemes, color blind friendly palettes, scale-able fonts or text-to-speech can be made of use. While not all of these features will be implemented, it is good to have it in mind in case it is needed. Participants of the evaluation were asked two days before the game assessment whether any specific aid was needed.

4.7. Timeline

The time plan of the game development took a total of six weeks. Two weeks were used to devise the game, such as its content, its inner workings and how the design principles will be included. Following that, the game was implemented over a period of three weeks which included further research, development and testing. Lastly, the evaluation was done in the time span of a week where participants had to be found, the evaluation had to be designed, and finally the assessment was then held.

5. Implementation

As the groundwork with background information, related works and the game concept has been laid, now the implementation of the game will be discussed. This chapter will cover the inner workings of the program and its modules as well as the ideas behind certain features. First a look at the external elements such as the tools and assets used will be taken.

5.1. Tools and Technologies

This game was created on the Unity Platform, primarily making use of the Vuforia AR plugin. It was programmed on Windows 10 and built in Xcode 13 on macOS Monterey. The target platform were mobile devices, the specific device used was an iPhone 11 running on iOS 16 as it supports AR features [2].

Unity is a widely-used game engine and was chosen for developing MagnetAR due to its intuitive development environment and its versatile features. It allows for efficient integration of code and designs, meaning that a bigger focus can be put on game mechanics and content instead. Furthermore, Unity offers an extensive asset store and plugin system which makes it easy to integrate new elements such as 3D models, animations and sound effects. Lastly, Unity offers cross-platform build compatibility, meaning that it supports iOS and other operating systems such as Android. [30]

Alongside Unity the Vuforia AR package was used, due to the wide range of AR features it provides. For example, it offers robust image recognition, ground plane detection and marker-based as well as marker-less tracking capabilities. This enables MagnetAR to include immersive interactions with real-world objects and allows for adaptation to the user's environment. [31] [27]

5.2. Assets

Most assets were taken from the Unity asset store, as they allow free usage after acquisition of an asset [24]. The specific asset packs used were "2D Casual UI" by MiMU Studio, "UX Flat Icons" by Heathen Engineering, "Pixelfont" by Thaleah, "Forest - Low Poly Toon Battle Arena / Tower Defense" by AurynSky and lastly "Colorblind Effect" by Project Wilberforce. A lot of the game object models are also from Kenney, which provide a variety of free assets on their website under the public domain CC0 license [20]. From Kenney the "Golf" and "Town" package were used.

Now that the external components have been covered, the attention will be shifted to the actual program and code. In the following sections, the application in general will be explained as well as its individual parts, such as the implementation of the physics, augmented reality and gameplay.

5.3. System

The overall program is separated into four major modules: the user interface, the game manager, the physics package and Vuforia. Shortly explained, the user interface detects user inputs and displays relevant information. The game manager is responsible for the game logic and controls the interaction between all other modules. The physics package is from the adapted game by Aymane Chaoui, Matthias Mitschele, and Felix Bartossek [3]. After receiving the positions of relevant objects, it can return the specific magnetic force applied at some location. Lastly, the Vuforia Engine detects ground planes and image targets and delivers their location to the manager. If then prompted by the manager, it displays the levels and magnets accordingly. Below a diagram of the system and it's interactions can be seen. Next, a closer look at will be taken at the individual modules to explain their functionality in depth.

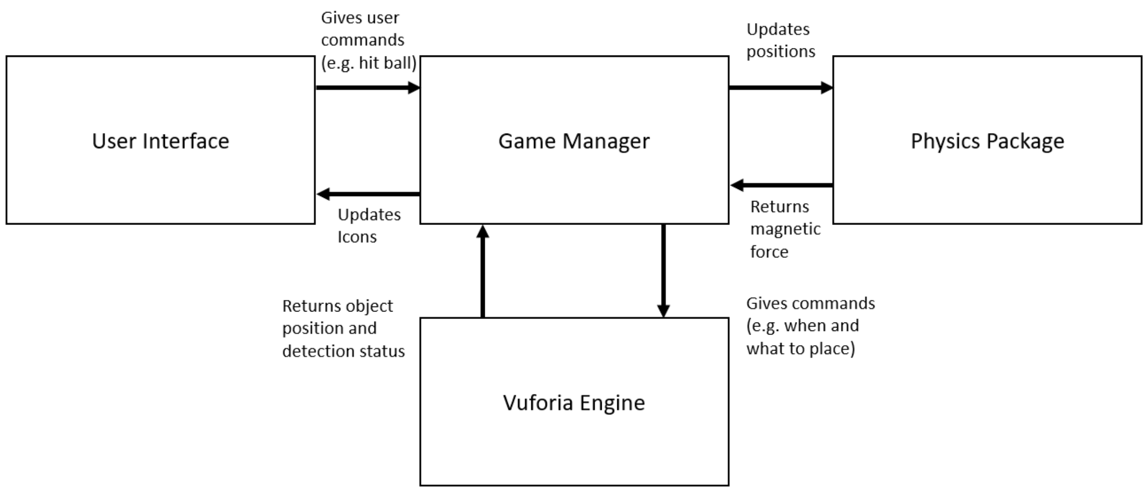

Figure 5.1.: A diagram depicting the interactions between the core program modules

5.4. Game Manager

In Figure 5.2 below an example of a level can be seen. When a suitable surface has been found by the Vuforia Engine, the game manager is notified and users can then place the level by tapping on the screen. Afterwards, they can explore the stage with their camera. Once a power has been selected on the slider and the "HIT" button on the bottom right is pressed, the game manager applies a forward force to the ball. However, to hit the goal (in this case, the windmill) players will have to place a magnet. This can be achieved by placing a marker (which needs to be printed out beforehand), this will cause a magnet to appear exactly at that location. However, when placed under the playing field, the magnet will instead be moved directly onto the playing field.

Figure 5.2.: A placed level with and without magnet marker underneath. The ball needs to be shot into the windmill to score. The trajectory is changed according to the pink arrows. The direction of said arrows can be reversed by shooting through the gate. Optionally, the yellow coin can be collected. Other objects are for decoration.

When the player now decides to shoot again, the ball's position gets sent to the physics module to calculate an according magnetic force for every frame. If the ball then touches the windmill, the result screen appears and the player wins. However, there are also additional objects on the field which can be interacted with. In Figure 5.2 for example, there is also a gate in front of the ball which reverses the polarity of the magnet. Additionally, there is a coin which can be collected if touched by the ball. If these mechanics are used/collected the player earns extra stars, this aims to encourage players to repeat the level.

5.5. User Interface

The next point of interest is the user interface. The interface displayed while playing the game, as well as other menus will be discussed. It is worth mentioning that the game is exclusively playable in portrait mode, which is reflected in the figures.

5.5.1. In-game Interface

As was able to be seen in Figure 5.2 on the previous page, the layout was similar as proposed in the game concept section. On the bottom left the force with which the ball is shot can be set via a slider. In the bottom right the "HIT" button is used to apply said force to the ball. On the top right other miscellaneous menu items are located, going from top to bottom these buttons are 1.) a pause screen which leads to a tutorial or back to the main menu 2.) an information screen containing the lesson associated with the level and lastly 3.) a button to reset the ball position. All UI elements were placed with the aim of facilitating single right-handed operation.

5.5.2. Menus

Upon beginning the game, players are greeted with a starting screen with the options to play or to exit the application. Once "PLAY" is pressed, a level selection menu will be loaded. Here players can choose what level to play and navigate between worlds. Progress can also be tracked easily via the stars displayed under each level. To be reminiscent of golf, a green color scheme was used to mimic the grass on a golf course. In Figure 5.3 these menus can be seen.

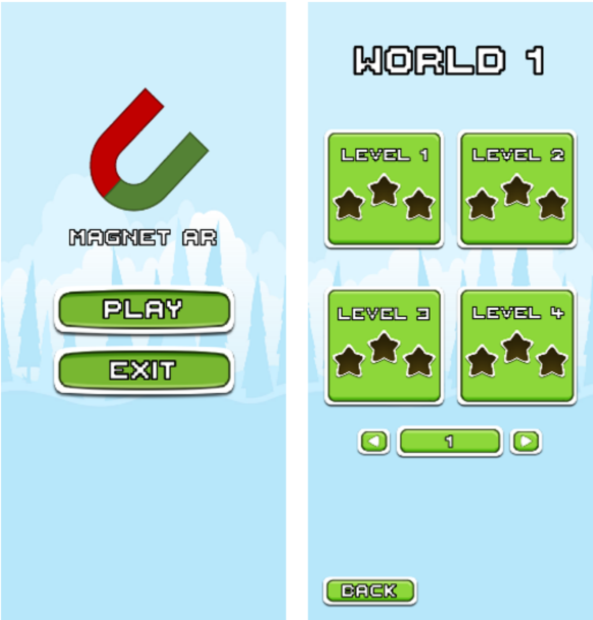

Figure 5.3.: The main menu and level selection screen

Other menu screens include an information menu (which describe the current lessons and game mechanics of a level), a tutorial (with explanations of the game icons and how to operate the game), and other miscellaneous menus (such as when the game is paused). These menus are shown on the next page in Figure 5.4.

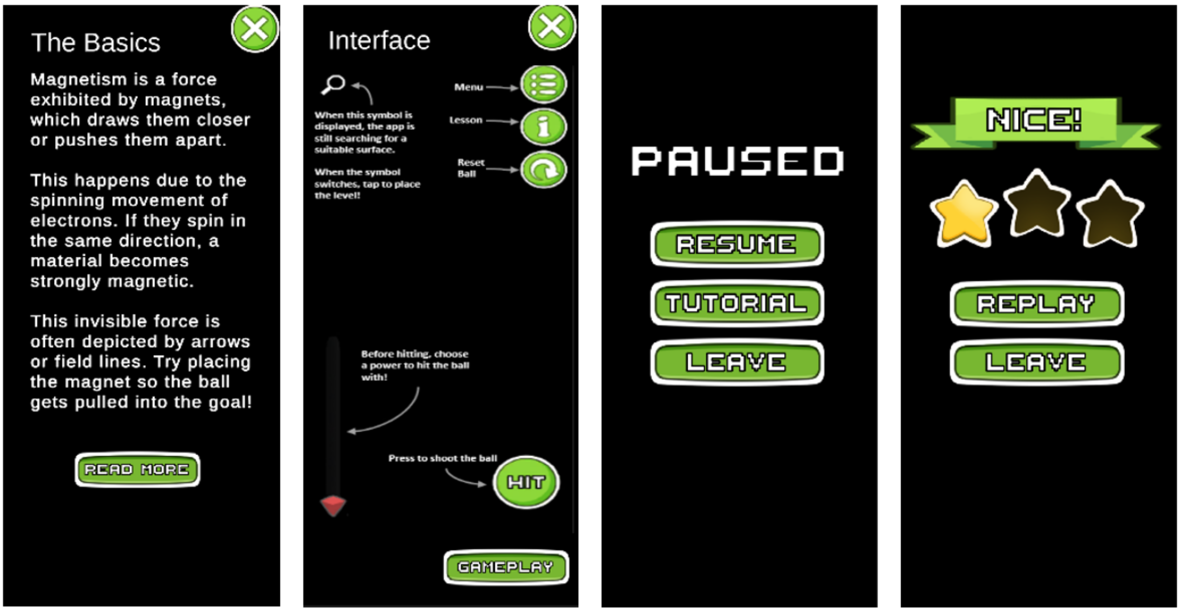

Figure 5.4.: From left to right: An example of a lesson displayed before for a level, a tutorial explaining the interface, a pause menu and the result screen which shows how many stars were achieved

5.6. Physics Package

The physics module has been adapted from the project "Magnetic Field Visualization in Augmented Reality and Serious Games" which was originally designed for a Practical Course at the Technical University of Munich [3]. It simulates magnetic behavior by breaking it down into scripts for the core components of a magnet, such as homogeneous fields and poles. These parts are then consolidated into one item using an interface for magnet objects. The magnet can be adjusted in a variety of ways, such as setting the strength of the magnetic influence or the size of the magnetic field.

$$Force = dist.normal * (pole.maxStr + ((pole.maxDist - dist.magnitude)/pole.maxDist)$$

After magnet entities have been created and are placed in the scene, a central script then can calculate the final magnetic force at any given location. This is done by first iterating through all existing poles in a scene, applying the formula above and then summing all the forces. In this formula "dist" is the distance between the pole and the specific position and "maxStr" as well as "maxDist" are as mentioned pre-determined values to affect it's power and range respectively. Afterwards, the influence of any other magnetic related components will be added as well, by using an adapted formula. For example, if the given location is within a so called homogeneous area then force is applied in the direction of the field multiplied with a pre-set power.

5.7. Vuforia Engine

The implementation of the AR features in this game relied on the utilization of the Vuforia Engine, with a specific emphasis on the functionalities of ground plane detection and image tracking. To include these functions, a special Vuforia object called the "AR camera" was incorporated within the scene. Once configured, it provided the needed tracking capabilities.

- **The image detection** feature functioned by introducing a digital marker into the scene, allowing for the subsequent assignment of other objects to it. When the camera identifies this marker within the physical environment, it dynamically positions the assigned objects within that real-world context.
- Meanwhile, **the ground plane detection** required the introduction of a content placer. Once instantiated and scaled appropriately, it operated similarly to the image tracker, allowing for assigned objects to be positioned at a selected location on the ground.

In an effort to enhance user feedback, various Vuforia methods were linked to the game manager. For instance, when a ground plane or an image is successfully detected, it triggers real-time updates to the user interface and in doing so causes a more responsive AR experience.

Nevertheless, a noteworthy challenge in this endeavor was that the detected planes and images were always placed at an incline within the scene. This inherent sloping required various adjustments to maintain player immersion and to ensure smooth gameplay. For instance, the in-game gravity settings were modified to consistently orient the gravitational force in a downward direction relative to the level, allowing the ball to maintain its expected horizontal motion. Furthermore, if the magnet is placed on the level it is rotated accordingly such that it remains visually coherent.

Lastly, for image tracking purposes, a standard image from the Vuforia Example Package was employed.

5.8. Levels

Now that the inner workings have been explained, a look at the individual levels will be taken. It will cover their specific implementation, the intention behind the level design, and what lesson players will learn in said level.

5.8.1. Level 1 & Level 2

Level one and two can be seen in Figure 5.5 as a) and b) respectively. Level one was designed as a tutorial in mind. Therefore it is a simple, wide and very open area allowing the player to experiment freely and to try out the AR controls. The goal is also easy to reach to provide the player with an easy first victory and show them the game's win condition. It must be noted that other items such as the fences or the trees do not have collisions to further simplify the gameplay, but they were included to add to the atmosphere of the level. To achieve three stars, a player simply has to finish and collect the coin.

In this level, players learn about the fundamental of magnets and how they function. As such, they learn that magnetism is a force exhibited by magnets and that it can draw them closer or push each other apart. They get explained that this is caused due to the spinning movement of electrons and if they all spin in the same direction, a material becomes strongly magnetic. Lastly, it is described that the invisible magnetic force is often depicted by arrows and field lines. They are then encouraged to place a magnet and try it out for themselves.

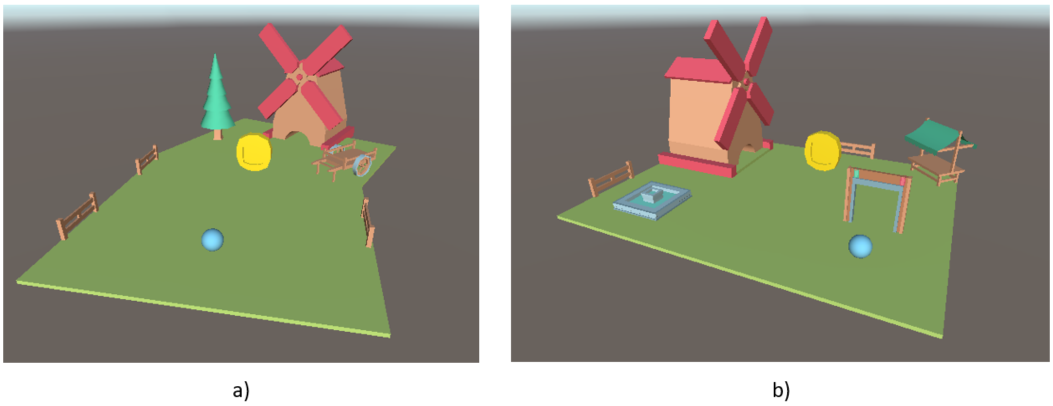

Figure 5.5.: Screenshots of MagnetAR a) Level 1 and b) Level 2

Level two is meant to be more advanced and a first challenge to the player and it introduces players to the mechanics of gates. In the case of this level, when the ball is shot through the gate the polarity of the magnet changes. This means the clock-wise magnetic force goes in the opposite direction. This was implemented by simply flipping the magnet. This encourages players to creatively deploy the magnet in order to reach the goal. In order to gain all three stars, players must complete the level, use the gate and collect the coin.

As the polarisation gate is the main gameplay mechanic of this level, players learn more information about poles in general. For example, it is explained that all magnets have areas with especially strong magnetic strength, the north and south poles. It is illustrated that as can be seen on the in-game magnet north is typically marked in red whereas south is blue or green. The most important fact was that different poles attract and same poles repel. But when they are the same, players are also taught that the force goes from north to south. Lastly, players get receive a hint to use the gate in this level.

5.8.2. Level 3 & Level 4

In Figure 5.6 the levels three (c) and four (d) are displayed. Level three aims to provide a challenge on a scale similar to level two. It presents players with a new type of gate, the material gate. When the ball passes through, it changes the material of the ball to a more metallic element. This causes the ball to be affected much more by magnetic fields, allowing players to reach further distances. This mechanic encourages the design of the level, being the longest of the four. The magnet has to be placed so the ball can be accelerated all the way into the goal. To reach all three stars the same conditions as in level two have to be met.

As there is a strong focus on materials in this level, the player receives a lesson about magnet materials. They learn that everything is magnetic to some extent which as they have learned before is due to the movement of electrons. Normally this movement canceld out, but when they align it becomes stronger. They then are informed about the fact that materials which keep their alignment well, such as iron, make for good permanent magnets. Last of all, the game then again suggest to use the gate to change the properties of the ball.

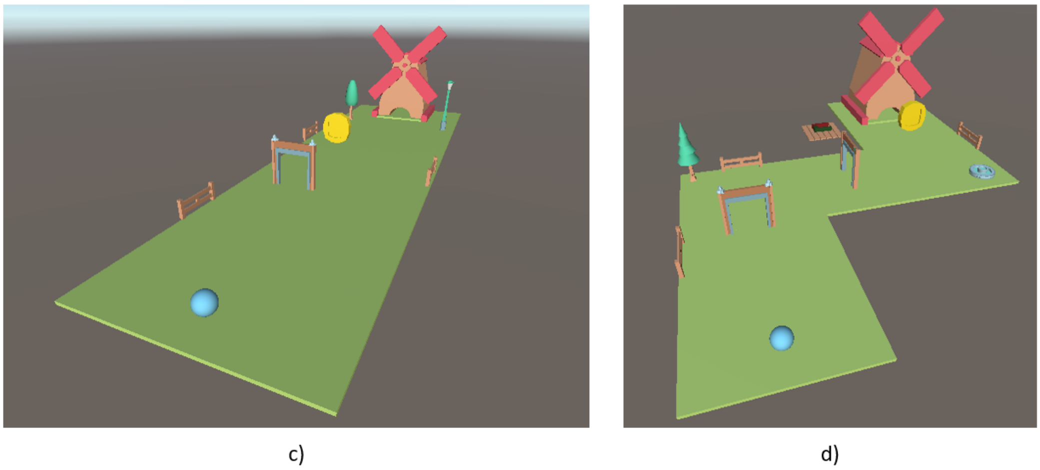

Figure 5.6.: Screenshots of MagnetAR c) Level 3 and d) Level 4

Level four presents a final challenge for players, here all game mechanics of the previous levels are combined to test what was learned over the last few levels. Additionally, an extra magnet is part of the course (see Figure 5.6 d) left to the windmill) to show users how different magnetic fields interact with each other when close to one another. To score, players will have to shoot through both the material gate and the polarisation gate. This means if players cleverly places the magnet, it undergoes a zig zag movement due to the changed direction and higher applied force. Players get three stars when both gates are used and the coin is once again collected.

The lesson reflects the fact that all game mechanics are revisited again, it summarizes most of the important lessons from the past few levels and explains them again. Most notably what field lines are, the alignment of electrons and how north/south poles can repel/attract.

5.9. Accessibility

To reach a wider audience and to make the game more comfortable to use for certain groups, two accessibility features were implemented.

5.9.1. Color-blind Mode

First of all is a color blind friendly filter. In order to achieve this, the package "Colorblind Effect" was used from Project Wilberforce. It provides a script which can be applied to an in-game camera. From this, a mode depending on the type of color-blindness can be chosen. According to Color Blind Awareness there are three different types of color blindness, to quote them "The different anomalous condition types are protanomaly, which is a reduced sensitivity to red light, deuteranomaly which is a reduced sensitivity to green light (the most common form of colour blindness) and tritanomaly which is a reduced sensitivity to blue light (extremely rare)" [8]. To aid people with said conditions, a filter gets applied to the camera. The effects and their corresponding conditions can be seen in Figure 5.7. However, it should be mentioned that this isn't an optimal solution, as the effect of color-blindness can vary a lot [8]. While not yet the case, a way to change the intensity of the filters needs to be implemented in the future to provide a better experience to those affected.

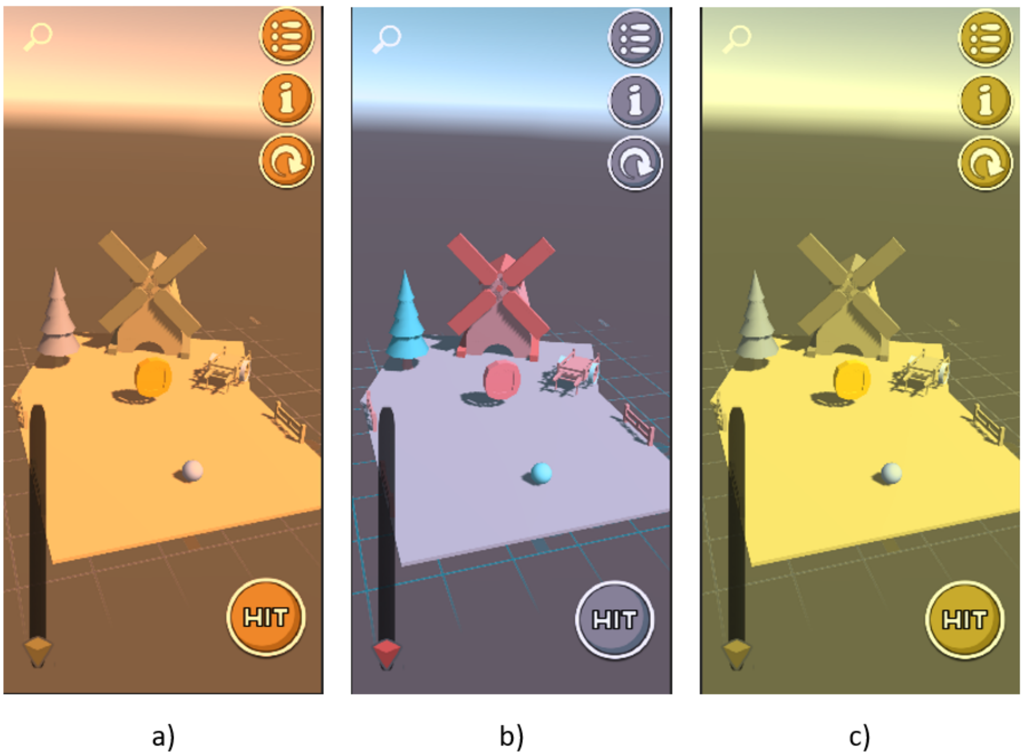

Figure 5.7.: Screenshots of color blind modes for a) Deuteranopia, b) Tritanopia and c) Protanopia

5.9.2. Left-handed Mode

As one of the AR design principles stated, the application should be able to be operated one-handed. However, the base game was designed with right-handed usage in mind. Therefore, to allow more users to comfortably use the app, a left-handed mode was implemented so they can use their dominant hand too. About 10% of the population are left-handed and therefore this feature could aid a large range of users [16]. This was implemented by identifying all interact-able menu items and then flipping their positioning horizontally. This caused centered elements to remain at the same location, but buttons such as the "Hit" or power slider changed spots. However, this could cause certain other UI elements to be covered up, which therefore had to be flipped as well or moved accordingly. While this is a rather basic approach, it provides a basis for further left-handed related improvements and feedback.

5.10. Implementation Conclusion

In summary, all of these elements were combined to create MagnetAR. It is important to highlight that while some of the scripts may not have been fully optimized, during play testing on the designated test device, no discernible performance-related issues were encountered. Now that it was illustrated how the application was constructed and how both SG and AR features were included, the focus turns to the evaluation of how effective these implementations have proven to be. This evaluation will shed light on the overall success and impact of the discussed game features.

6. Evaluation

To determine to what extent the game has achieved its objectives and to answer the proposed research questions, a small user study was held. It serves as a preliminary evaluation to get first insights into a player's game experience, to discover any potential issues and to find out how well participants absorbed the material taught. First it will be explained how the evaluation was conducted and how the questionnaire was designed.

6.1. Participants

The intended audience for this game were student and high schoolers with an interest in magnetism. Therefore, a total of six participants in the age group of 20-25 were selected to test the game. Participants were tested individually, but all were gathered when testing. In order to create a comfortable setting, the assessment took place in one of the participant's own residence. All of the participants had previous experiences with video games, however none have declared much experience with AR applications. Participants were also asked to rate their interest in Physics in general, most were only "somewhat" interested.

6.2. Procedure

Before playing the game, participants had to fill out basic information such as their gender, age and previous experiences (most importantly, their previous knowledge regarding magnets). Following that, players were shown the tutorial and given a quick introduction to the gameplay. Afterwards, participants were tasked with playing the first four levels of the game. If they wanted to stop however, participants were always allowed to quit. After finishing the game, they were tasked with finishing the rest of the questionnaire. For testing, an iPhone 11 was used. The procedure for one person took about 30 minutes.

6.3. Questionnaire

The full questionnaire can be seen in Appendix A. It consists of three main parts. The first were general demographic questions and previous knowledge, where participants got asked to explain what they currently know about magnets. This is to determine possible trends and differences among certain groups of people, as well as to ascertain what new knowledge players have gained in comparison to their current knowledge.

Afterwards, the core module of the Game Experience Questionnaire created by IJsselsteijn et al. [18] was included. It asks participants to rate the game for several categories in order to develop a score. There is an overall score for different game related sections such as competence, immersion, flow, tension, negative and positive affect, and challenge. This was used in order to determine the quality of the player experience, which has shown to be a good method according to a review by K. Norman [25] stating it to be a "reasonable and applicable in studying player experiences with video games".

Lastly, some questions were asked regarding the design choices based on the principles explained in the game concept section. For example, participants were asked whether they could play the game one handed and if the star system encouraged replay-ability. This was to establish the effectiveness of some of the design principles used. Following this, general questions about the game were asked such as aspects they liked and disliked, or how it could be improved. This was done in order to measure general feedback and to spot the effects of certain techniques used throughout the development process. At the end, players were tasked with listing what they have learned about magnets, to see the difference in knowledge compared to before playing MagnetAR.

6.4. Results

Now that the procedure and questionnaire have been clarified, the results will be shown. To calculate the results of the evaluation, the mean average of the answers was taken. Firstly, in Figure 6.1 the results of the game experience core module can be seen. Here the score 0 represents strong disagreement whereas 4 is strongly agreeing.

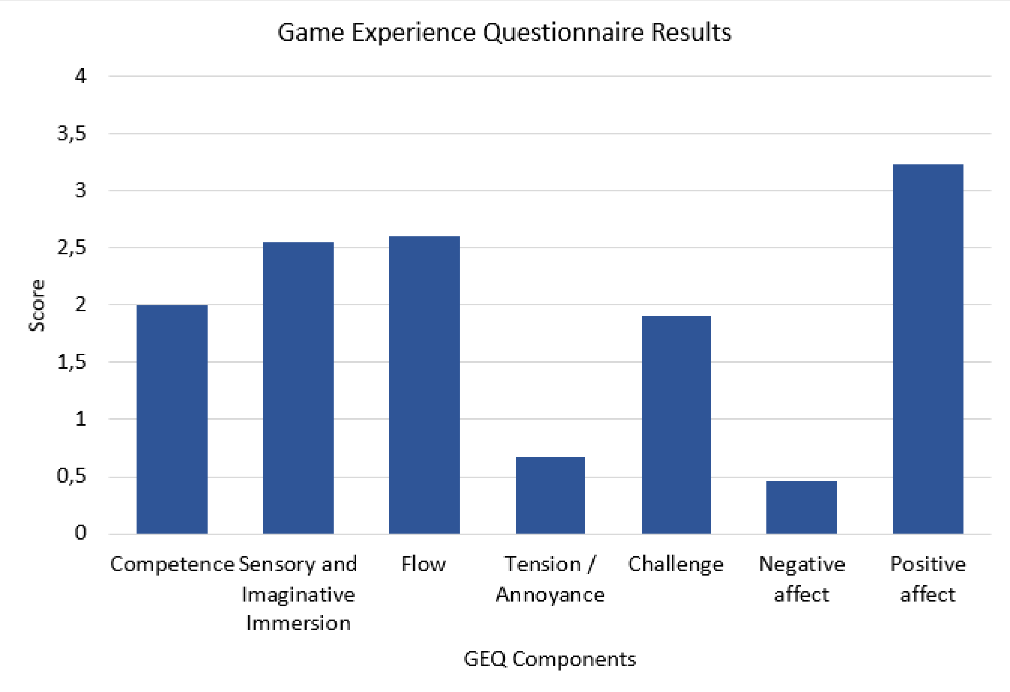

Figure 6.1.: The average results of the GEQ core module questions

As can be seen, the most notable module was the Positive Affect with a score of 3.23. On the other hand, rather low scores were achieved in the categories of Tension/Annoyance and Negative affect. Both extremes are a good sign that the game performed well. More average scores are Competence with 2.00, Sensory and Imaginative Immersion at 2.56, Flow at 2.60 and Challenge at 1.90. No significant change between demographics was able to be established due to the fact that most of the participants had similar traits with all of them being in a similar age group of 20-25, all having previous experience with video games and almost all of them being male.

In regards to user experience, additional questions were asked also on a scale from 0 representing "very bad" to 4 meaning "very good". They were tasked with rating the user interface, the controls of the game, the tutorial and how familiar they were with the icons. Additionally, a space was provided for any further comments regarding these things. The results of these can be seen in Figure 6.2.

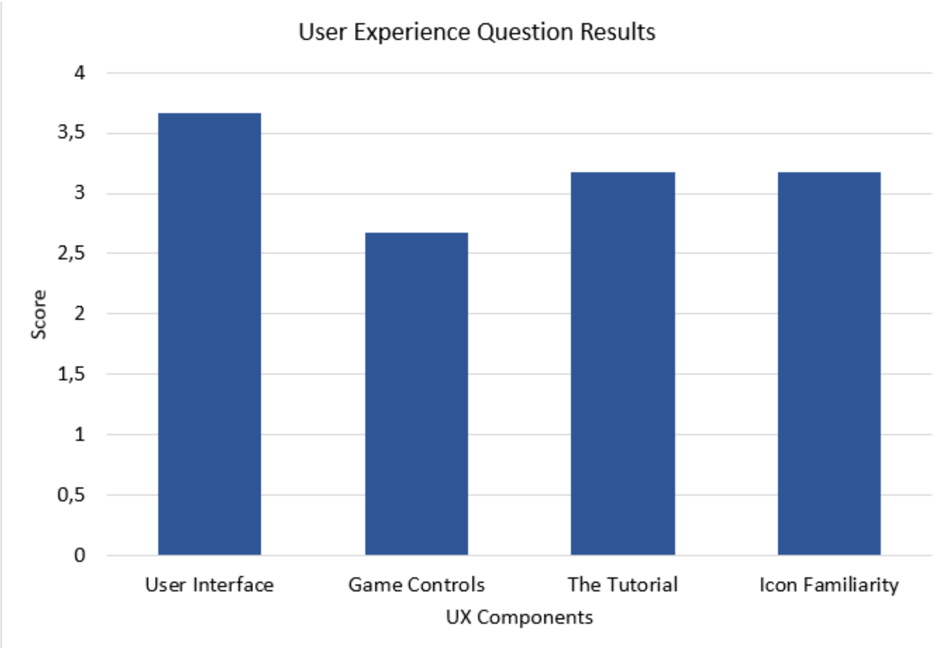

Figure 6.2.: The results of the user experience questions

Two participants commented that they accidentally kept closing the information screen due to the habit of pressing "X" and the "Read More" button being too prominent. It was also expressed that the tutorial wasn't needed and that the game mechanics could easily be picked up through gameplay.

Participants were asked further Yes or No questions regarding the AR and SG aspects. In regards to motion sickness, none of the participants suffered from it. Four of the players stated that, in this game context, they preferred the AR experience over playing it on a traditional monitor. Most of the participants ticked that the 3-star system encouraged them to replay the levels in order to get the full three stars. Also a majority of players expressed that they were able to operate the game one-handed, although a participant remarked that while they were able to use the app with one hand, they had to use their other hand and foot to move the marker. Finally, when asked whether they would play the game again if more content were to be released, all of the participants agreed.

The penultimate part of the questionnaire gave them space to for some open-ended questions such as what they enjoyed about the game, what they disliked or how they would use it. In terms of enjoyment no specific trend could be determined as the participants enjoyed a wide array of things. Answers ranged from simply appreciating AR usage, liking the challenge, and enjoying fiddling with the magnets and ball. However, there was a clear consensus among the participants that placing the level was often awkward and often accidental. This is due to the fact that players could tap anywhere on the screen to place the level, often resulting in players then accidentally placing the level upon missing the press of a different button. Almost all also expressed that they would use this game in their free time or to challenge themselves a bit. When asked how the magnetism could be improved, a majority were satisfied but would've preferred further options such as more obstacles and being able to modify aspects of the magnet (e.g. strength, rotation). Lastly, participants were inquired how the game in general could be further improved. Most stated that the aforementioned dislikes should be fixed and that general bugs should be taken care of.

Finally, participants were quizzed on what they have learned after playing the game. Before, every participant was able to answer that magnets have a north and south pole and can attract or repel one another, nearly all also wrote that magnets are commonly made out of metal. Afterwards, while all of them were able to learn something new, the answers strongly varied. While others were able to learn a lot, some only learned very little from the experience. About a third memorized that the magnetism is caused due to movement of electrons, a fact that wasn't directly in the game but mentioned in some lessons on the information screen. The same third also remembered that the force in magnets flows from north to south, again a fact only in the information screen. Other than that, two thirds of the participants recalled that magnets can be made out of all kinds of materials and can also be stronger or weaker depending on the substance, this was also one of the mechanics in the game. Half of the players were able to glean from the game that the polarity in magnets can be changed, another game mechanic. Last but not least, only one person explicitly stated that they now have a better understanding of what a magnetic field looks like around a magnet. It is noteworthy that about half of the players learned a lot, whereas the other half mostly only remembered surface level facts or things that were directly in the game.

7. Discussion

Now, the results of the evaluation will be discussed with the aim to answer the research questions of this thesis.

7.1. How effective is the game at relaying information about magnetism?

All of the participants were able to list more information about magnets after having played the game. Interestingly, the facts that were remembered the most were linked to the gameplay elements of each level. For example, the most remembered fact was that some materials can be a lot more magnetic than others and that the polarity of magnets can be changed. These two facts were game mechanics, in which players had to shoot through a gate to turn their ball into metal to boost the magnetic effect, or shooting through a different type of gate would flip their magnets polarity. However, information presented in the level and articles was scarcely remembered. Even though the role of electrons in magnetism was mentioned multiple times in the explanations, that fact seemed to have been forgotten by almost all participants. Therefore, while gameplay seem to be effective at relaying some lessons, the additional information is severely lacking and needs to be integrated better.

This was a similar result as with EdAR [28]. In their conclusion it was stated that while AR education has its merits, it actually hindered some aspects of the learning experience. In their experiment the AR group scored lower in the category of making the link between magnetic fields and physical motion, because participants wearing a Hololens would often disregard using available tools such as compasses and posters. They have focused less on the physical material, "likely due to highly stimulating AR visualizations" stopping them from learning some of the information.

Both of these findings suggest that AR is a useful tool at relaying certain material, however it can also be a hindrance and distract from other additionally provided facts. If one aims to better teach such additional facts, one must make an effort to include such information directly into the game and its mechanics.

7.2. How well does it motivate players to learn more about the topic?

All of the players answered that they would play the game again if more content were to be added, showing an interest in the topic and the game. However, while observing the players it was notable that almost all participants did not make use of the "Read More" functionality and often quickly read over the information in game as well. This indicates that players were more interested in the game than the information connected to it. So within the game the players interest has been captured, but this motivation hasn't sufficiently encouraged them to seek out further information outside of the experience.

In contrast, different discoveries were made with the game AROSE [7]. It was found that AR significantly improved the participants self-efficacy about studying physics and promoted specifically "Conceptual understanding, Higher-order cognitive skills, Practical work and Social Communication". Furthermore it caused students to have a positive learning attitude towards the activity and improved their learning motivation.

Therefore it can be concluded that while MagnetAR does achieve to motivate students to a certain extent, however given other research has shown such promising positive results more can still be done in order to achieve better results. Perhaps it is related to the approach of both games, AROSE focused heavily on a practical implementation with a focus on real experiments done virtually, while MagnetAR on the other hand chose a more playful approach to the situation. This difference could be one of the causes of this discrepancy and is worth further investigation in the future (see Ch. 8 Future Work).

7.3. How do serious game and augmented reality methods aid the educational experience?

Four people have stated that they prefer AR for this context over a typical 2D scene experience, with some stating that they enjoyed the novelty of it. However, the AR aspects were also the most criticized. Players would often accidentally move the stage, the tracking would be inconsistent and the level might not have been appropriately sized when placed on surfaces other than the floor. This is a large part due to configuration errors, however it shows while AR can be interesting it is incredibly important to get it right otherwise it can have a strong negative effect on the experience.

In terms of SG methods, it was a mixed result. Parts such as the "Read More" button or the information screen were ineffective as explained prior. However, some methods proved rather effective. For example, the implemented three star system (rewarding players for achieving certain challenges in a level) caused players to repeat levels multiple times as five players have answered that they replayed the levels to get three stars. Another AR guideline was to include a help menu with explanations how to operate the program and given that the tutorial was rated an average of 3.16 it was another positive addition. But, a player did comment that it in terms of learning, it would also be nice to have a quiz at the end of a level to test their knowledge.

All in all, while some of the design principles and methods were effective, some of them didn't have the effect they sought out to achieve. This could be caused by either a misunderstanding of the design principles and therefore faulty/ineffective implementation or perhaps these design principles were not entirely fit for the situation. It would be interesting to explore and apply more and other design principles to judge the impact of SG and AR methods effectiveness with more accuracy.

7.4. Discussion Conclusion

In conclusion, all of the research questions were able to be answered and compared to other findings. Overall using games to teach is an exciting new prospect and could potentially be very effective, but at it's current state some kinks still have to be worked out. AR has proven to be an effective approach and has shown to have several benefits, however some of its drawbacks and limitations have to be kept in mind in order to create a rounded experience. Using SG methods has shown a combination of successes and setbacks with some techniques encouraging the players to repeat levels and learn more, whereas some methods didn't have much of an effect.

In the following chapter, several approaches how to improve the projects and the findings will be laid out and explained.

8. Future Work

Even though the research questions were able to be answered, there is room for improvement for several aspects of this project such as it's conception, implementation and evaluation. Therefore, this chapter will explore some possible future work which could be done.

8.1. Conception

First of all, the usage of design principles could be improved. This project has used guidelines proposed by Gunther et al. [15] and Ko et al. [21] as is, however to ensure better results perhaps alternative guidelines should have also been taken into consideration. Furthermore, it is unclear whether both set of design principles can be applied to the same project without interfering with one another, potential comparability problems and synergistic effects of using SGs and AR should be further investigated.

In addition to that, seeing how projects such as AROSE [7] and EdAR [28] took a more experimental approach (which turned out to be quite effective), it would be interesting to follow a similar strategy for MagnetAR. For example, the current information players learn about is taken from online sources such as National Geographic [17] and Encyclopedia Britannica [12]. Instead, perhaps information from school syllabuses should be used to provide a closer experience to what is studied academically, opening up the way for MagnetAR to be used within classrooms.

8.2. Implementation

As mentioned in the discussion chapter, there were several bugs which while not game breaking, dampened the playing experience for the participants.

Firstly and most importantly, the ground plane tracking requires adjustment. The game performed fine when standing and placing it on the ground, however placing it on a table or playing while seated caused levels to appear too large. This could be solved by dynamically adjusting the camera settings, such as player height, depending on player actions or input. One participant suggested to include plus and minus buttons, to be able to scale levels themselves.

Secondly, the UI needs to be reworked. While participants rated the overall User Interface at 3.67, their comments expressed they would like to see some changes. The most prominent request a designated button for placing the level. The game currently allows players to tap anywhere on the screen to place a level, however a specific button was wished for to avoid accidentally moving the scene. Secondly, the information screen needs to be reworked.

They often accidentally skipped it or pressed "Read More" when they didn't mean to. This, according to the participants, was due to the placement of the buttons. For example the "X" on the top right reminded them of advertisements and "Read More" was often confused for a "Continue" Button. Therefore the UI needs to be carefully dissected and improved in the future.

Thirdly, the way the educational content is taught needs to be revamped. As just mentioned, players would often skip it, but even when instructed to read it, some of the information was lost. As described in the results section, participants mostly retained facts related to specific game mechanics. Therefore, a greater focus should be put on integration the information into the gameplay. For example, one fact that was often forgotten by the participants is that electrons align to form a magnetic field, a specific scene where players can interact with the magnet and view this phenomenon would perhaps help them. Such a concept could look similar as in Figure 8.1. This could further be enhanced by using Vuforia's object tracking, with which arrows could be displayed on a real magnet, making the experience even more immersive.

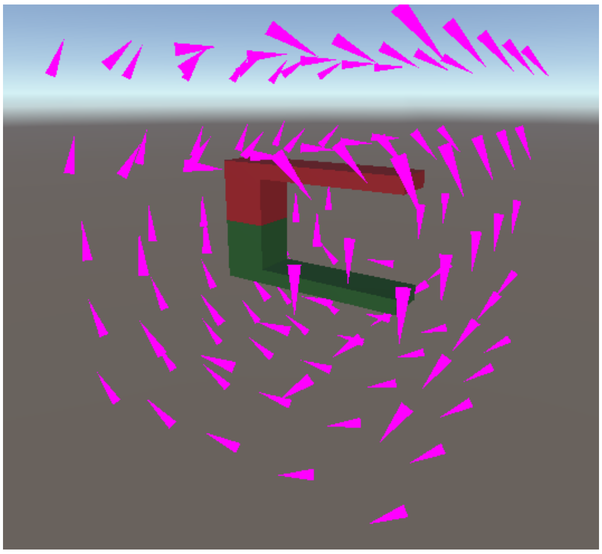

Figure 8.1.: Rough concept how electron alignment could be displayed.

8.3. Evaluation

While the current evaluation was able to deliver certain insights, it was also limited due to the fact that only six participants took part. In order to get better results, more participants should be found. Additionally, a bigger variety of demographics should be chosen, all of the participants had previous experiences with video games and most of them were also male. A better diversity could show other trends and correlations which weren't able to be determined with the current evaluation. It would also be interesting to see the usage over a larger period of time, to see if players remember some of the lessons learned even in the long term.

9. Conclusion

This thesis set out to explore the usage of SG games and AR to teach about the complex topic of magnetism. After the topic was introduced, research questions were formulated with the aim of assessing the effectiveness of this medium in educating players about magnetism and to gauge how well it motivates them to further learn about the subject. It was also investigated to what extent SG game and AR methods aid the educational experience.

After the goals of this thesis were defined, some related background information was covered to help to further understand the problem. As such, advantages and disadvantages as well as certain design principles regarding SG games and AR were listed. Alongside other game related terminology, readers were also informed about basic magnetism information to reflect what would be taught in the game.

Following that, a review of some related works were conducted, where a closer look at the projects AROSE, EdAR and Parallel were taken. Through this review, commonalities and differences were able to be identified which were used in order to find best practices and guide the conceptualization of this project.

Afterwards, with a better understanding of the topic, a proper concept and plan for the game was able to be established. This section explained the core gameplay mechanics and how the design principles were going to be done and implemented. A look was also taken at what specific educational content will be used and why the so called "low poly" art style was chosen. Then some accessibility options were considered and the timeline of the project was laid out.

Next, after the concept was laid out, the game implementation was covered. The application was developed using the Unity game engine, the Vuforia AR package and a previous project by Aymane Chaoui, Matthias Mitschele, and Felix Bartossek [3]. At its core, the game consists of a game manager, the user interface, the Vuforia engine and a physics package. The chapter explains in further detail how these components work on their own and how they interact with one another. It was also described how they levels were structured and what lessons they teach. Then the inclusion of some accessibility options were detailed.

Then, as the game implementation has been explained, an evaluation followed. A total of six participants were tasked with playing the game and filling out a questionnaire. The questionnaire contained questions regarding their demographics, their previous experiences, what they have learned and the core game experience questionnaire module. While the number of participants was low, the evaluation still served to give a rough estimate of the findings. Overall the game was received positively.

Subsequently the results were discussed and compared to the related works in order to answer the proposed research question. It was found that AR is a useful tool for teaching, but if not careful can also come in the way of certain things (e.g. disregarding other available tools due to the presence of AR alternatives [28]). To answer the question of motivation, players were interested in further playing the game if more content were to be released, however players showed no interest in further learning about it on their own. This was in contrast to AROSE where it was reported to have increased motivation and encouraged a positive learning attitude [7]. Lastly, some of the design principles regarding both SG games and AR were effective whereas some didn't have much of an influence.

Lastly, possible future improvements or alternative approaches were presented. For example, the usage of design principles could be refined by taking into account further guidelines. In terms of implementation, a few bugs were discovered and undesirable features found which can be ironed out. The most prominent things requiring attention are the reworking of some user interface elements, a more comfortable tracking experience and a better suited integration of educational content. Finally, as the participant count was quite low an evaluation with more people could be held, optionally with a bigger demographic of people and over a longer period of time.

In conclusion, this research shows that using SG AR games can make complex science a bit easier to learn in a fun and interactive way. This new approach could change how we learn and might shape the future of education in our tech-driven world. As we look forward, combining SG games with AR holds great promise for creating captivating, educational experiences that inspire both curiosity and understanding among learners.

List of Figures

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A. Questionnaire

Demographic Questions

Please state your gender:

- o Male
- o Female
- o Other _______________

Please state your age:

- o <18
- o 18-29
- o 30-44
- o 45-64
- o >64

Previous Knowledge

Do you have any experience with video games?

- o Yes
- o No

If yes, what kind of experience?

On a scale of 1 to 10, how much do you enjoy playing video games? (1 not at all – 10 very much): ___

On a scale of 1 to 10, how much do you like physics? (1 not at all – 10 very much): ___

To the best of your abilities, explain what you know about magnets.

Game Experience

Please indicate on a scale of 1-5 how you felt for each of the items in the table below.

	Not at all (0)	Slightly (1)	Moderately (2)	Fairly (3)	Extremely (4)
I felt content					
I felt skillful					
I was interested in the game's story					
I thought it was fun					
I was fully occupied with the game					
I felt happy					
It gave me a bad mood					
I thought about other things					
I found it tiresome					
I felt competent					
I thought it was hard					
It was aesthetically pleasing					
I forgot everything around me					
I felt good					
I was good at it					
I felt bored					
I felt successful					
I felt imaginative					
I felt that I could explore things					
I enjoyed it					
I was fast at reaching the games target					
I felt annoyed					
I felt pressured					
I felt irritable					
I lost track of time					
I felt challenged					
I found it impressive					
I was deeply concentrated in the game					
I felt frustrated					
It felt like a rich experience					
I lost connection to the outside world					
I felt time pressure					
I had to put a lot of effort into it					

Other

Did you experience motion sickness while playing the game?

- Yes
- No
- A bit

On a scale of 0 to 4 rate the following items (0 very bad – 4 very good)

The user interface: ___

The controls of the game: ___

The tutorial: ___

Familiarity with the icons: ___

Any further comments on these aspects:

Do you prefer the augmented reality experience compared to the typical monitor experience in this game context?

- Yes
- No

Would you play this game again if more content got added?

- Yes
- No

Did you replay the levels to try to get 3 stars?

- Yes
- No

Were you able to operate the game one-handed?

- Yes
- No

What did you enjoy most about the game?

What did you dislike about the game?

How would you use this game? (as a study aid, in your freetime etc.)

How would you change/improve how magnetism was included in the game?

If you could include something in the game, what would it be?

How could the overall game be improved?

Other ideas and suggestions:

Retention

Again, after having played the game. To the best of your abilities, please explain what you know/have learned about magnets.