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Designing a Motivational Augmented Reality (AR) Math Learning App

Design Framework & Process

Masterarbeit

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von:

Huang Chen, BSc

it181512

Betreuer*in: FH-Prof. Dipl.-Ing. (FH) Matthias Husinsky
Zweitbetreuer*in: Mag. Dr. Christian F. Freisleben-Teutscher

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Abstract

Math skills are important in various fields, not only is it the basis for STEM (Science, Technology, Engineering, and Mathematics) studies, but it is also frequently needed in daily life. Most schools have mathematics as a compulsory subject, but it often reported as one of the least favourite subjects by students. The lack of motivation has often been described as the cause of it. Consequently, many students take private tutoring, which not every family can afford. Technological advancements can help with the above-mentioned problems. Amongst those is *augmented reality* (AR).

This master's thesis aims at answering the research question "How can AR learning exercises for a math learning app be created to foster the motivation of upper secondary school students, especially for remote or blended learning situations?". This is achieved through two *design-based research* (DBR) iterations. The goal of the first iteration is to generate an overview of the main benefits an AR math learning app has for upper secondary school students. To accomplish this, a literature research, qualitative interviews, brainstorming sessions, and a design sprint where an AR prototype on the intersection point between two linear functions was created and tested. Using the findings of the first iteration, the prototype was refined in the second iteration. The prototype was improved using *principles of the multimedia learning theory* (Richard E. Mayer, 2001) and tested using the *Reduced Instructional Materials Motivation Survey* (RIMMS) (N. Loorbach et al., 2015). Those scores were compared with the RIMMS results after students learnt traditionally from the book.

In the end, the research question was answered through providing a suggestion for a design framework and a process framework. For the design framework, this thesis suggests using a combination of the multimedia learning theory (Richard E. Mayer, 2001), and the ARCS-V (Keller, 1987) model to create motivational AR exercises. Regarding the process framework, Keller's 10-steps motivational instruction design framework (Keller, 2010, 2016) was enhanced with suggestions on using different approaches, dependent on the goal of an intervention.

Kurzfassung

Mathematik spielt in vielen Bereichen eine wichtige Rolle. Sie bildet nicht nur die Basis für MINT-Themen (Mathematik, Informatik, Naturwissenschaft, Technik), sondern wird auch häufig im täglichen Leben benötigt. Zusätzlich ist Mathematik in den meisten Schulen ein Pflichtfach, ist jedoch eines der unbeliebteren Fächer bei Schüler*innen. Oftmals wurde eine fehlende Motivation beobachtet. Dies hat zur Folge, dass viele Schüler*innen private Nachhilfe nehmen müssen, welche sich nicht jede Familie leisten kann. Technologischer Fortschritt kann helfen, um die oben genannten Problemen zu lösen. Unter diesen Entwicklungen befindet sich *Augmented Reality* (AR).

In dieser Masterarbeit wird folgende Forschungsfrage beantwortet: „Wie können AR Beispiele für eine Mathe-Lern-App gestaltet werden, um die Motivation von Oberstufenschüler*innen, vor allem bei Fernlehre oder Mischbetrieb, zu fördern?“ Um diese Frage zu beantworten, werden zwei Iterationen des *Design-Based Research* (DBR) Ansatzes durchgeführt. Das Ziel der ersten Iteration ist es, einen Überblick über die Hauptvorteile einer AR Mathe-Lern-App für Oberstufenschüler*innen zu schaffen. Dies wird durch eine Literaturrecherche, qualitativen Interviews, Brainstroming Sitzungen, und einem Design Sprint erreicht. Dabei wird ein AR Prototyp entwickelt, welcher ein Beispiel aus dem Themengebiet Schnittpunkt zweier linearen Funktionen behandelt, und getestet. Die zweite Iteration nutzt die Erkenntnisse der ersten Iteration, und verbessert den Prototypen mit Hilfe der *Kognitiven Theorien des multimedialen Lernens* (Richard E. Mayer, 2001). Dieser Prototyp wurde mit Hilfe des *Reduced Instructional Materials Motivation Survey* (RIMMS) (N. Loorbach et al., 2015) getestet.

Die Forschungsfrage wird durch einen Vorschlag für ein Design-Framework und ein Prozess-Framework beantwortet. Das Design-Framework empfiehlt dabei die Kognitiven Theorien des multimedialen Lernens (Richard E. Mayer, 2001) mit dem *ARCS-V model* (Keller, 1987) zu kombinieren, um motivierende AR Beispiele zu erstellen. Bezüglich des Prozess-Frameworks wird ein Vorschlag präsentiert, wie Kellers 10-Schritte des Instruktionsdesigns für Motivation (Keller, 2010, 2016) abhängig vom Interventionsziel angewendet werden kann.

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1 Introduction

Math skills are important in various fields. According to the forecast of Cedefop, the “European Centre for the Development of Vocational Training”, the need for STEM (Science, Technology, Engineering and Mathematics) workers in the EU will continue to rise between 2014 and 2025 (*Rising STEMs*, 2014) although there is already a shortage of qualified STEM workers internationally (Müller et al., 2013).

Not only is mathematics the basis for other STEM subjects, but it is also often needed in daily life. Nonetheless, it is not a secret that mathematics is one of the least favourite subjects amongst students (Gafoor & Kurukkan, 2015). The reasons why students do not find mathematics or math classes appealing are varied. For example, some students state that they do not see the necessity to learn maths for their daily life or that they find maths boring. Others explain that they do not understand the mathematical problems stated in their textbooks and the explanations by their teachers. Additionally, students with low self-efficacy in mathematics doubt that they can understand mathematical concepts in general, often resulting in math anxiety (Tobias, 1991; Gafoor & Kurukkan, 2015). All those components added together, result in a lack of motivation to learn mathematics, which in turn lowers the overall mathematical literacy (Keller, 2010).

Moreover, most schools have mathematics as a compulsory subject. Therefore, students are obliged to learn maths to advance to the next grade (Bundesministerium für Digitalisierung und Wirtschaftsstandort, 2020). In Austria, students often take private tutoring. According to the Austrian chamber for workers and employees, private tutoring is mostly taken by upper secondary school students. In year 2019, an Austrian family averagely spent € 580 per child on private tutoring on average. However, not every family can afford private tutoring (IFES, 2019). Given the above, it shows that motivating low-cost alternatives are needed to convey mathematics to decrease social injustice.

Often, technological innovations can help with the above-stated problems. Amongst the technological advancements over the last years is augmented reality (AR). According to Milgram AR can be described as overlaying simulated visual

data over the real world (Milgram et al., 1995). The 2012 K-12 edition of the *Horizon Report*, a guideline about emerging technologies for teaching and learning, enforced to implement AR in educational settings. This report stated that the main advantage of AR is its ability to convey information in new and different ways (Johnson et al., 2012). According to the state-of-the art in research, the usage of AR shows various potentials in educational settings. In a systematic literature review, Diegmann and Schmidt (2015) identified 14 advantages which AR has over other methods in formal school settings. Amongst those are improved attention span, concentration, satisfaction, creativity, a better learning curve, spatial understanding, and memory retention (Diegmann et al., 2015). Moreover, AR also shows great potential in informal settings, such as museums (Sommerauer & Müller, 2014). In 2017, Chen et al. conducted a literature review on AR in educational settings. The researchers have recognised that there is a yearly rise in papers about AR in the field of education. Additionally, they have recommend conducting more research on the usage of technology in different settings, such as in primary and secondary education (P. Chen et al., 2017).

1.1 Research Objectives

As a result of the previously mentioned issues, the start-up idea of *ARchimedes – Your pocket math tutor* emerged. *ARchimedes* is a math learning app which conveys abstract math concepts with different multimedia methods to upper secondary school students. During the environmental analysis for *ARchimedes*, it showed that many math learning apps use videos, storytelling, and simple interactions, such as drag and drop exercises. However, there are only a few apps offering AR features. Consequently, this thesis focusses on creating a design framework and a design process for motivational AR exercises for a math learning app. This thesis aims at answering the following research question and following sub-questions:

How can AR learning exercises for a math learning app be created to foster the motivation of upper secondary school students, especially for remote or blended learning situations?

- Which main benefits of using an AR mathematics learning app for upper secondary school students can be found during research?
- Which elements should a motivational AR learning experience include?
- How should a creation process look like to effectively create motivational AR math learning experiences?

1.2 Research Process

To answer the previously mentioned research questions, two design-based research (DBR) iterations[1] were conducted (Chapter 6 – Empirical Study). The goal of the first iteration was to generate an understanding of the potential and the main benefits of AR technology in math education. For this purpose, multiple methods were used.

- The literature research contained studies about the methodology (Chapter 2 - Design-based Research), the state-of-the-art AR technology (Chapter 3 - Augmented Reality (AR)), and the state-of-the-art research on the usage of AR in educational settings (Chapter 4 - AR in Educational Settings).
- Qualitative interviews with an upper secondary school math professor and six students were conducted, as well as a brain storming session with the same math professor.
- A so-called design sprint[2] was conducted where an AR prototype (Chapter 7.3.2 - Prototype 1 – Indirect Augmentation with an Island) was created and tested.
- In the end, all data were analysed and served as a basis for the second iteration.

The goal of the second iteration was to generate a suggestion on how to create a motivational AR exercise for a learning app by going through the following process.

- The first prototype was refined using the findings of the first iteration, the multimedia learning theory (Chapter 5 - Multimedia Learning Theory) and motivational theories, especially the ARCS-V model (Chapter 6.2 - ARCS - V Model).
- Consequently, a second prototype was created (Chapter 7.3.3 - Prototype 2 – Augmentation of a coordinate system).
- This prototype was tested on six Austrian upper secondary school students, and its motivational effects were compared to the students' motivation after learning traditionally with a book. For testing, the Instructional Materials Motivation Survey (IMMS) (Chapter 6.3 - IMMS & RIMMS) was used.

[1] Explanation on what DBR iterations are can be found in Chapter 2 - Design-based Research

[2] Originally, the design sprint concept was formed by Jake Knapp (2016). The idea behind design sprints is to solve a problem within a short amount of time and combines design thinking and agile methods.

- In the end, the data was analysed, the findings were combined and discussed (Chapter 8 - Discussion), concluded, and an outlook to the future was given (Chapter 10 - Conclusion).

1.3 Thesis Structure

This thesis will first give the results of the literature research (Chapter 2, 3, 4, 5 & 6). Then, in the empirical part (Chapter 7), details on the methods (Chapter 7.1), participants (Chapter 7.2), created prototypes (Chapter 7.3), data collection & procedure (Chapter 7.4), and the analysis of the results (Chapter 7.5) will be presented. In Chapter 8, all findings will be combined and discussed. In the end, an outlook to the future will be given, and the thesis will be concluded (Chapter 10).

2 Design-based Research

Design-based research (DBR) is a relatively young research paradigm compared to traditional research and has first been mentioned under the term design experiments (Brown, 1992; Collins, 1992). It shows differences to traditional research designs and connects educational research with real-world problems (Amiel & Reeves, 2008). Researchers see high potential in using DBR to effectively and efficiently implement technology into teaching and learning scenarios (Barab & Squire, 2004; Herrington et al., 2007; Wang & Hannafin, 2005).

This chapter introduces the design-based research (DBR) paradigm, which was used to conduct this study, described in Chapter 7.1 - Methodology. The terms covered in this chapter will be reused throughout the thesis.

2.1 Iteration Process

Amiel & Reeves (2008) visualised the DBR process in Figure 1, which shows the recreated representation of full DBR cycles. One full cycle can be defined as one iteration and consists of the analysis, the development of solutions, iterative testing and the refinements, and the reflection with the goal to create design principles. Later iterations do not necessarily need to start with the analysis but could also immediately start with e.g. further development of solutions or testing and refining the old solution. The findings of previous iterations serve as the basis for the following ones. The new iterations attempt to solve different problems than the old ones, by creating other solutions and by using refined methods. The iterations have the goal to create new design principles (Amiel & Reeves, 2008).

In this study, two iterations were conducted, which will be more closely described in Chapter 7.1 - Methodology.

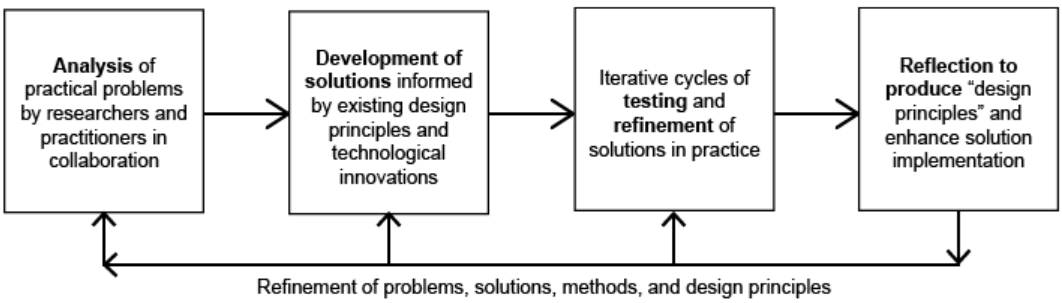


Figure 1. DBR approach, recreated (Amiel & Reeves, 2008)

2.2 Main Characteristics

In educational research, there are several synonyms for DBR, which are design experiments (Brown, 1992; Collins, 1992), design research (Edelson, 2002) and design science (Collins, 1992) When taking a closer look at the research design and research focus of each of these synonyms, there might be slight differences, however, there are certain characteristics which reoccur (Swan, 2014):

- **Creativity and Visionary**
  At the beginning of DBR, an initial design draft is created by researchers, usually in collaboration with practitioners with the aim to create an effective design (e.g. learning application, curriculum) (Swan, 2014; Wang & Hannafin, 2005). The design must be based on theories, analysed and tested in typical end user environments (Swan, 2014).
- **Ecologically Validity**
  The design is studied and refined in realistic settings by the researcher, without manipulating the occurring variables (Swan, 2014).
- **Interventionist, Iterative & Flexible**
  In the first iterations, researchers usually provide sketches or designs and might interfere during tests to make certain features work. Later, researchers mainly stay in an observer role. First iterations can be done in smaller and more favourable settings, to better find out the possibilities a certain type of intervention has. In later interventions, sample-sizes usually increase, and the typical target group will be selected (Swan, 2014). Nonetheless, DBR is flexible and allows a smaller sample size in later interventions, when e.g. a problem occurs which the researcher want to take a closer look at (Swan, 2014; Wang & Hannafin, 2005).
- **Theory Driven**
  DBR must be based on previous theories, and generate generalizable theory in the end (Edelson, 2002; Swan, 2014).

Moreover, in literature, the importance to use a variety of different research methods to answer one research question is highlighted too (Wang & Hannafin, 2005).

2.3 Generated Theories

Edelson (2002) describes that with DBR, three types of theory can be developed. Those are domain theories, design frameworks and design methodologies.

Domain theories describe two components. Firstly, the challenges and possibilities which occur in an environment, to understand the circumstances why and how an intervention will be implemented. Secondly, why certain interventions work or do not work, in the context of environmental influences (Edelson, 2002).

Design framework focusses more on the design or prototype itself. It describes which parts of a design or prototype need to exist to achieve a certain goal. At this point, a coherent guideline to overcome certain design challenges which occurred during research will be created (Edelson, 2002).

Design methodologies provide a guideline for the process, rather than the design or product. This contains statements on the sequence of methods used to achieve a certain goal, the expertise required in the process, and which role should be played by which individual (Edelson, 2002).

2.4 Conclusion - DBR

This chapter provides an overview on what design-based research is, how a general iteration process looks like, what the main characteristics of DBR are, and what theories can be created from this process. The terms that were mentioned in this chapter will reoccur throughout this thesis. Additionally, in the empirical study part (Chapter 7), two DBR iterations were conducted to answer the research questions. Chapter 7.1 - Methodology, provides an overview on how the DBR approach is used in this thesis, and which methods were used in which phase. Chapter 7.2 contains information about the participants, Chapter 7.3 presents the created prototypes, Chapter 7.4 deals with the data collection and procedure, and Chapter 7.5 provides the analysis and the results of both iterations.

3 Augmented Reality (AR)

There are multiple attempts to define augmented reality (AR), which is why this chapter is dedicated to introducing different taxonomies to define AR. The goal of this chapter is to give an overview on different AR delivery systems and to help understanding how AR is defined in the context of this thesis. Additionally, the answer on why this thesis focusses on handheld AR applications will be provided.

3.1 General Taxonomies

Milgram (1995) describes the well-known *reality-virtuality continuum* model which brings AR into a bigger context. This taxonomy describes the differences of AR to virtuality, augmented virtuality (AV) and mixed reality (MR). Figure 2 shows the recreated version of the reality-virtuality continuum. While far-left side portrays the physical environment, also known as our reality, the far-right side of this continuum stands for a complete virtual environment (virtuality) (Milgram et al., 1995).

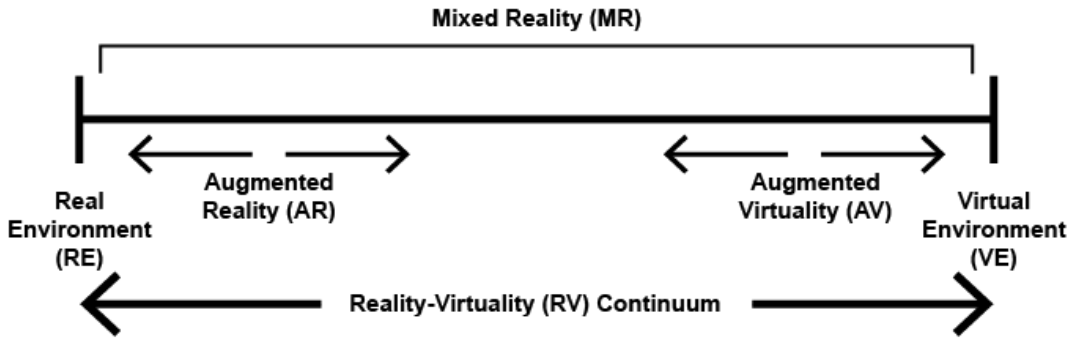


Figure 2. Reality-virtuality continuum, recreated (Milgram et al., 1995, p. 283)

Every mixture in between these extremities is described under the umbrella term “mixed reality” (MR). While in AR, information is added to the real environment, AV describes a virtual environment which is enhanced through real-world information (Milgram et al., 1995). Virtual reality (VR) is similar to augmented virtuality. The difference between AV and VR is, is that in AV, the virtual world is augmented by only visual information, e.g. webcam camera, (Milgram et al., 1995), and in VR the real-world input contains movement and interaction data.

Another taxonomy, defined by Azuma (1997), focusses on defining AR more in detail. Their model describes AR to be any system which has the subsequent three characteristics:

1. blending virtuality and reality together,
2. interaction with the system is in real-time, and
3. the tracking, which describes the registration of the world and the positioning of virtual object, must occur in three dimensions.

Azuma describe that, although AR research is mostly focussed on enhancing the real world with visual components, other AR systems which stimulate other senses are called AR as well. However, the three above-mentioned requirements need to be fulfilled, for a system to be counted as augmented reality (Azuma, 1997).

3.2 Delivery Systems for AR

The delivery systems currently available can be differentiated between head-attached systems, handheld systems, and spatial systems. Figure 3 shows an overview of different AR image generation techniques, recreated from Bimber's & Raskar's book on spatial AR (Bimber & Raskar, 2005).

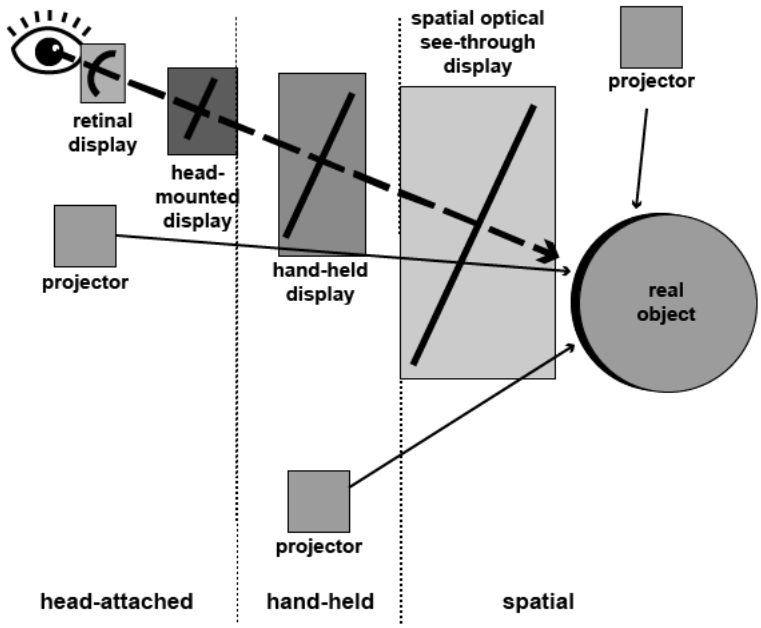


Figure 3. Overview of AR delivery systems, recreated (Bimber & Raskar, 2005, p. 72).

Head-attached systems or head mounted displays (HMDs) can be differentiated between optical see-through and video-see-through techniques (Bimber & Raskar, 2005). Currently well-known optical see-through systems would include e.g. HoloLens[3] and Magic Leap[4]. Established video-see through systems would be e.g. VARJO[5], Oculus Quest[6], and Gear VR[7].

As Figure 4 shows how a simplified video see-through system combines the camera-image and the virtual image in a computer and then render both content onto the display. The image on the display is then perceived by the user. When a user is wearing an HMD that uses a video see-through system, the vision is usually completely shielded off from the real environment (Bimber & Raskar, 2005).

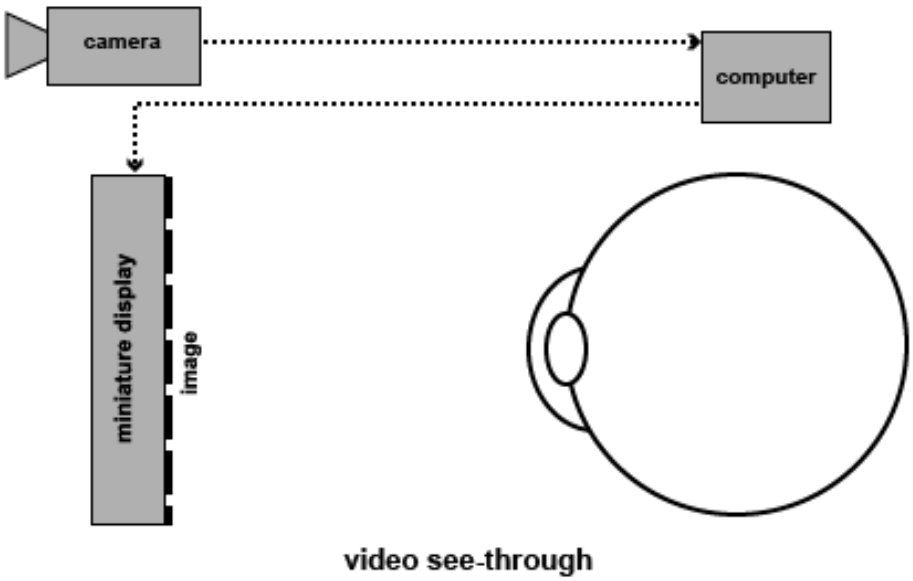


Figure 4. Simplified visualisation of video see-through systems, recreated (Bimber & Raskar, 2005, p. 74)

When using optical see-through systems, Figure 5, the users wear (darkened) glasses. This allows the users to perceive the real environment though the glasses. At the same time, computer-generated assets are projected onto a miniature display. Both, the real world, and the computer-generated image are sent through

[3] https://www.microsoft.com/en-us/hololens

[4] https://www.magicleap.com/en-us

[5] https://varjo.com/

[6] https://www.oculus.com/quest/

[7] https://www.samsung.com/global/galaxy/gear-vr/

a beam-splitter, which allows the user to perceive the channels as one (Bimber & Raskar, 2005).

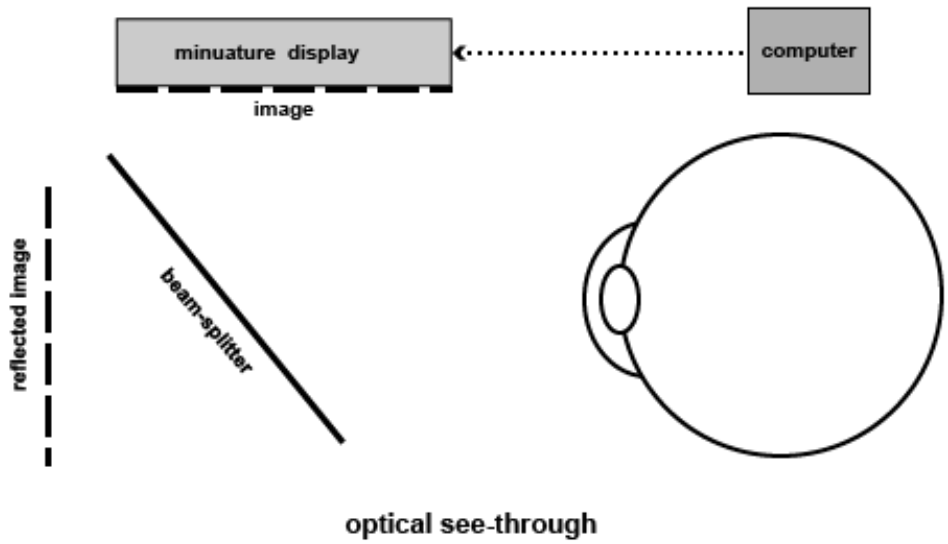


Figure 5. Simplified visualisation of optical see-through systems, recreated (Bimber & Raskar, 2005, p. 74)

Although effective AR HMDs became more popular for research and development purposes in recent years, they still are not widely available in the general public. Additionally, the price range can vary depending on the used system. For instance, currently Oculus Quest costs € 450 (Oculus Quest, 2020), and VARJO's VR-2 Pro costs over $ 6000, which is approximately € 5000 (Lang, 2019). When showing HMDs to people who are inexperienced with AR, they might be reserved to put on the device due to e.g. weight and size. However, the barrier is smaller when an optical see-through HMD is used, because with those, users are still able to see the real environment. Additionally, both, video see-through and optical see-through HMDs might cause eyestrain (Bimber & Raskar, 2005). Nonetheless, current head-attached AR systems often offer the opportunity to move the hands freely or use controllers as input device.

When talking about **handheld AR systems**, often smartphones and tablets come to one's mind. The biggest advantage in those systems, is its wide availability amongst people. Compared to other systems, people's perseverance to use handheld AR systems might not be that high, because they already use the device in daily life. However, when it comes to comfortability, handheld AR might cause arm fatigue. Additionally, it might be immersion breaking, because the screen does

not cover the entire field of view of the eyes, which might cut off the augmentation because of the limited screen-size (Schmalstieg & Höllerer, 2016).

Spatial AR systems often use displays which are detached from the users and integrated to the real-world environment. One of the biggest advantages of Spatial AR systems, compared to HMDs and handheld AR is its impact on human factors, such as fatigue, eye strain and cumbersomeness. Additionally, usually those systems provide a better visual quality, including field of view and resolution, and have fewer technical issues, related to tracking and lighting. Often, spatial AR systems are implemented using video projector technologies, transparent screens, or holograms (Bimber & Raskar, 2005). An example for using a projector would be MARVIS (Medical Augmented Reality VISualizer) (Gierwiało et al., 2019). In this study, a projector visualises internal information onto a liver phantom, helping medical students to decrease the errors during the process of syringe insertions. To project the visualisation accurately, the system tracked not only the liver phantom, but also the user's head. This study reported e.g. reduced eye-strain and the researchers were satisfied with its accuracy (Gierwiało et al., 2019). However, spatial AR systems are mostly location bound, and can therefore, not always be accessed (Bimber & Raskar, 2005).

AR interventions for formal educational purposes mostly use screen-based displays (da Silva et al., 2019), tablets or other mobile devices (Maas & Hughes, 2020). This is because screen-based displays (e.g. PCs) are widely available in schools and that most handheld AR systems are cost-efficient (da Silva et al., 2019). However, there are also papers using HMDs and (spatial) displays, whiteboards and spatial projector technologies (da Silva et al., 2019; Maas & Hughes, 2020). In 2019, Garzón et al. noticed an increase in the number of studies conducted on AR in educational settings, caused by the rise of technological advancements and availability of smartphones (Garzón et al., 2019). Therefore, researchers are expecting a rise in popularity using handheld AR in education in the future (Akçayır & Akçayır, 2016).

Due to the wide-spread use and acceptance of smartphones, this thesis will focus on creating prototypes for handheld AR systems, and definitions for handheld AR systems will be discussed in the next chapter. Nonetheless, definitions, differentiations, and an overview of commonly used terms was given. Additionally, an impression on the existing AR system was provided. These taxonomies and the overview of the systems will be used as a reference to create application lists with a variety of AR system to introduce AR to unexperienced students or teachers.

3.3 Handheld AR

In more recent research, there has been multiple attempts to classify augmented reality technology more closely. To name a few, Gjøsæter (2012) provided a taxonomy for categorising handheld AR applications, e.g. phones and tablets. He shows that handheld AR application can be broken down into six layers, as shown in Figure 6. The layers are the following (Gjøsæter, 2012):

1. World
2. Registration
3. Augmentation
4. Graphical user interface (GUI) or WIMP (Windows, Icons, Menus, Pointer)
5. Device
6. User

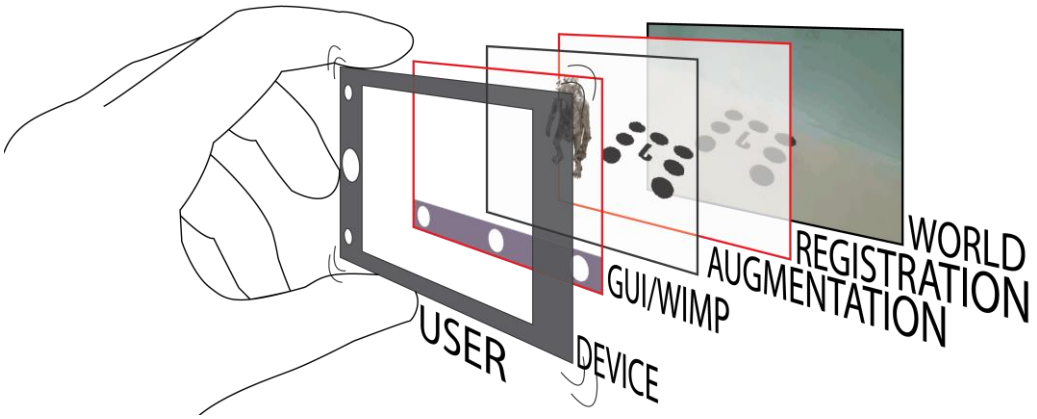
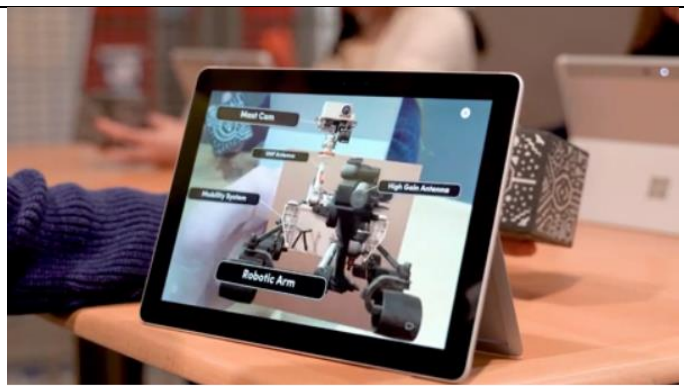
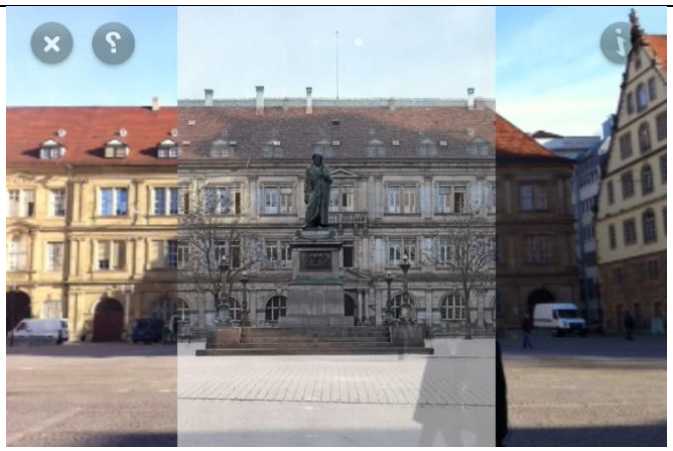


Figure 6 Visual representation of a taxonomy of handheld AR systems, permission obtained (Gjøsæter, 2012, p. 2)

The world layer describes which part of the real environment is being tracked. In Figure 6, the world layer is being represented as a real-world environment with a marker on it. The registration layer shows how a certain marker is being tracked. For example, the Figure 6 shows the extracted marker only, without the background of the real-world. The next layer, augmentation, is defined as the components which are added onto the real environment, which is portrayed as a 3D-object of a robot. The fourth layer deals with the GUI (graphical user interface) and WIMP (windows, icons, menus, and pointer). Although AR enables a more natural interaction with 3D objects, especially hand-held AR systems often require e.g. buttons or other GUI elements. The fifth layer is about the used device, which is important when it comes to e.g. the available sensors, and the device's limitations. The last layer deals with the impact of an AR application on users and the user experience (UX), portrayed as a hand in Figure 6 (Gjøsæter, 2012).

While the above-mentioned taxonomy by Gjøsæter (2012) provides an overview of layers, which handheld AR applications have, it does not subdivide the above-mentioned layers in detail. However, there is an attempt by Edwards-Steward et al. (2016) to classify different augmented reality technologies more precisely. They differentiate between two main categories, which are trigger-based AR and non-trigger-based AR. Table 1 shows the adapted taxonomy with an EdTech or entertainment app as example for each sub-category (Edwards-Stewart et al., 2016).

Trigger-based AR	
1a) Image-based markers	 *Figure 7. An example for an augmented history book page (*Areeka - Augmented Reality Education*, 2018)*
1b) Object-based markers	 *Figure 8. Object-based Marker example by Merge Labs (*Hands-On Digital Play & Learning | AR/VR Learning & Creation*, n.d.)*

2) Location based AR	 *Figure 9. Using GPS and other sensors to identify the placement of celestial bodies (*Star Walk 2 Preview Video. Guide to the Sky on Your Mobile Device*., 2015)*
3) Dynamic augmentation of objects	 *Figure 10. Snapchat Lens – Exemplatory 3D Face Mesh (Lens Studio - Lens Studio by Snap Inc., n.d.)*
4) Complex augmentation, combining dynamic object recognition and GPS location	 *Figure 11. Example for complex augmentation, using GPS and object recognition to overlaying old and digitalized images onto real buildings (*Eine App Für Die Zeitreise in Stuttgart - Studieren. Wissen. Machen*., 2012)*

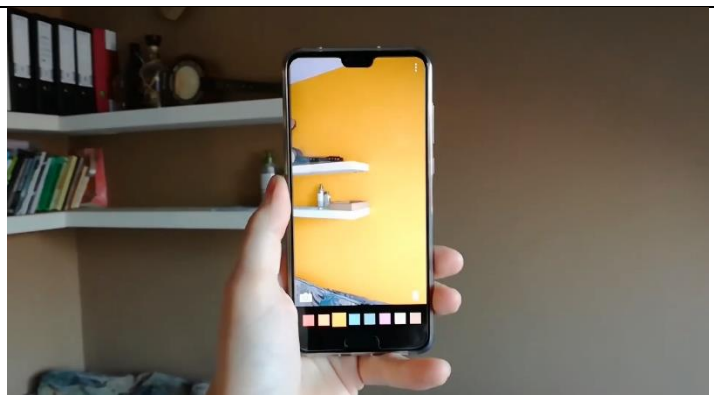
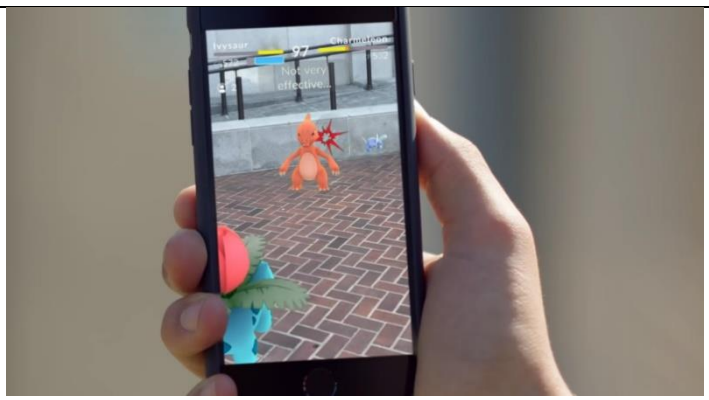
Non-trigger-based AR	
1) Indirect augmentation	 *Figure 12. An app which intelligently finds walls and paint them in a colour (Paint My Room - Google Play Video, 2020)*
2) Non-specific digital augmentation	 *Figure 13. Pokémon Go as an example for non-specific digital augmentation (Pokémon GO - Get Up and Go!, 2016)*

Table 1. Taxonomy by Edwards-Stewart et al. (2016) with added EdTech or entertainment apps (Edwards-Stewart et al., 2016).

When it comes to tracking techniques, researchers identify that most AR educational interventions make use of image-based AR techniques (P. Chen et al., 2017; Ibáñez & Delgado-Kloos, 2018), with marker-based AR being the most frequently used tracking type for formal education (Hantono et al., 2018; Maas & Hughes, 2020; Pellas et al., 2019; Saltan & Arslan, 2016). This is because this type of technology is easy to use (Saltan & Arslan, 2016), more stable and readily available than markerless techniques (Hantono et al., 2018). When it comes to providing better learning experiences, marker-based techniques are currently recommended until other more reliable and cost-efficient technologies are widely

available (Pellas et al., 2019). Location-based AR approaches are also commonly used (Hantono et al., 2018; Pellas et al., 2019) due to the availability of GPS, accelerometers, and gyroscopes (Hantono et al., 2018).

This chapter gives possibilities to differentiate handheld AR systems. The above-mentioned taxonomy by Gjøsæter (2012) focusses on handheld devices and its technical layers, while Edwards-Stewart et al.'s (2016) categories concentrate on the tracking technique. Both introduced taxonomies will be reused to describe and to break down the created prototypes in Chapter 7 - Empirical Study.

3.4 Conclusion – Augmented Reality (AR)

This chapter provides an overview of several taxonomies, defines common terms, presents the differences between AR delivery systems, including HMDs, handheld AR, and spatial AR. Due to the wide availability of smartphones, this thesis focusses on handheld AR systems, which is why this chapter presents a model to describe handheld AR systems, and differentiates common tracking techniques for smartphones. Those two models are helpful when it comes to describing AR prototypes, as in Chapter 7.3 - Created Prototypes. Although other delivery systems are not the focus of this thesis, they show the various possibilities which AR technology offers. Therefore, the different systems were used as a reference for application lists to show the variety of AR during e.g. brainstorming sessions.

4 AR in Educational Settings

The aim of this chapter is to provide an overview of the current research landscape of AR in educational settings. In the beginning, this chapter provides a general overview of the AR usage in different subjects. Later, more detailed studies about using AR in math education will be introduced.

4.1 General

Several literature reviews observe an increase in research carried out on AR in educational settings in recent years (Akçayır & Akçayır, 2016; Maas & Hughes, 2020; Pellas et al., 2019), with 2014 having the highest number of papers between 2009 and 2017 according to one literature-review (da Silva et al., 2019). Another systematic literature review stated that most of their 28 reviewed articles between 2010 and 2017 were published after 2013. Additionally, those researchers noticed that the majority of the studies are focussing on classroom activities, rather than out-of-class contexts (e.g. museums), and only one dealing with learn-at-home activities (Ibáñez & Delgado-Kloos, 2018).

Although the number of studies in this area is progressively increasing, the amount of articles, especially for the secondary school level, seems to be limited (Pellas et al., 2019). Garzón et al. (2019) found in their meta-analysis that most studies focus on primary education or on the bachelor level (Garzón et al., 2019). Other researchers recommend conducting studies on the topic of AR for K-12 students[8]. Moreover, a literature review focussing on research in K-12 education stated that it was a challenging task to find studies dealing with the usage of AR, VR or MR for this level of education. The same researchers concluded that studies might only be recently carried out, due to the increase of smartphone efficiency and technological availability across the countries (Maas & Hughes, 2020). Ibáñez & Delgado-Kloos (2018) found most articles on AR in STEM education targeting lower secondary school students (12 articles) and higher education students (7 articles). Nonetheless, they only found one article aiming at upper secondary school students and two studies targeting students from different levels (Ibáñez & Delgado-Kloos, 2018).

[8] An American expression for kindergarten to 12th grade

4.1.1 Topics & Subjects

Across the different reviews, researchers agree that the majority of the conducted studies focus on STEM fields (P. Chen et al., 2017; Hantono et al., 2018; Maas & Hughes, 2020; Pellas et al., 2019). Other topics include social sciences (e.g. language learning and visual arts), engineering, manufacturing, construction and health care (P. Chen et al., 2017; Maas & Hughes, 2020). Maas & Hughes found three studies on using AR interventions in math education and 14 on science education (Maas & Hughes, 2020). In 2019, Pellas et al. found in their literature review on AR game-based learning that the focus in primary education research is on formal science and natural science. This is followed by physical science and social science. In secondary education, studies focussing on natural science are prevalent, followed by physical science and then formal and social sciences (Pellas et al., 2019). Nonetheless, a lack of research in the topics of law, administration and business; agriculture, fisheries and forestry; and services has been detected in a meta-review (Garzón et al., 2019).

In the STEM-centred literature review by Ibáñez & Delgado-Kloos (2018), the researchers found 10 articles on physical sciences, 7 articles on mathematics, 7 articles on life sciences, 3 articles on earth sciences and one article on multiple subjects (Ibáñez & Delgado-Kloos, 2018). Researchers suggest that the strong focus on STEM topics is due to the ability of AR to visualise the invisible, the complex, or abstract concepts. This allows to make those concepts perceivable in a real world environment (Pellas et al., 2019).

4.1.2 Effects & Conflicting Insights

The general perception of implementing AR in educational settings is positive (Akçayır & Akçayır, 2016; P. Chen et al., 2017; Garzón et al., 2019; Maas & Hughes, 2020). In 2016 Saltan & Arslan detected ten different effects on using AR in educational settings within their analysed studies. Those educational outcomes were attention, engagement, interest, motivation, satisfaction, knowledge comprehension, academic achievement, knowledge retention, enjoyment, and autonomy (Saltan & Arslan, 2016). Other researchers detected improved learning performance and motivation as the main advantages in their reviews (P. Chen et al., 2017; Garzón et al., 2019). Additionally, they mentioned effects on increase of joy, positive attitudes, engagement (P. Chen et al., 2017) and social inclusion (Garzón et al., 2019) as well. Maas & Hughes (2020) also highlight the possibility of developing 21st century skills (e.g. critical thinking and problem solving; collaboration; and communication) (Maas & Hughes, 2020). Moreover, there are also studies reporting only neutral effects when it comes to learning performances

but see a chance in increasing students' interest and independence (da Silva et al., 2019).

A study focussing on the emotional effects of educational AR interventions mentioned an increase of motivation, attitude, engagement and enjoyment (Ibáñez & Delgado-Kloos, 2018). Moreover, Pellas et al. (2019) concluded in his study on game-based AR, that motivation and the overall learning experience are the two main factors of AR learning situations, with studies reporting effectiveness of their intervention caused by either one, or even both factors (Pellas et al., 2019).

Despite the general positive attitude towards AR in educational settings, there are also ambiguous results among the studies. Akçayır & Akçayır (2017), reported a conflicting aspect whether the usage of AR causes or decreases cognitive load and whether AR has positive effects on ease of use. Researchers concluded that the positive effects on ease of use and cognitive load are only possible when keeping usability problems under control (Akçayır & Akçayır, 2016; Saltan & Arslan, 2016). Issues mentioned were for example, that some systems did not provide immediate feedback, they lacked intuitive interfaces, or did not have a fast-enough system. Another factor to consider is the situation where AR is being used. This should be taken into account, because the lack of time in class or a crowded classroom can cause further pedagogical problems (Akçayır & Akçayır, 2016). Other issues mentioned were the lack of teachers, instructors or students being familiar or experienced in the use of AR technology (Akçayır & Akçayır, 2016; Ibáñez & Delgado-Kloos, 2018). Although AR technology seems to be motivating to students, the novelty effect[9] might cause these effects. Also, instructors were concerned whether the technology distracts from the actual educational content (Ibáñez & Delgado-Kloos, 2018). Researchers also suggest to involve teachers in the development process in future studies, to pre-detect pedagogical challenges (da Silva et al., 2019).

4.2 AR in Math Education

The research approaches of the different studies on using AR in math education are varied. When researching on studies dealing with specific math topics, most aim at the effects of AR on spatial ability (de Ravé et al., 2016; Dominguez et al.,

[9] The novelty effect explains that media and emerging technologies do not have any influence on learning in the long run. The positive effects, which come alongside with the usage of new technologies, are only by the initial curiosity of the users, and fade after an amount of use (Clark, 1983).

2012; Kaufmann & Schmalstieg, 2003; Lin et al., 2015; Salinas & González-Mendívil, 2017; Tosik Gün & Atasoy, 2017) or deal with geometric representation (Babinská et al., 2020; Botana et al., 2020; Tomaschko & Hohenwarter, 2020). Although most studies on AR usage in education is dealing with STEM topics, it seems that there are only limited studies covering other curriculum topics than geometry. Research which focus on other topics in math education than geometry, for example, test AR learning environments covering several math topics (Laine et al., 2016), show possibilities of using AR systems for students with special needs (Cascales-Martínez et al., 2016; Kumar & Troussas, 2020; Munoz et al., 2014), present possible design frameworks (Bujak et al., 2013), provide specific prototyping suggestions for AR applications for a selection of math problems (Babinská et al., 2020; Radu et al., 2016) and research on the motivational effects of AR (Y. Chen, 2013; Estapa & Nadolny, 2015).

4.2.1 Geometry

Studies which aim at improving spatial ability use marker-based technology to overlay the virtual content over, either 2D representations of 3D objects, or random markers, allowing the users to interact with the virtual 3D objects by moving the markers (de Ravé et al., 2016; Dominguez et al., 2012; Kaufmann & Schmalstieg, 2003; Lin et al., 2015; Salinas & González-Mendívil, 2017; Tosik Gün & Atasoy, 2017). Additionally, some also included further video material, animations and interactions to the screen (Salinas & González-Mendívil, 2017). While most found studies used mobile applications, a few used personal computers (Lin et al., 2015) or AR glasses (Kaufmann & Schmalstieg, 2003).

Apart from applications used in classroom settings there are also examples which provide suggestions for future feature development of the application *GeoGebra Augmented Reality*[10], with use cases in formal and non-formal education (Botana et al., 2020; Tomaschko & Hohenwarter, 2020).

Regarding AR experiences covering multiple topics, Laine et al. (2016) tested the feasibility of an AR exhibition on 61 Korean 5th graders, conveying concepts of spatial ability and kinetics using storytelling and gamification factors with the goal to improve students' intrinsic motivation (Laine et al., 2016).

[10] https://apps.apple.com/us/app/geogebra-augmented-reality/id1276964610

4.2.2 Design Framework

Bujak et al. (2013) presented a three-dimensional design framework. Those dimensions include the physical, the cognitive and contextual dimension. This guideline was made by combining pedagogical theories and research on AR in education (Bujak et al., 2013).

- The physical dimension consists of intuitive interactions and physical action encoding (Bujak et al., 2013):
    a. Intuitive interaction explains the significance to consider the interactions which users have already learnt and the affordances of AR.
    b. Physical action encoding describes the importance of immediate feedback, interactivity, connecting digital content to the spatial environment, and giving users the control over the application.
- The cognitive dimension covers spatial and temporal contiguity and abstract-physical encoding (Bujak et al., 2013):
    a. Temporal contiguity describes the difficulty to make connections between an abstract concept and a physical object. This can be solved by aligning information spatiotemporally.
    b. Abstract-physical encoding describes the connection between the real-world environment with its manipulatives and their abstract and symbolic representation. This is especially important to consider when designing applications for young learners, to differentiate abstract presentation from reality, to avoid confusion when e.g. visualising usually invisible elements.
- The contextual dimension describes the learning environment and contains the factors of collaboration, contextual relevance, and personal relevance (Bujak et al., 2013):
    a. In this framework, so-called micro-scaled interactions describe the chance to increase collaboration and communication skills using AR and to improve knowledge retention and concept comprehension.
    b. The macro-scale interactions define the context about when and where an application is used, which are relevant for e.g. hardware and activity choices.
    c. Personal relevance motivates learners and provides positive attitude. By augmenting physical objects which are relevant to the user AR enables a new perspective on objects and trigger user's curiosity.

4.2.3 Prototype Suggestions

Radu et al. (2016) explored the possibilities to address curricula topics between first to third grade, which are difficult to teach, by prototyping with primary school teachers (Radu et al., 2016). Babinská et al. (2020) created a list of suggestions on how to solve math problems using AR technology with 40 teachers-to-be. For example, when working with direct and inverse proportionality, one could use the technology of e.g. Photomath[11], which scans an equation, and the app would draw a graph of it. Another example would be to add coordinate systems above students' drawings or to create a grid for already existing coordinate systems, with the goal to detect points according to their coordinates (Babinská et al., 2020).

4.2.4 Inclusive Learning

There are a couple of studies focussing on inclusive learning as well. For example, an AR system, to increase math competencies for students with ADHD, autism, mental retardation, Asperger, microcephaly, down syndrome, and deafness, has shown positive effects on general motivation and learning of the students (Munoz et al., 2014). While Munoz et al. (2014) used spatial displays and marker-based AR to interact with the virtual environment, Cascales-Martinéz et al. (2016) used a table-top system. They focussed on students with learning disabilities and disorders, and taught primary school students the concept of banknotes, coins, and money, also with significant effects on motivation and learning outcomes (Cascales-Martínez et al., 2016).

During research, mostly studies tested in classroom settings could be found. However, due to the current COVID-19 situation, approaches for inclusive blended-learning were explored as well. For example, Kumar & Troussas (2020) are currently creating a system using a multi-sensory user interface, combining a braille display, touch gestures, touch screen and audio, to provide an inclusive math tutoring system for visually impaired students. The goal is to help them with independent math learning (Kumar & Troussas, 2020).

4.2.5 Motivational Effects of AR in Math

Many studies found motivational effects in using AR in math education, while testing the application on students. One study specifically researched on the effects of using mobile AR instructions in primary math education (algebra and geometry) on motivation and math-anxiety. They tested the mobile AR application

[11] https://www.photomath.net/en/

HP Reveal and Augment[12] on 137 Taiwanese sixth graders. After comparing the outcomes between high-anxiety learners and low-anxiety learners using the ARCS model (Chapter 6.2 - ARCS - V Model) the results confirmed an increase in motivation, performance, and a decrease in anxiety for those who used the AR system. Moreover, the researchers highlighted that these effects are due to the perceived playfulness of the system. Additionally, they emphasised the importance to take pedagogical and learning perspectives into account when designing math learning environments (Y. Chen, 2019).

Another AR intervention focussed on evaluating motivational outcomes and achievement. In a quasi-experimental study, 61 students took part. The participants either tried the AR application, or used the website version about dimensional analysis, and were then tested on their motivation and achievement with a pre-, post- and one month delayed-post-test. The researchers found that both, the website and the AR application, showed increased achievement, while the motivation using AR was higher (Estapa & Nadolny, 2015).

4.3 Conclusion – AR in Education

The literature review on AR in education shows that using AR can significantly increase students' motivation, when the learning environment and the application are set up carefully by taking several psychological, design, and pedagogical factors into account. However, the studies conducted mainly focus on either primary school students, or higher education. Additionally, the AR interventions take place in class-room settings most of the time. Although there are remote learning and blended-learning attempts already, situations such as COVID-19 have shown a lack in proper blended-learning or home-schooling tools. While parents can help their children with elementary school math, upper secondary school math topics are more challenging to explain. With the possibility of AR to convey abstract concepts, it is suggestable to conduct research on the motivational effects of AR in math education in blended-learning situations for upper secondary school students.

[12] https://www8.hp.com/us/en/printers/reveal.html

5 Multimedia Learning Theory

The multimedia learning theory describes multiple design principles for effective multimedia learning. For example, Mayer states three core theories from the field of cognitive science (R.E. Mayer, 2017; Richard E Mayer & Moreno, 2002; Moreno & Mayer, 2007). Those principles are first, the dual coding theory (Paivio, 1979), which states that people have different channels to process information (e.g. visual and auditive). The second theory is the limited capacity principle (Baddeley & Hitch, 1974) which suggests that the working memory can only process a certain amount of information in each channel at one time. The third theory is the active processing assumption from the model of generative learning (Wittrock, 1989), which implies that learners gain a deeper understanding of instructional materials, when they are actively involved in the learning process through interaction, e.g. organising or selecting objects (R.E. Mayer, 2017; Richard E Mayer & Moreno, 2002; Moreno & Mayer, 2007).

In 2017, Richard E. Mayer, summarised 11 principles of multimedia learning theory, after three decades of research in this field. Those principles have found to be effective in designing multimedia learning material, and aim to, firstly, reduce cognitive overload ("reducing extraneous processing" (R.E. Mayer, 2017, p. 4)), secondly, to "managing essential processing" (R.E. Mayer, 2017, p. 8), and thirdly, to help to understand the material more deeply ("fostering generative processing" (R.E. Mayer, 2017, p. 11)). In the following, those strategies will be described shortly (R.E. Mayer, 2017).

5.1 Reducing extraneous processing

- The *coherence principle* states that reducing additional information, such as background music, videos, or words, to the most essential information, people can learn better (R.E. Mayer, 2017).
- The *signalling principle* explains that highlighting essential information in learning material is helpful for learners (R.E. Mayer, 2017).
- The *redundancy principle* indicates that, especially students with low prior knowledge benefit when the channels are not cluttered with redundant information. An example for that would be comparing an animation plus narration to an animation, plus narration, plus on-screen text (Richard E Mayer & Moreno, 2002). However, it can be helpful, when 1-2 key words

are added next to a graphic. It is also helpful when the narrator rephrases the written description (R.E. Mayer, 2017).

- *Spatial contiguity* describes that the distance between e.g. an animation and the screen text affects the learners (Richard E Mayer & Moreno, 2002). For instance, it is suggested to place relevant screen text next to according graphics (R.E. Mayer, 2017).
- *Temporal contiguity* describes that e.g. an animation or graphic should be simultaneously presented (R.E. Mayer, 2017).

5.2 Managing essential processing

- The *segmenting* (R.E. Mayer, 2017) or *pacing* (Moreno & Mayer, 2007) principle describes that the multimedia material should be broken down into smaller segments. The pacing should be controlled by the learners themselves, so they can take their needed time to process the presented information (R.E. Mayer, 2017).
- The *pre-training* principle indicates that certain knowledge (such as key terms or interactions) should be shown before the start of an e-learning lesson (R.E. Mayer, 2017).
- Next, the *modality* principle indicates that for learners, especially for ones with low prior knowledge, it is more helpful to present the graphics with narration together, than presenting graphics with on-screen text. Additionally, familiar words should be used, and the auditive sections should not be too long (R.E. Mayer, 2017).

5.3 Fostering generative processing

- *Personalisation* compares the effects between a narration in formal style versus in conversational style. Conversational style has been found to be effective, especially for learners with no to low prior knowledge and / or experience with the e-Learning material. Moreover, this principle seems to work better for shorter lessons, indicating that, especially in early stage learning, this could be helpful, until a connection between the learner and the virtual instructor is established (R.E. Mayer, 2017).
- The principle of *voice* states that learning with a narrator who has a human voice, is more helpful than learning with a narrator with an artificial or robot-like voice (R.E. Mayer, 2017).

- The *embodiment* principle indicates that a virtual instructor should use humanoid gestures. This principle, however, showed to be least effective, compared to the others mentioned above (R.E. Mayer, 2017).

In 2007, Moreno & Mayer additionally had three more design principles, especially for interactive e-learning environments, which are *guided activity*, *reflection*, and *feedback* (Moreno & Mayer, 2007):

5.4 Interactive Multimedia Learning Environments

- The principle of a *guided activity* describes that it is helpful when students have a virtual instructor who guides them through the e-learning material, by encouraging them to interact with the new information (Moreno & Mayer, 2007).
- The “reflection” principle promotes active reflection on the current learning process, for example by prompting questions during the learning process.
- The last principle is “feedback”, describes that explanatory “feedback” is more helpful than corrective feedback. This helps students to correct occurring misconceptions (Moreno & Mayer, 2007).

5.5 Conclusion – Multimedia Learning Theory

This chapter introduced 14 (interactive) multimedia learning principles which are built upon three theories from cognitive science. The effectiveness level of applying these principles are dependent on the target group’s prior knowledge about a subject and their previous experience with the used technology. In this thesis, those principles will be used during the empirical research (Chapter 7 - Empirical Study) for the prototype creation process and the analysis process. Additionally, it will be referenced in the discussion (Chapter 8 - Discussion) where the multimedia learning theory, the results of the empirical study, and Keller’s ARCS-V model for systematic motivation design (Chapter 6 - What is Motivation), are combined to generate a suggestion for the creation process.

6 What is Motivation

In previously mentioned studies, as shown in Chapter 4, motivation has been identified as one of the main advantages of AR when used in educational settings. Therefore, this chapter provides an overview on the definition of motivation, Keller's ARCS-V model and an introduction to the Instructional Materials Motivation Survey (IMMS), which has been used in this thesis in the empirical part in the second iteration, to test the motivation of the students (Keller, 2010).

6.1 Definition of Motivation

The dictionary describes the word motivation as "an inducement, reason or goal" (The American Heritage Dictionary Entry: Motivation, n.d.) as "the act or an instance of motivating", the "desire to do; interest or drive", "incentive or inducement" or "the process that arouses, sustains and regulates human and animal behaviour" (Motivation Definition and Meaning | Collins English Dictionary, n.d.).

In research, there are multiple attempts to characterise motivation. Keller (2010), identifies that motivational theories can be broadly categorised into four groups. The first group focusses on e.g. human psychology, neurology, and genetics and describes motivation as physiological or psychological processes. The second group focusses on human behaviour, which contains e.g. classical conditioning, reinforcements, incentive motivation, and environmental influences. The third group concentrates on cognitive theories – they deal with topics such as social motivation and competence theories. The fourth group would be the group which deals with emotion and affect (Keller, 2010). Keller described that those groups of motivational research are isolated from each other, and each field of study has its own strengths. Nonetheless, focussing on only one factor could be problematic when trying to understand the complexity of human behaviour (San Diego State University, 2011). Therefore, he combines the most common theories of those research groups into the ARCS - V model, with the goal to provide a clear and measurable model to describe motivation (Keller, 2010, 2016).

6.2 ARCS - V Model

By introducing the motivational learning design theory of attention, relevance, confidence, and satisfaction (ARCS) model, John Keller tried to solve two major issues in motivational research. Firstly, he combined several motivational research fields to a smaller set of measurable values. Secondly, the ARCS model suggests a 10-steps motivational design process, e.g. for classical classroom situations, e-learning, or blended learning (Keller, 1987, 2010). Later, Keller added Volition to the model and introduced the ARCS-V model (Keller, 2016). In the following, each letter and its characteristics will be described more closely, and the model for systematic motivational design will be introduced.

6.2.1 A – Attention

The first letter describes the learners' attention and sustain their curiosity. In the context of learning, the goal is to direct the learners' attention, by asking the question how one can make instructional materials interesting and stimulating (Keller, 2010).

6.2.2 R – Relevance

By raising the question, how a learning experience will be valuable for students, one should try to create personally relevant experiences for students. Common questions which students might ask are for example "Why should I study this?", "Where can I use this in daily life?", or "Will I ever need it again?". Therefore, the instructional material should align with the motives and goals of the learners to give them the feeling that the learning experience is personally relevant to them (Keller, 2010).

6.2.3 C – Confidence

The third letter describes the confidence level, and deals with both, too little and too much confidence. On the one hand, with too little confidence, a learner might experience e.g. math anxiety (Tobias & Weissbrod, 1980), which is a great problem for some students to learn effectively. On the other hand, when having too much confidence, learners might skip important information, with the belief that they already know everything (Keller, 2010).

6.2.4 S – Satisfaction

The fourth category indicates that the learning experience must be satisfactory, to generate a wish to learn more about a topic. Both, extrinsic and intrinsic components affect the satisfaction of a learner. Extrinsic factors would for example be certificates, grades, or other rewarding materials. Intrinsic aspects could include collaboration with friends, an increase of self-esteem or the feeling of being heard and respected (Keller, 2010).

6.2.5 V – Volition

An additional letter was added to the original ARCS model, forming the ARCS – V model. This is because, over time, it was identified that some learners would give up on tasks, despite the goal being important to them, while others would continue a task until the goal is accomplished. The fifth category contains theories on persistence and self-regulation, which is related to the term volition. The question what could help learners to maintain their task-focus and goal orientation during the learning experience should be answered in this category (Keller, 2016).

6.2.6 ARCS - V Model for Systematic Motivational Design

Apart from the categorisation of motivational concepts, the ARCS model also contains a set of 10 possible steps to take, to systematically create motivational instructional materials (Keller, 1987, 2010, 2016). Table 2 sums up all recommended steps. Usually not all steps need to be covered, however, Keller highlights step 3 – audience analysis, step 6 – the listing of potential tactics, and step 7 – selecting and designing tactics, as especially important, which should occur in each creation process of motivational design (Keller, 1987, 2010, 2016).

Phase	Motivational Design Steps
Analysis	1. Obtaining course information
	2. Obtaining audience information
	3. Analysis of audience
	4. Analysis of other course elements
	5. Listing objectives and assessments
Design	**6. Listing potential tactics**
	7. Selection & design of tactics
	8. Integration with instructions
Develop	9. Selection and development of materials
Implement & Evaluation	10. Evaluation and revision

Table 2. Keller's systematic motivational design steps, based on the ARCS-V model (Keller, 2010, 2016)

To analyse the audience, the inverted U-curve helps predicting the expected performance in connection to motivation, as shown in Figure 14. This visualisation indicates that when the motivation level is too high or too low, the performance will suffer. This is because, when the motivation is too low, the learners will not have the desire to learn, while when the motivation is too high, the already motivated learners might get annoyed. Therefore, depending on the motivation of the target group/audience, it is recommended, either to increase, maintain, or lower the learner's motivation, to assure high performance. For learners with high motivation, one should focus on increasing efficiency (Keller, 2010, 2016).

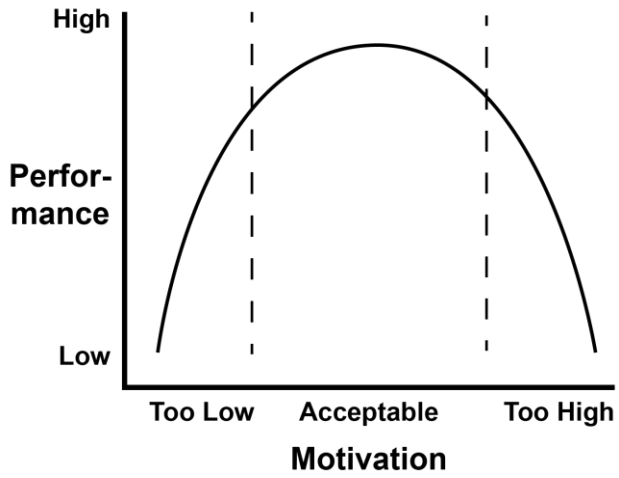


Figure 14. Inverted U-Curve to analyse the motivation of the target audience, recreated (Keller, 2010, 2016)

6.3 IMMS & RIMMS

To measure the ARCS model, one can use either the Course Interest Survey (CIS) or the Instructional Materials Motivation Survey (IMMS). While CIS measures the motivation in instructor-led classes, the goal of IMMS is to detect the reactions on self-directed learning materials (Keller, 2010). IMMS has widely been used for testing reactions on e.g. online courses, e-learning apps, and computer-based instructions, and has also been translated into multiple languages (Keller, 2010).

Originally, the IMMS contains of 36 Likert-scale items, with 9 sub-scales for Relevance and Confidence each, 6 for Satisfaction and 12 for attention. However, there are also a variation of it, such as the Reduced Instructional Materials Motivation Survey (RIMMS), a version with only 12 subscales, with 3 sub-scales for each ARCS category (N. Loorbach et al., 2015). Keller (2010) stated that the RIMMS has empirical validity, and Loorbach (2015) suggests that RIMMS can be more suitable in certain situations, such as in their self-directed instructional learning setting created for seniors. The main difference is fact items or ambiguous items were removed to reduce boredom caused by the length of the original survey, (N. Loorbach et al., 2015).

For both, IMMS and RIMMS, it is necessary to understand that the scoring and the numeric outcome of the tests can only be compared to a pre- or a post-test, since the surveys measure situation-specific motivation (Keller, 2010).

Since the prototype of the second iteration aims at motivating students to use a mobile AR application, the IMMS found to be suitable to serve as pre-and post-test. However, because the user test is mostly conducted remotely, there might be a higher risk of boredom and fatigue during the tests. Therefore, adapted versions of RIMMS found to be more suitable to measure motivation in the pre-test (book page) and post-test (prototype of the 2nd iteration) of the second iteration.

6.4 Conclusion – Motivation

This chapter introduced a general definition for motivation, it presented Keller's ARCS-V model, including the description of each letter, the 10-steps for systematic motivational design, and showed the importance of a balanced motivation level. Additionally, to statistically measure motivation, Keller's IMMS was introduced, and the reason why the shortened RIMMS was used for this study was described.

In the empirical part, the models, theories, and surveys mentioned in this chapter will be mainly needed for the second iteration. In the discussion (Chapter 8 - Discussion), the findings of the empirical research, Keller's systematic motivational design, and the multimedia learning theory (Chapter 5) will be combined to create a design framework and to give suggestions on the design process.

7 Empirical Study

The literature review showed that using AR can significantly increase students' motivation, when the learning environment and the application are set-up carefully in consideration with several psychological, design, and pedagogical factors. However, the studies conducted on AR usage in education mainly focus on either primary school students, or higher education. Additionally, most of the AR interventions focus on classroom settings. Situations such as COVID-19 have shown a lack in proper remote learning, blended learning, or home-schooling tools. While parents often can help their children with elementary school math, upper secondary school math topics are more challenging for them to explain. With the possibility of AR to convey abstract concepts, it is suggestable to conduct research on the motivational effects of AR in math education in remote situations for upper secondary school students.

The empirical study will go through a design process to create an AR math learning exercise to answer the research questions.

How can AR learning exercises for a math learning app be created to foster the motivation of upper secondary school students, especially for remote or blended learning situations?

- Which main benefits of using an AR mathematics learning app for upper secondary school students can be found during research?
- Which elements should a motivational AR learning experience include?
- How should a creation process look like to effectively create motivational AR math learning experiences?

The design process of the study consists of two design-based research[13] (DBR) iterations. In the following, the used methods and the iteration goals will be described (Chapter 7.1), the participants will be introduced (Chapter 7.2), the created prototypes presented (Chapter 7.3), details on the data collection and the research procedure given (Chapter 7.4), and the analysed data and results will be provided (Chapter 7.5).

[13] The general definition of the DBR process is described in Chapter 2 - Design-based Research.

7.1 Methodology

This chapter describes how DBR was conducted, what the goals of the iterations were, and which methods were used to answer the research questions. By using this paradigm, it is possible to systematically design and create solutions for real-world educational problems and was found to be suitable for designing new e-learning applications without disregarding previous research and available theory (Barab & Squire, 2004; Herrington et al., 2007; Wang & Hannafin, 2005). In this thesis, two DBR iterations were conducted. Each iteration had a different goal; therefore, the process of the different methods was used in each.

The next sub-chapters provide an overview of the goals and methods used in each iteration. Further details about how the specific methods were conducted will be described in Chapter 7.4 - Data Collection & Procedure.

7.1.1 Iteration 1

The goals of the first iteration were firstly, to explore the general challenges which students and teachers of upper secondary school students have and secondly, to discover the potential of AR for math education. To generate this understanding, a literature research, interviews, a brain storming session, and a design sprint (Chapter 7.2.2 - Design Sprint – Iteration 1) where a prototype was created and tested, were conducted. In the end, the findings were used as a basis for the second iteration, to define its goals, problems, and methods.

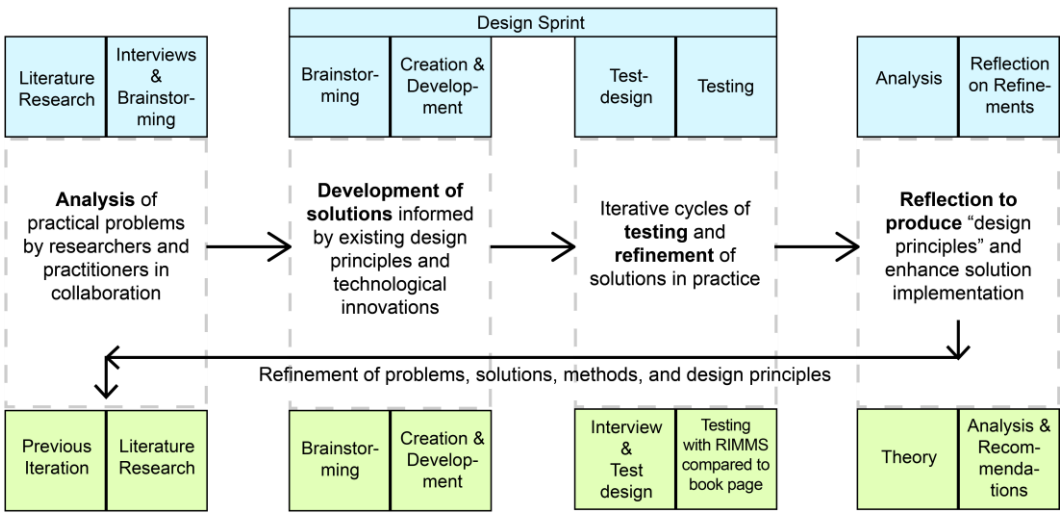


Figure 15. DBR process of this thesis with its methods for each phase; blue = 1st iteration, green = 2nd iteration; adapted from Reeves (2008)

The blue boxes in Figure 15 show the methods used in the first iteration. The analysis phase consisted of a literature research, interviews and brainstorming sessions with students and a math professor. The development phase and testing phase were conducted in a so-called design sprint. In the reflection phase, a qualitative analysis of the test results has been made, and recommendations for the next iteration were given.

7.1.2 Iteration 2

In the second iteration, the focus was set on the motivational effects of AR and blended-learning challenges and possibilities. The goal was to provide suggestions on the process of creating AR math learning experiences by going through a design process and gathering insights. The green boxes in Figure 15 show an overview of the processes of the second iteration. The analysis phase is based on the first iteration, and a literature research on motivational design theories and the multimedia design principles was conducted. During the development phase, the researcher conducted a single person brainstorming session, and developed the second AR prototype according to the previous findings. Between the development and testing phase, students (Table 7) were recruited, a short presentation on the project was held, and a semi-structured interview was conducted. In the testing phase, the created prototype was tested on those students, and the participants' perception and motivation were compared to after learning with a book page. The students were encouraged to speak out their thoughts while testing the prototype. After each test, they were asked about their feelings and thoughts on the prototype, and whether they have ideas on improving it. Additionally, the students filled out the RIMMS (N. R. Loorbach, 2013), which is based on the ARCS model (Chapter 5 - Motivation). Qualitative data and quantitative data were then analysed and suggestions on refining the prototype and methodology were given.

7.2 Participants

During the empirical research, multiple methods needed the contribution of external participants. In this chapter, the required participants for those methods are stated and the actual participants who took part in this study will shortly be introduced anonymously.

7.2.1 Interview & Brainstorming – Iteration 1

The initial interviews were held with six Austrian students from different upper secondary schools (Table 3) and a teacher of a business secondary school (P1 in Table 6). At this point, the goal was to gather a variety of opinions on the problems which students faced with mathematics. Those participants were chosen because they attended different types of schools which are also located in three different Austrian provinces. One brainstorming session was conducted with P1 who also was the teacher of the students in iteration 2 (Table 7).

Number	**Student 1**	**Student 2**	**Student 3**	**Student 4**	**Student 5**	**Student 6**
School	Upper secondary school for economic profession (HLW)	Upper secondary school for technical profession (HTL)	Upper secondary school for nursery education (BAfEP)	Academic upper secondary school (AHS)	Academic upper secondary school (AHS)	Academic upper secondary school (AHS)
Grade	10th grade	10th grade	9th grade	10th grade	10th grade	10th grade
Interview format	Remote	Remote	In person	In person	In person	In person
Province of attended school	Tyrol	Vienna	Vienna	Vienna	Lower-Austria	Lower-Austria

Table 3. Participants for the initial interviews in iteration 1

7.2.2 Design Sprint – Iteration 1

At first, it was planned to conduct brainstorming workshops with potential practitioners (students and teachers), as recommended for DBR interventions (Chapter 2 - Design-based Research). The plan was to show the participants AR

applications, and then conduct a brainstorming session. However, this was not possible due to the COVID-19 outbreak and the following restrictions in Austria in mid-March 2020. Although it is possible to conduct brainstorming sessions remotely, there is a need for participants who already know a variety of AR applications for a successful session. However, due to the lack of teachers and upper secondary school students who already had the chance to try out a variation of AR applications, three master's students with the study focus on augmented and virtual reality contributed to the first prototype (Table 4). Due to their diverse educational backgrounds and their different approaches towards mathematical concepts, they were suitable to brainstorm, design and prototype together (Swan, 2014).

	Participant 1	**Participant 2**	**Participant 3**
Role(s) during sprint	Facilitator, Researcher, Interviewer	Designer, Gamification	Math concept validator
Bachelor thesis focus	Human- Computer Interaction	Gamification	Industry usage of hololens
Attended high school	General high school	Designer High school	Business and Programming
Additional information	Used to be a tutor for French at her high school	Describes herself as a visual learner and likes unconventional representations when learning new concepts	Used to be a math and programming tutor at his high school

Table 4. Participants for the design sprint in iteration 1

Each participant was assigned a different role (researcher, designer, and math concept validator).

- The first participant is the author of this thesis who also took the role of the facilitator. With interviews and literature, she explored on common challenges and possibilities that occur in using AR in math education. Additionally, she has knowledge in the field of human-computer interaction due to her bachelor's thesis and has French tutoring experience.
- Participant 2 took the role of the designer, since she attended an upper secondary school for prospective designers in her past. Moreover, she also

has experience in the field of gamification due to her bachelor's thesis and her experience in game development.

- The third participant was assigned the role of the math concept validator. He attended an upper secondary school with focus on business and technology. In the past, he used to be a math and programming tutor, and has always been fascinated by maths and abstract concepts.

Usually, an additional IT expert is needed to implement the ideas (Swan, 2014), however, since all participants were knowledgeable about app creation, it was possible to create the first prototype with only the previously mentioned participants.

7.2.3 Testing – Iteration 1

The testing of the first prototype was done with students (Table 5) and math professors (Table 6) who have high understanding in the topic of linear functions, which is the topic of the prototypes. These students were selected because all have a different level of understanding about AR. While S2 also developed own AR and VR games, S8 barely knew AR applications apart from entertainment apps. S7 has already tried out several VR and AR experiences and has used *HoloLens before.*

	Student (S) 2	**S7**	**S8**
School(s)	Upper secondary school for technical professions (HTL)	Upper secondary school for economic professions (HLW)	Vienna University of Economics and Business
Grade	10th grade	13th grade (last year)	University student (bachelor's semester)
Previous AR experience	High	Mid	Low
Test Device	iPhone 10	iPhone X	iPhone 8

Table 5. Students who tested the first prototype with indirect augmentation

The teachers also had different experience with AR. The author of this thesis went through a remote brainstorming session with P1 and showed her a variety of

application possibilities and let her test different handheld applications, while professor 2 stated that she barely tried AR applications before.

Number	**Professor (P) 1**	**P2**
Background	Mathematics professor of at a business high school (HAK) and informatics and mathematics professor at general secondary schools (AHS)	Math professor at a general upper secondary school (AHS)
Interview format	Interview: in person Brainstorming: remote Testing: remote	Testing: remote
Previous AR experience	Mid	Mid
Test Device	iPhone 7	iPhone 6S

Table 6. Math professors who provided suggestions on creating and improving AR math learning exercises

Another prerequisite for the participants was their access to suitable hardware. Since the prototype was created with *Torch*[14], a rapid prototyping tool which is powered by *ARKit*[15], all participants needed an ARKit supported device.

7.2.4 Interviews & Tests - Iteration 2

P1 recruited six students (Table 7) with whom the researcher was able to conduct a pre-interview and test the second prototype with. In general, the students only have little knowledge about AR, and showed different levels of performance in math lessons according to P1. Four students attended the 9th grade where they first learn about using multiple linear functions. S12 and S13 were chosen as well because they are overall very good students and the teacher expected that they

[14] https://torch.app/

[15] https://developer.apple.com/augmented-reality/

can give helpful feedback on refining the prototype. Additionally, the students needed a smartphone which can run ARCore[16].

Number	**S9**	**S10**	**S11**	**S12**	**S13**	**S14**
Grade	9th grade	9th grade	9th grade	9th grade	10th grade	10th grade
Teacher's assessment on student's math performance	B-C	A-B	B+	B-	A	A
Previous AR experience	Low	Low	Low	Low	Low	Mid
Test Device	Samsung Galaxy A7	Samsung Galaxy S9	Samsung Galaxy A5 & Samsung Galaxy J5	Samsung Galaxy J7, Samsung Galaxy A30s & Samsung Galaxy S9	Samsung Galaxy S10	Samsung Galaxy A50

Table 7. Students for testing the second prototype with image-based augmentation

[16] https://developers.google.com/ar/discover/supported-devices

7.3 Created Prototypes

This chapter introduces the two created prototypes during the iterations (Chapter 7.1 - Methodology). In the following, the prototypes will be described using the tracking techniques and the system layers, using Edwards-Stewart's (2016) and Gjøsæter's taxonomy (2012) for handheld AR, respectively (Chapter 3.3 - Handheld AR). Additionally, the reason for the design decisions will be covered in this chapter as well.

7.3.1 Decision of the topic

Due to the time limitations of this master's thesis, only one math problem could be selected and was used for both prototypes. During the first iteration, the math problem about the point of intersection of two linear functions was selected. This decision was made because firstly, the researcher decided to focus on another subject matter than geometry and spatial understanding, since research so far majorly dealt with those topics. Secondly, the researcher chose to focus on math topics for the 9th grade, which is the first year of upper secondary school. Therefore, those math problems serve as a basis for the following grades. From the pool of possibilities, the topic about linear functions was chosen since this concept is the basis to understand more complex functions. With these boundaries, three solutions with different scenarios and take-aways were sketched out on the second day of the design sprint (Chapter 7.4.1.4.2 - Sketch - 2nd Day). In the end, the solution sketch with the scenario which dealt with the math problem about the point of intersection of two linear functions was selected.

7.3.2 Prototype 1 – Indirect Augmentation with an Island

The first prototype was created during the design sprint, which will be covered in detail in Chapter 7.4.1.4 - Design Sprint (Phase 2 – Iteration 1). However, to facilitate a better understanding, the prototype will be introduced in this chapter.

When designing the first prototype, the findings of prior literature research, interviews, and brainstorming sessions were considered (Chapter 7.4.1 - Iteration 1). The summary of those findings are as follows.

- **What should the students take away from this AR learning experience?**

The goal was firstly, to generate a real-world connection between linear functions and linear motion. The second aim was to convey what the point of intersection of two linear functions mean in the context of linear motion. Thirdly, the visual

representation of a linear function changes when the slope changes, or the zero-point moves. Finally, the prototype should help students to interpret multiple linear functions in the context of linear motions.

- **How should AR be used in this prototype?**

During the *Lightning Demos* activity in chapter 7.4.1.4.2 - Sketch - 2nd Day the participants were inspired by the example of ARCore Elements[17], shown in Figure 16. Therefore, the first prototype should be a non-trigger-based AR technique with indirect augmentation (Edwards-Stewart et al., 2016), with a virtual island being placed onto a surface.

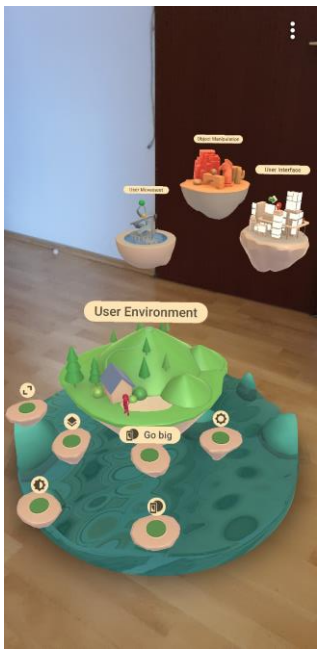


*Figure 16. ARCore Elements' islands (*ARCore Elements - Apps on Google Play*, n.d.)*

The final version of the first prototype (Figure 17) had 3D models of a house, an ice cream store, a street, a cyclist, and a pedestrian on top of the island. Close behind the island, there is a whiteboard with the graphical representation of linear functions on a coordinate system. This should help the users to understand the connections between a possible real-world scenario and the mathematical representation of linear functions, using the spatial contiguity, and modality

[17] https://play.google.com/store/apps/details?id=com.google.ar.unity.ddelements&hl=en

principle of the multimedia learning theory (R.E. Mayer, 2017; Richard E Mayer & Moreno, 2002).

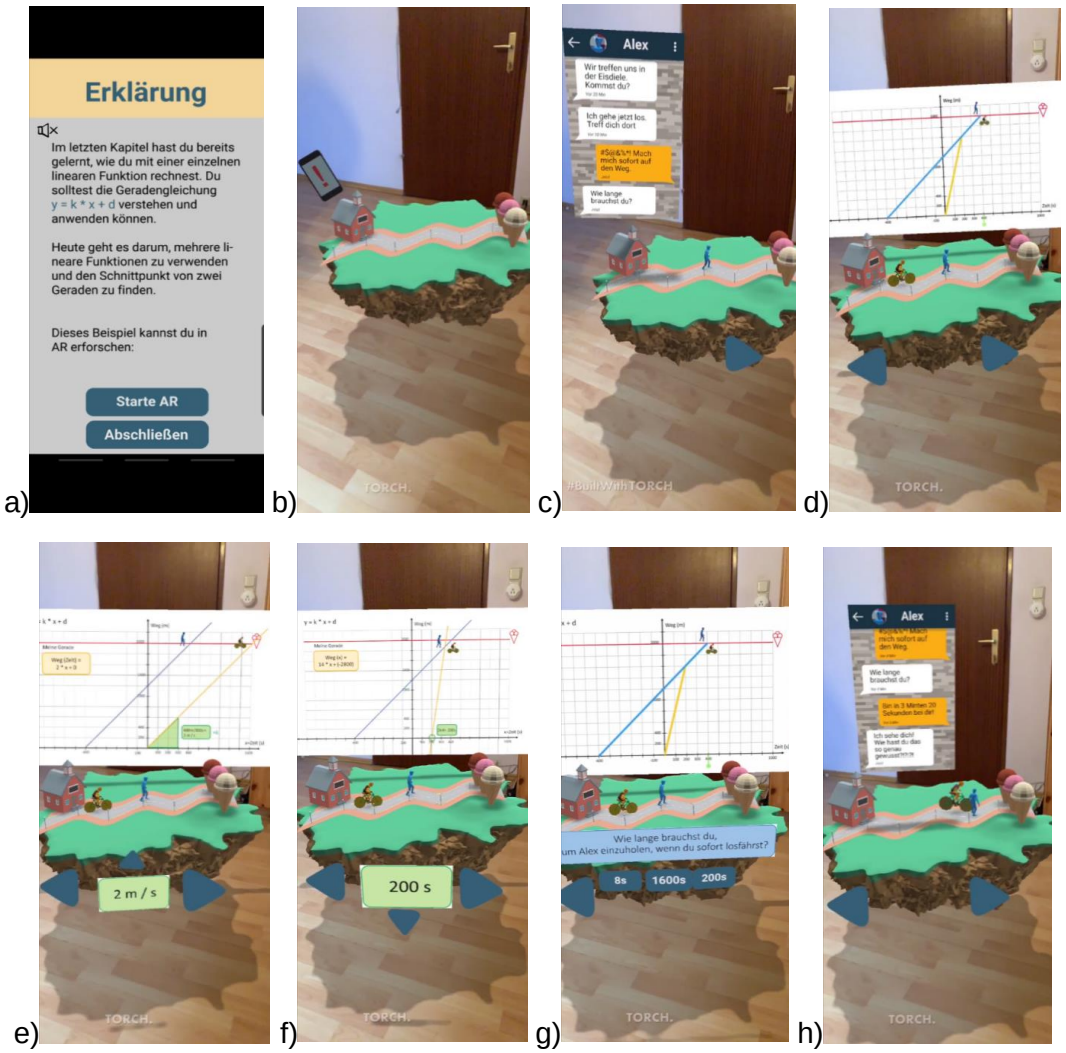


Figure 17. Screens from the first prototype with indirect augmentation

- **Which elements triggers students' attention and helps students to stay interested?**

The AR scene should trigger the user's attention and grab their interest. Although the novelty effect explains that the positive effects which come alongside with the usage of new technologies, are only by the initial curiosity of the users, and fade away after an certain time (Clark, 1983), this phenomenon should trigger the user's attention in the first DBR iteration. The story is tailored to the target groups' interests, which is about meeting up friends in their free time. This should also provide relevance to students and give them a feeling that they could use math concepts in their daily life (R.E. Mayer, 2017). The story was narrated from the

first-person perspective, giving users the feeling of personalisation (R.E. Mayer, 2017; Richard E Mayer & Moreno, 2002). Through the usage and variation of multiple perception channels (e.g. auditive and visual), it is possible to convey more information at once, without overstraining one channel (Baddeley & Hitch, 1974). Moreover, questions (e.g. “Will you be able to catch up to him?”) and call-to-actions (e.g. “Give it a try!”) should grab the students’ attention, and guide them through the exercise (Moreno & Mayer, 2007).

- **How should the prototype be structured?**

From a technical point of view, the taxonomy from Gjøsæter (2012) can be used to describe the structure of this handheld AR experience (Chapter 3.3 - Handheld AR). Table 8 shows a description of all six layers. The users of this prototype can either be students who learn about linear functions, students who revise on the topic of linear functions, or math professors who are preparing for their lessons. In this prototype, the device must be compatible with *ARKit* and have *Torch AR* installed on it. The GUI/WIMP layer contains buttons, screens, and the whiteboard which transitions to the Augmentation category, because they are also placed in the 3D space. The Augmentation category additionally contains the 3D environment with the 3D island, the cyclist, and the walker. The registration of the world is done via ARKit, and it scans the surfaces of the environment. The world should in best case be, a mid- to big-sized room with floors, and other surfaces with many feature points.

Users	**Device**	**GUI/WIMP**	**Augmen-tation**	**Registration**	**World**
Learning students Revising students Preparing teachers	Supports ARKit with Torch AR installed on it	Button and panels which transition to the augmentation category	3D environment	Surfaces using ARKit	Rooms or outside (e.g. grass) Often sit in front of the table

Table 8. Layers of the first prototype; adapted (Gjøsæter, 2012)

Content-wise, the first screen revises the basics of linear functions (Figure 17a) to remind the students on what prior knowledge is needed for the following AR prototype. The initial idea was that there should be an onboarding process, which invites unexperienced AR users to scan the environment, however, *Torch AR* did

not allow to implement this, which is why this part was left out. After placing the virtual 3D island to the real world, the testers were encouraged to explore and interact with the scene by clicking on a virtually displayed phone with a notification symbol (Figure 17b). Then, a phone screen with a chat history shows up, and a narrator starts the story, introducing the user to the scenario (Figure 17c). Afterwards, a whiteboard appears, demonstrating the connection between the 3D models and the linear functions using the same icons and colours (Figure 17d). The story was sectioned into smaller parts, and the users could proceed using arrows below the island. Later, the user can change variables, which influences a function (Figure 17e & f). In the end, a question to the learned content is asked (Figure 17g). The story ends with a chat screen, with different content, depending whether one has solved the problem correctly (Figure 17h).

7.3.3 Prototype 2 – Augmentation of a coordinate system

The second prototype (Figure 18) was created using the findings gathered in the previous iteration (Chapter 7.5 - Analysis & Results). Additionally, the researcher conducted further literature research on the multimedia learning theory (Chapter 5 - Multimedia Learning Theory) and motivational theories (Chapter 6 - What is Motivation). The detailed process is described in Chapter 7.4.2.1 - Literature Research & Brainstorming (Phase 1 – Iteration 2).

7.3.3.1 Design Considerations based on the results of the first prototype

- **Usage of AR**

Students and teachers wished that the app would involve more interaction with the real-world environment. Therefore, a system was thought of, which would help students to understand a concept better. The idea to augment a self-drawn coordinate system was built up on following thoughts:

a. Augmenting a self-drawn system would provide a greater feeling of personal relevance to students than e.g. a normal video (Keller, 1987). However, due technical difficulties of implementing a mechanism to detect and recognize coordinate systems, the recognition part was done using the augmented image system by ARCore to enhance a previously drawn and printed coordinate system.
b. Coordinate systems are also needed for more complex math concepts. Although linear functions are not seen as a very complex

topic, the layout of the prototype (3D world and virtual coordinate-system) might be helpful to deliver more topics of more complex areas, such as 3D vectors, matrices, and trigonometry.

c. Students might not be able to walk around during a learning session which is why every task should be able to be done at a desk.
d. When augmenting a coordinate system on one's own sheet of paper, it is easier for students to understand how to use this knowledge to draw own linear functions, than watching a video or a whiteboard.

- **Scanning the Room & Placing the 3D Scene**

All participants had problems with the scanning of the room or the placing of the 3D scene. Although S2 did not have problems with the scanning, because he was already experienced with AR development, the island was still too big. Additionally, he and P1 stated that the process takes too long which might make them not wanting to use the app or might not be interesting for students in the long run. Therefore, when designing the second prototype, it was important to have a straightforward system, which gave immediate feedback to the users without much struggle. The solution is to scan the marker like a QR-code – a system which students already are familiar with.

- **Visual Design**

First, the students wished that the animations in the 3D scene would move with the story like the graph does, as recommended in the temporal contiguity principle (R.E. Mayer, 2017). Secondly, the visual design of the 3D models of the island did not seem to meet the target group's taste and the users were even confused by the representation of the island (the earth at the bottom). Lastly, P2 suggested to use either a hilly or curved route, so the students understand that a linear function is still straight, although the path is curved. Therefore, when selecting a new model, the coherence principle (R.E. Mayer, 2017) was considered, to reduce unnecessary information. Also, the street needed to be curved.

- **Voice, Video & Animation**

The testers reported that the audio was too loud, which is why it was levelled down for the following prototype. Also, to fulfil the temporal contiguity principle (Moreno & Mayer, 2007), the 3D objects of the pedestrian and the cyclist have been animated according to the narration.

- **Didactical Considerations**
    a. Both P1 and P2 (Table 6) suggested to implement a reward system so students would stay motivated in the long run. Therefore, in the start screen, it was mentioned that the student can collect points, and in the end screen, the students would see their received points, based on the answer they give (Figure 18a & k)
    b. P1 wished, when interacting with the velocity, the app would show how fast one would be, when e.g. driving with a car. This could help to increase relevance for the students (Keller, 1987).
    c. P2 stated that it is advisable to not mention the formula $y = k * x + d$ when the narrator does not explain it more in detail. This would reduce unnecessary information, as the coherence principle (R.E. Mayer, 2017) suggests.

7.3.3.2 Design Decision

After combining all information, the initial idea was that the app should be able to scan a self-drawn coordinate system and superimpose a virtual coordinate system above it. For feasibility reasons, however, this idea was implemented using a marker, which was placed beneath the coordinate-system. This solution was chosen because of the following factors.

- Firstly, marker-based systems are easy to use (Saltan & Arslan, 2016). Most students usually do not have extensive experience in using different AR systems, which is why the AR component of an app should be, in the best case, straightforward. This is important because AR and its strengths can only affect students positively when usability issues are reduced to a minimum (Akçayır & Akçayır, 2016; Saltan & Arslan, 2016).
- Secondly, marker-based systems are easier to implement, are more stable than other techniques (Hantono et al., 2018) and are more accessible than other systems (Pellas et al., 2019). These factors are especially important because social interactions needed to be reduced to a minimum, because

of the COVID-19 outbreak. Therefore, students needed to have the essential hardware at home to use and test the application.

- Thirdly, problems with placing bigger virtual elements into a room has been detected when testing the first prototype. Additionally, students stated that they usually learn in front of a desk when they are at home. Therefore, the app design should be designed for this purpose.
- Lastly, an augmented coordinate system can be reused for other topics in the math curriculum which are more complex than the topic of linear functions. Examples for this would be 3D-vectors and matrices, polar coordinates, or polynomial functions.

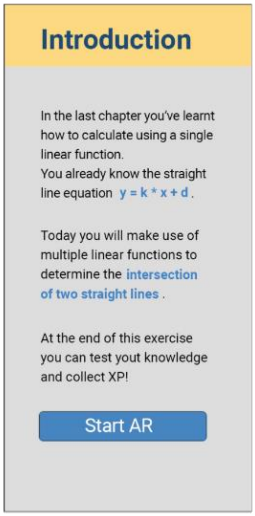
7.3.3.3 Description of the second prototype

For a clearer understanding, the prototype will be broken down into the technical layers of Gjøsæter's taxonomy for handheld AR applications (2012), as shown in Table 9.

Users	**Device**	**GUI/WIMP**	**Augmentation**	**Registration**	**World**
Students who want or must learn about linear functions Students who revise Teachers who prepare for a lesson	An ARCore supported device with the app preinstalled on it	Different between the scenes – For instance, full screen, buttons, control panel, and interactive buttons	Coordinate System 3D scene	Marker	Surface with the printed graph paper on it

Table 9. Layers of the second prototype, adapted (Gjøsæter, 2012)

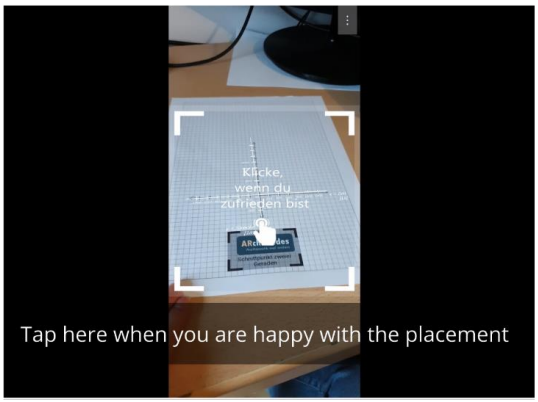
a)


Introduction
In the last chapter you've learnt how to calculate using a single linear function.
You already know the straight line equation y = k * x + d .
Today you will make use of multiple linear functions to determine the intersection of two straight lines .
At the end of this exercise you can test yout knowledge and collect XP!
Start AR

b)


Bild scannen
Scan Picture

c)


Klicke, wenn du zufrieden bist
Tap here when you are happy with the placement

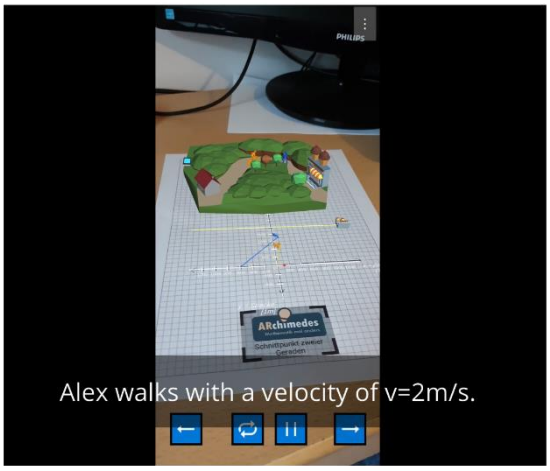
d)



e)



f)


Alex walks with a velocity of v=2m/s.

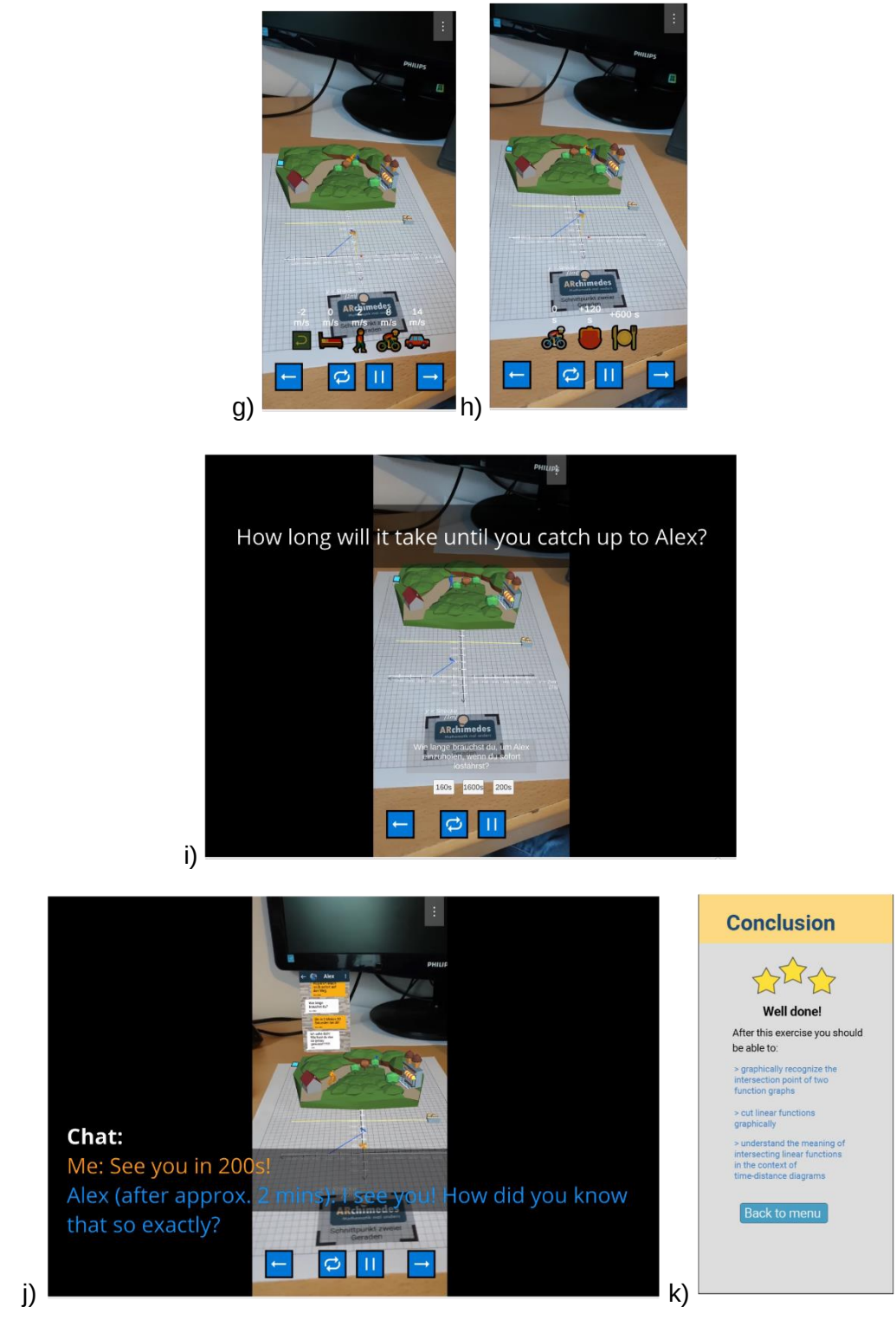


Figure 18. Prototype 2 - Augmented Coordinate System

The user would be the participants found in chapter 7.2.4, which are students who either are currently learning about linear functions or want to revise about this specific topic. Generally, they do not have a lot of experience with AR yet.

The device would be an AR ready phone. For this prototype, the plan was to cover ARKit and ARCore ready phones, however, due to a tracking problem when using AR Foundation, the researcher decided to only cover ARCore supported phones.

Regarding the GUI, it differs between the scenes. Before the application starts, there is a full screen text with the button “START AR” on it. Later, when the AR camera shows up, the GUI elements are reduced to a repositioning button at the top-right corner and a control panel with a “backwards”, ”replay”, “pause”/ “play” and a “forward” button. In two scenes, emojis were added to the bottom of the screen. Those served as buttons to manipulate the functions.

For the registration, a marker with a logo on a graph paper triggered the creation of the 3D scene, using ARCore. At this point, it was necessary to find the right AR development kit and the right marker. The initial idea was to scan the coordinate system, without the marker. However, this did not result in a satisfactory recognition velocity and accuracy, which is why the marker has been implemented. Moreover, at the beginning, the plan was to use AR Foundation to register the world, which, however, resulted in heavy jittering of the augmentation. Therefore, the researcher switched to ARCore, which improved the jittering of the 3D objects.

The world layer is usually different from user to user, but during the tests, the users printed out a graph paper, with a drawn coordinate system, and the marker on it (Appendix A - Graph paper with coordinate system and marker). The paper can for example be placed onto the desk, the floor, or another surface.

The differences between this prototype and the first prototype are the following:

- changes to the technical implementation,
- revising usability issues found during the test,
- incorporating the principles of Multimedia Learning Theory,
- and implementing a reward system.

The audio files and the structure of the delivered content stayed the same.

7.4 Data Collection & Procedure

In this chapter, the detailed procedure, on how the data was collected will be described. Figure 15 shows a general overview on the data collection procedure.

7.4.1 Iteration 1

The first iteration focusses on understanding which practical problems upper secondary school students and teachers currently face in math education. This iteration gathered insights on which math topics are perceived as difficult, on the reasons which cause aversion towards math, and explored the possibilities to overcome those problems using AR technology. To gather this information, a literature research, interviews, a remote brainstorming session, and a design sprint were conducted. During the design sprint a prototype was created and tested, and the data was analysed after each phase.

7.4.1.1 Literature Research (Phase 1 – Iteration 1)

The literature research in the first iteration consisted of a preliminary state-of-the-art research on the problematics (Chapter 1 - Introduction), methodology (Chapter 2 – Design-based Research), AR systems (Chapter 3 – Augmented Reality (AR), and approaches in research using AR in education (Chapter 4 – AR in Educational Settings). During the first iteration, this stage has been revisited several times and findings were broadened throughout the design process, which led to the final version of the literature research.

7.4.1.2 Semi-Structured and Problem-Centred Interview (Phase 1 – Iteration 1)

After a first literature research, six secondary school students (Table 3) from Austria and one teacher, P1 in Table 6, were interviewed using a problem-centred approach (Witzel, 1985). The interview was semi-structured. The interview guide can be found in the appendix SD.

The conversations were conducted either online or in person. All interviews were audio-recorded and transcribed. Finally, similar statements were categorised, and analysed, using Kuckartz's qualitative content analysis approach (Kuckartz, 2016). The teacher's opinion was compared with the students' view to understand, whether both parties have similar problems, whether there are conflicts, and to understand, how the challenges can be solved.

7.4.1.3 Problem-Centric Brainstorming (Phase 1 – Iteration 1)

One brainstorming session with the P1 (Table 6) was conducted. Due to obligatory social distancing in Austria caused by COVID-19, the brainstorming session was conducted online. For this session, *Microsoft Teams*[18] and the *Miro*[19] board were used.

Tool	**Use Case**
Microsoft Teams	Communication
Miro	Arranging the examples

Table 10. Used tools for the problem-centric brainstorming in the first iteration

Firstly, the teacher was asked general questions e.g. on how she would imagine the future of math teaching. Secondly, exemplary videos on the usage of AR in the fields of entertainment, marketing, and industry were shown via screensharing to her. Thirdly, ten video examples were presented, on how modern and interactive technologies can be used for classroom math education.

Those videos were selected by the researcher, with the goal to show a variety of examples. The taxonomies in chapter 3 - Augmented Reality (AR) were used as a reference. After each example, P1 expressed her thoughts on possible implementation of AR in her classroom. In the end, she highlighted the favourite parts of the shown examples and ranked them in *Miro*.

Additional to the brainstorming session, a list with six contrasting apps from the *App Store*[20] were chosen, for P1 to try out. Since P1 was not experienced with AR prior to this project, this session has been conducted, so she can give feedback easier, when testing the prototype.

[18] https://www.microsoft.com/en-gb/microsoft-365/

[19] https://miro.com/

[20] https://www.apple.com/ios/app-store/

7.4.1.4 Design Sprint (Phase 2 – Iteration 1)

After the initial literature research, interviews, and brainstorming session, a design sprint with the researcher as facilitator, a designer, and a math concept validator was conducted (Table 4). Originally, the design sprint concept was formed by Jake Knapp (2016), who created this method at *Google Ventures*[21]. The idea behind design sprints is to solve a problem within a short amount of time and combines design thinking and agile methods. This method encourages teams to create, test and fail faster, without spending too many resources and taking on too much risk, especially for testing innovative ideas. Knapp (2016) provides online resources on design sprints, which include a five-day-framework and a step by step checklist for each day (Knapp, 2016). For this thesis, the original checklists were adapted, and the new version can be found in the appendix SD. Additionally, all three participants wrote a diary entry after each day, to see, how the process can be improved. Usually, design sprints are done in person, however, this one was conducted remotely by communicating via *Microsoft Teams* and brainstorming on the interactive whiteboard *Miro.* Additionally, to create and test the prototype, several other services and software were used, as shown in Table 11.

[21] https://www.gv.com/

Tools	**Use**
Microsoft Teams	Internal communication (Day 1 – 5)
Miro	Brainstorming (Day 1 - 5)
Torch AR	AR Prototyping (Day 4)
Figma[22]	UI Prototyping (Day 4)
Hitfilm Pro[23], Power Point[24] & Audacity[25]	Video & Audio (Day 4)
Adobe Photoshop[26] & Illustrator	2D Graphics (Day 4)
Poly[27]	3D Graphics (Day 4)
Google Drive[28]	Data Transfer (Day 4 & 5)
Google Hangouts[29]	Communication with participants (Day 5)
Lookback Participate[30]	Observation of phone screen (Day 5)

Table 11. Overview of the used tools in the design sprint

The days of a traditional design sprint are structured by the names “Map”, “Sketch”, “Decide”, “Prototype”, and “Test”. In the following chapters, each day and its methods will be described.

7.4.1.4.1 Map - 1st Day

The goal of the first day was to create the same understanding of the problem which should be solved at the end of the sprint. The methods used are called *Start at the End*, *Get Pessimistic, Mapping, and How Might We*. During each activity,

[22] https://www.figma.com/

[23] https://fxhome.com/hitfilm-pro

[24] https://www.microsoft.com/en/microsoft-365/powerpoint

[25] https://www.audacityteam.org/

[26] https://www.adobe.com/products/

[27] https://poly.google.com/

[28] https://www.google.com/drive/

[29] https://hangouts.google.com/

[30] https://lookback.io/features/participate/

everyone would silently add notes onto the virtual whiteboard. After one activity, the participants sorted the notes and/or voted for them.

Start at the end was about communicating the goals which every participant has by taking part at the design sprint. These could have been short-term, mid-term or long-term goals. *Get pessimistic* is an activity to ask how one could fail to achieve the previously mentioned goals. *Mapping* was about understanding which steps needed to be taken to achieve certain goals. The aim of the *How Might We* activity was to form questions that could be answered during the remaining days of the sprint. Afterwards, the participants voted for the questions which they aimed to answer at the end of the week. Figure 19 shows the *How might we questions,* created during the sprint and the voting (written in German). At the end of the day, the participants have decided on finding an answer to the main question “How might we create an AR module so that students understand the math concepts, and are not overwhelmed by the interactions?” (Figure 19, with the blue frame). Other questions with votes were „How might we provide short and understandable explanations of the math problem?” (three voting points) and “How might we include the field of interest of students into the application, so they understand the use of math for their daily life?” (two voting points). These two questions will also be considered when sketching out the prototype.

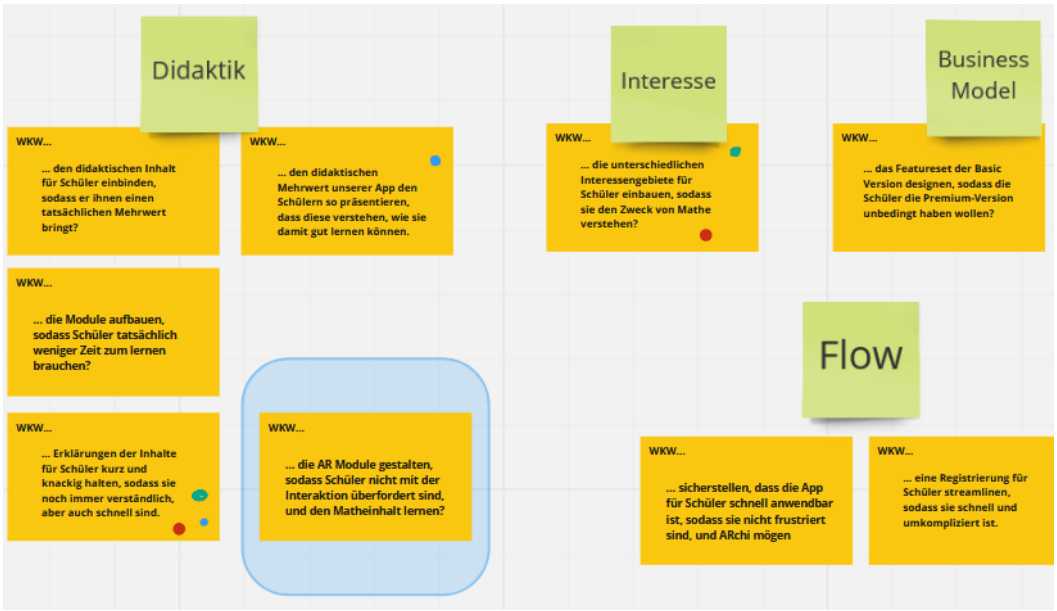


Figure 19. How-might-we-questions (in German) after first day of problem mapping

7.4.1.4.2 Sketch - 2nd Day

The goal of the second day was to sketch out rough ideas, to achieve the *How Might We* – goals. On the second day, the contributors decided to focus on the math topics of the 9th grade of vocational upper secondary schools. The methods used for this day are called *Lightning Demos* and *4-Step Sketch*.

In the activity Lightning Demos, every participant presented four ideas of inspirational examples from external sources. Figure 20 shows an overview of the created demos.

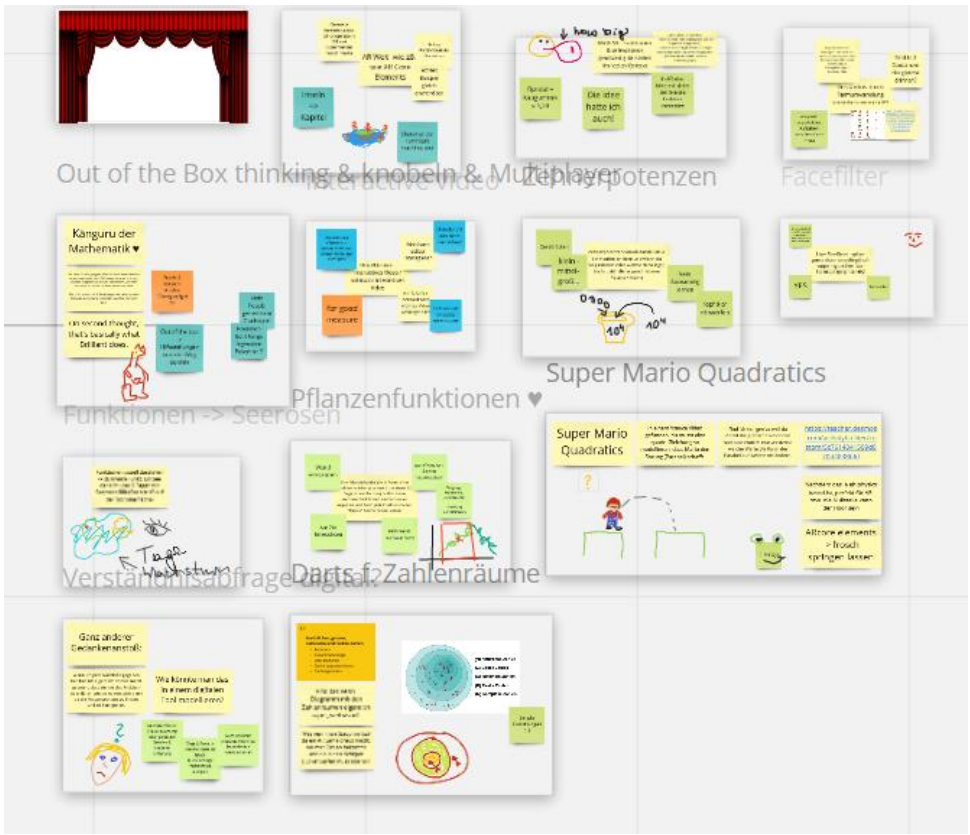


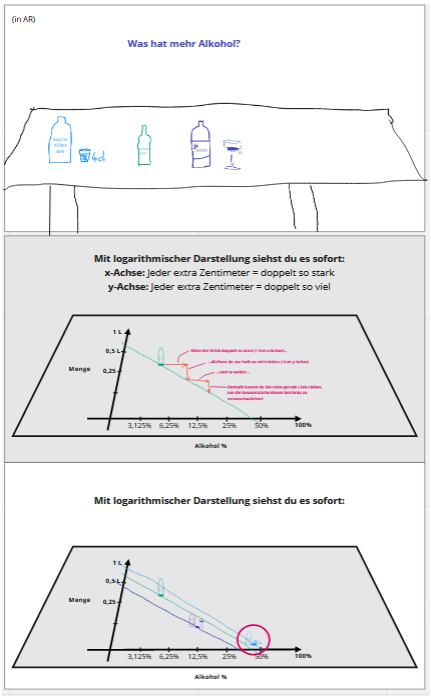
Figure 20. Overview of the created Lightning Demos

The *4-step sketch* consists of four parts, firstly, taking notes, secondly, writing or sketching down ideas, thirdly the activity *Crazy8's, and lastly, Solution Sketch.*

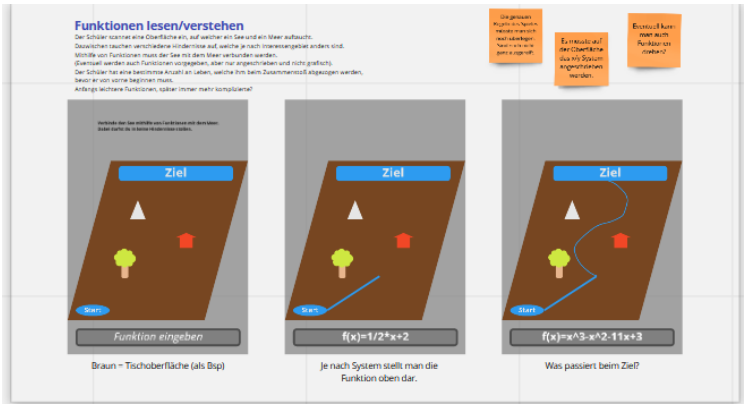
After taking half an hour to take notes and to sketch ideas down of the previous days, the activity *Crazy8's* was performed. In *Crazy8's* each participant created eight rough ideas within eight minutes, by spending one minute on each idea. Later, in *Solution Sketch*, each participant would create one idea to solve the created *How Might We* question, by adding all inspiration and ideas up. The

sketches were presented the following day. Figure 21 shows the final solution sketches after the second day.

a)



b)



c)

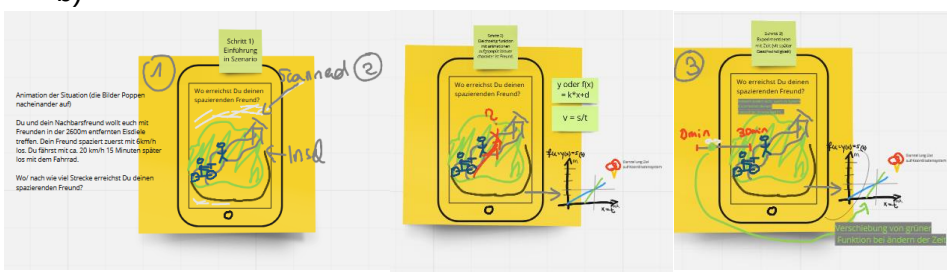


Figure 21. Final solution sketches after the 2nd Day – Sketch

7.4.1.4.3 Decide - 3rd Day

The goal of the third day was to decide on which idea should be prototyped and tested. The methods used are called *Sticky Decision* and *Storyboard*. At the end of this day, every participant should know what to prototype the following day.

The method *Sticky Decision* in this design sprint contained of the activities *Heat Map*, *Speed Critique*, *Straw Poll, Super Vote*. First, in *Heat Map,* every participant highlighted the parts of the solution sketches, presented in Figure 21, which they liked, with red dots. Afterwards, in *Speed Critique*, each sketch was presented to the group, by another person than the creator of the idea. Later, he/she was asked whether the group misunderstood or forgot something to mention. *Straw Poll* and *Super Vote* were about voting for the ideas every participant liked the most. In the end, Figure 21c, was chosen, and the favourite parts of the other sketches were also considered in the storyboard. A closer description to this solution is given in Chapter 7.3.2 - Prototype 1 – Indirect Augmentation with an Island.

The method *Storyboard* started with creating frames and possible user flows. Every contributor wrote down six to seven steps, which they believed, how the users would experience the prototype. After presenting the user flows, every participant voted on their favourite flow. Then, the steps of one selected user flow were added to the frames of the storyboard. Additional steps from other user flows were also included. Figure 22 shows the created user flows.



Figure 22. Created User Flows

After adding the steps of the user flow to the storyboard, the participants started to sketch out how the prototype should look like in the end. Figure 23 shows the final storyboard at the end of the third day. During storyboard creation, multiple changes to the initial idea of the solution sketch were made, which will be presented in the next chapter, when describing the final version of the first draft.

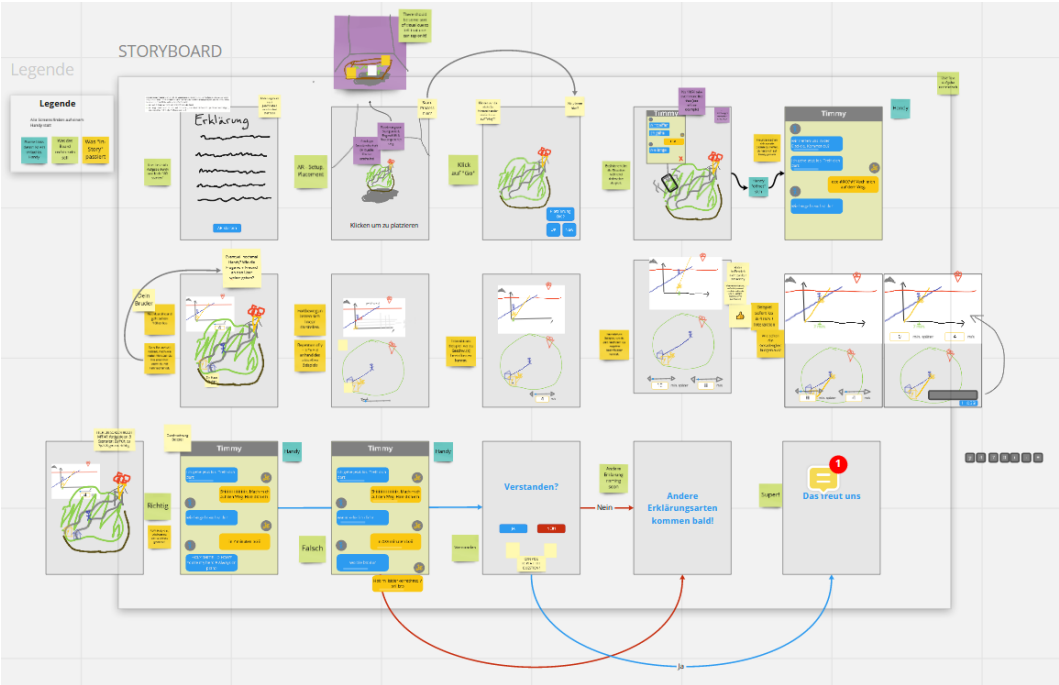


Figure 23. Storyboard after 3rd day of the design sprint

7.4.1.4.4 Prototype - 4th Day

At the beginning of the fourth day, the roles of the “writer”, “assets collector” and “stitcher” were defined and prototyping tools were evaluated. In the end, the AR prototyping tools *Torch AR* and *Figma* were used. The prototyping phase included screen design, text creation of the math problem, animating the linear graphs, audio recording, 3D asset collection, and assembling all parts in *Torch AR*, using an *iPhone XR*[31]. Other tools used to create this prototype can be seen in Table 11. After stitching all the parts together, the facilitator also wrote the test design and tested the prototype with the test design on two people to find possible mistakes. The first prototype is described more closely in Chapter 7.3.2 - Prototype 1 – Indirect Augmentation with an Island.

[31] https://www.apple.com/iphone-xr/

7.4.1.4.5 "Testing" – 5th Day (Phase 3)

The goal of the third phase was to receive qualitative feedback on the prototype (Chapter 7.3.2 - Prototype 1 – Indirect Augmentation with an Island) through tests with potential users. The tests were conducted using a previously created test design, aiming at finding possibilities and problems when using AR applications in math education. For a more realistic scenario, the tests were conducted remotely, where the participants (Table 5) tested the app at home in front of their PC or notebook. The tests took place on April 20th between 12:00 and 19:00, and on May 11th between 9:30 and 10:30 using *Google Hangouts* and *Lookback Participate*.

A couple minutes before each test, the testers received a mail with the information on the process and the programs they had to download. The test was structured into three parts and the users needed two different devices. The first part was a short initial interview through *Google Hangouts* and the users were asked to use their PC or notebook. The users were interrogated about their previous experience with augmented reality, how the students assess their understanding about linear functions and whether the teachers could generalise problems which students have with linear functions.

The scenario presented to the students was the following (translated from German): *Please imagine that you are currently at home, learning for a math lesson. At school, you have already learnt about linear functions. You use a mobile app for learning, and now you discover the augmented reality functionality, which you want to try.*

The teachers were put into a different scenario (translated from German): *Please imagine that you are at home, and you are preparing for your mathematics lessons for the 9th grade. The next topic that you are going to teach is the intersection point between two linear functions. During your research, you discover an app with augmented reality functionality, and you think – why not give it a try?*

For the second part, the users needed an iPhone or iPad with the apps *Lookback Participate,* and *Torch AR* installed on it. The interviewer and the observers were able to see the testers' display via *Lookback Participate*. After the initial set-up, the users were introduced to the scenario. Then, the users were asked to share their honest opinion and thoughts. Afterwards, they started the *Torch AR* prototype. When testing the app, it was not always possible to see the testers' facial expressions and gesturing through *Lookback Participate*. This was caused by the limitation that most smartphones only supported one active camera at the same time. Therefore, it was a challenge to observe the testers movements and facial expressions closely when the camera was not shared via *Google Hangouts.*

Therefore, interviewer and the observers partially had to rely on the testers' words, voice, and language.

The third part of the test took place again in *Google Hangouts* where the testers were requested to answer final questions. For example, the users were asked to share their thoughts on the prototype, highlighting both, the positive and negative aspects. They were interrogated on if and in which scenarios they would use the app and evaluate whether the prototype helped them or their students to understand the concept better. The complete test design can be found in the appendix SD.

The interviewer of the tests was always the author of this thesis, and observers varied between 0 and 2 people. The second part of the interview, where the participants tested the prototype, was always recorded, because it would be a challenge for the observers to write down all actions and comments of the users at the same time. When it happened that no observer was available, the author would record the entire interview, then re-watch the recordings and write down notes (e.g. observations, citations, and keywords). In case there were observers, they would take notes on the *Miro* board throughout the interview. Figure 24 shows an exemplary snippet of the collected notes (written in German). The rows represent the scene categories, the columns stand for the testers and the notes are colour coded. Turquoise means observations, green is good, orange is bad, and yellow stands for comments. For example, the translated notes in the cell in the second row (engl.: *explanation of situation with smartphone)* from S7 mean the following: yellow: "Ice cream is cool", green: immediately clicked on the phone model, turquoise: first explanation closes again (after clicking on phone again), orange: did not find the arrows.



Figure 24. Exemplary snippet of note taking when testing the first prototype

7.4.1.5 Qualitative Content Analysis (Phase 4 – Iteration1)

7.4.1.5.1 Interviews & Brainstorming Session

The analysis of the interviews was done with the help of Kuckartz's (2016) qualitative analysis approach (Kuckartz, 2016). All interviews from phase 1 were transcribed after the interview. The interviews were then categorised in two ways, using a colour code. The first categorisation was done by using the asked questions. The second round of categorisation focussed on commonly mentioned fields of problems. The categories were "personalisation", "relevance", "different ways of explanations & differently formulated problems", "language", "teaching methods", "self-efficacy", "situations to use e-Learning Apps", and "ease-of-use". Afterwards, all statements in the categories were placed next to each other to generalise the identified problems in this category.

The brainstorming session aimed at gathering ideas and possibilities to solve the above-mentioned problems. Therefore, after transcribing the brainstorming session, the analysis focussed on finding inspiration to solve the identified problems found during the interview.

7.4.1.5.2 Testing

During the tests, the observers took notes on *Miro*. The categories were predetermined by the structure of the interview and the structure of the prototype. Those categories were extended organically during the test. The notes were

colour-coded into good (green), bad (orange), comment (yellow) and observations (turquoise). Figure 24 shows a part of the board and the notes. This way, the biggest problems could be visually identified. The interviewer wrote down noteworthy observations and citations directly onto the testing guide. After the analysis, several problems and potential to improve the prototype on its effects on motivation and perceived usefulness were identified.

7.4.2 Iteration 2

Iteration 2 focusses on using an AR app to increase motivation in remote/blended-learning situations. This decision was made after the analysis of the first iteration in which the potential of AR to motivate students was identified.

7.4.2.1 Literature Research & Brainstorming (Phase 1 – Iteration 2)

The first phase (exploration phase) was mainly based on the findings of iteration 1. The researcher took a closer look at the multimedia learning theory (Chapter 5 - Multimedia Learning Theory) and on motivational design (Chapter 6 - What is Motivation). During the research, the author found the ARCS model (Chapter 6.2 - ARCS - V Model). Then, she conducted a brainstorming session by herself, using the findings of the literature research and the findings of the first iteration, with the goal to explore different approaches of AR to motivate students.

For this purpose, the taxonomy by Edwards-Steward et al. (2016), which categorises different tracking methods of handheld AR technologies more closely (Chapter 3.3 - Handheld AR), was used. The single categories (image-based markers, object-based markers, location-based AR, dynamic augmentation of objects, complex augmentation, indirect augmentation, and non-specific digital augmentation) were taken into account. Then, research on current possibilities to convey the topic of linear equations was done, e.g. by testing Brilliant[32], a distance learning website which offers interactive online courses in the fields of mathematics, science, and computer science, with the goal to foster user's problem-solving skills (*Our Principles for Learning | Brilliant*, n.d.). After gathering inspiration, ideas to refine the first prototype with another tracking technique than the first prototype were formed. Before selecting the final idea, different aspects were considered; for example, the experience the target group previously have with AR, what currently is technically feasible and testable and what system could

[32] https://brilliant.org/

be reused for other topics. The selected idea was to augment a self-drawn coordinate system.

7.4.2.2 Development Process (Phase 2 – Iteration 2)

The second prototype and the design choices are presented in Chapter 7.3.3 - Prototype 2 – Augmentation of a coordinate system and was created using the findings after the first iteration and further research on the multimedia learning theory and motivational theories. In this chapter, the development components, and an authoring system will be presented.

7.4.2.2.1 Development Components

The development was mainly done in the Game Engine Unity[33]. This time, a game engine was chosen, because more animations and interactivity can be provided than with rapid-prototyping tools, such as Torch AR. The initial plan was to use AR Foundation so the researchers could find participants more easily. However, after several attempts, the tracking stability was unsatisfying which is why the researcher switched to the augmented image system by ARCore.

For the second prototype, the plugins XR Legacy Input Helpers, AR Foundation and ARCore XR Plug in were used. Several audio and graphical assets were reused from the prototype of iteration 1. Additional 3D assets were chosen from Poly by Google[34], and emojis from GetEmoji[35] were used. Those assets were refined using Autodesk Maya[36] and Adobe Photoshop. A Samsung Galaxy S9[37] was used as testing device, to ensure that the prototype works technically correctly. Table 12 shows an overview of all technical components used to create the second prototype (Chapter 7.3.3 - Prototype 2 – Augmentation of a coordinate system).

[33] https://unity.com/

[34] https://poly.google.com/

[35] https://getemoji.com/

[36] https://www.autodesk.de/

[37] https://www.samsung.com/at/smartphones/galaxy-s9/

Development Environment
Unity 2019.2.13f1 with Android Build Support
Unity Plug Ins
XR Legacy Input Helpers 2.1.4
AR Foundation 2.0.2
ARCore XR Plugin 2.0.2
3D & Graphical Assets
Google Poly
GetEmoji
Autodesk Maya
Adobe Photoshop
Hardware
Samsung Galaxy S9

Table 12. Overview of the used technical components for the second prototype

7.4.2.2.2 Authoring System

During the implementation of the tool, a rudimentary authoring system was created in Unity, handling the sequences of the animations and the synchronisation between scene components and audio. For instance, it was possible to choose the order of the scenes and choose a different starting point of a scene.

7.4.2.3 Problem-Centred Pre-Interviews & Presentations (Phase 1-2 – Iteration 2)

Before the development of the prototype was finished, the participants for the second test were recruited. Six students of P1 volunteered (Table 7), and the author of this thesis presented them the goal of the project and interviewed them. The aim of the interviews was to find the current problems which they currently have with the remote-learning situation due to COVID-19 and their general relationship towards math, so the scores can be interpreted more easily. Both, the presentations, and pre-interviews were conducted remotely using *Microsoft Teams*. The researcher recorded the interviews and took notes during the interviews.

The presentation aimed at triggering the students' attention, the students were asked the question "Why can't maths be as interesting as e.g. social media?". Later, they were asked "What does mathematics and eating ice cream have in common? Test the prototype to figure this out!", and they were shown a screenshot of the first prototype, Additionally, they would receive a €10,- coupon for a store of their choice.

The interviews were problem-centred (Witzel, 1985), semi-structured and used open-end questions. The questions focussed on the students' relationship to mathematics, how they currently learn maths, and how they generally perceive smartphones in learning situations. The interview guideline can be found in the appendix SD.

7.4.2.4 Testing (Phase 3 – Iteration 2)

This testing phase was planned to be conduct remotely, using the tools in Table 13, and followed the test design in the appendix SD. The goal was to get an insight on how a student would react to the prototype while being in a comfortable environment. However, for S10, S11 and S12 there were difficulties and deviations, which is why with S10 and S12, the test needed to be conducted completely in person or partly in person, respectively.

The test design started with a short introduction on what the goal of the test is, encouraging the users to give honest feedback, so the researcher can improve the prototype. Then, an overview on the single steps were given. Afterwards, they were asked what they have already learnt about linear functions, to gather a broad overview, on what their current knowledge on the topic is. Later, they were presented a book page about the topic linear functions, which was taken from the book they are currently using in class. They were introduced to the scenario, were requested to learn with the book page, and were asked to speak out their thoughts out loudly. Afterwards, they were asked to give a description on how they are feeling about learning with the book page and what they are thinking. This was followed by an IMMS-test, which they filled out silently.

Pre-Interview & Post-Interview	*Microsoft Teams* (Except S9 & S11)
Observation	*Microsoft Teams & Lookback Participate* (Except S9 & S11)
Pre-Test	Book Page & IMMS
Post-Test	Prototype 2 & IMMS
Participating Roles	Interviewer Observer Student/Test Subject
Recording Software	*OBS*

Table 13. Software used for testing the second prototype

Next, after being introduced to the scenario, the students tested the prototype. Again, they were encouraged to speak their thoughts out loudly. During the test, the students were observed, they were asked follow-up questions when they remained silent, and comments were written down by the researcher immediately. After finishing the last scene of the prototype, the students were asked open-end questions. The questions were about their thoughts, emotions, and feedback how they would improve the prototype and in what situations they would use this kind of application. In the end, they were thanked for their participation and received a voucher.

7.4.2.5 Qualitative Content Analysis (Phase 4)

Pre-interviews were conducted to better understand the background of each tester, and to assure that they have an ARCore compatible smartphone.

For the testing, the qualitative analysis was done using Kuckartz' (2016) method for qualitative content analysis (Kuckartz, 2016). The categories created were "personalisation", "relevance", "different ways of explanations and differently formulated problems", "language", "variation of teaching methods", "self-efficacy", "situations to use the eLearning app", and "ease-of-use".

The RIMMS questionnaire was used to assess motivation after using the book page and after testing the AR prototype. Then, the scorings were compared to each other and interpreted with help of the comments, observations, and backgrounds of the testers.

7.5 Analysis & Results

7.5.1 Iteration 1

7.5.1.1 Interview & Brainstorming Session

The interviews were conducted with six upper secondary school students from the 9th and 10th grade (Table 3) and the mathematics professor P1 (Table 6). Afterwards, the interviews were transcribed, analysed and the answers categorised. In this chapter, the results of the interviews will be presented.

7.5.1.1.1 Personalisation

- Math curriculum is built upon previously learnt concepts. Teachers expect that students already have internalised previously taught topics. This is especially problematic when pupils from different schools change into one class. In class, there is not always the possibility to tackle students' deficits. Additionally, math is often taught using a teacher-centred learning approach which makes learning in one's own velocity difficult.
- S1 states that she feels "completely lost" and that her teacher does not consider helping students with strong deficits, which is especially problematic since she already had problems in maths in her previous school. S2 sees a similar problem and believes her teacher does not pay attention to all students in the classroom the same. P1 stated, that, although she sometimes notices some difficulties in class, she must take a certain knowledge base for granted. Therefore, she cannot revise every single chapter that they have learnt before. However, she offers additional courses after class, but added that most students do not take this chance.
- Students think learning with relatives is more efficient than with the teacher in the classroom. For example, S5 stated that she rather learns with her cousin because the explanations are much more personal. S3 stated that he would enjoy learning with a mathematics app to learn in his own velocity.

7.5.1.1.2 Relevance

- Subjects are perceived as boring when students do not know whether they will reuse the learnt material again the future. S1 stated that she would describe mathematics as boring and does not know whether she will ever use the learnt concepts again. Additionally, S1 and S5, both stated they probably do not like mathematics because they want to become a kindergarten teacher, and a nurse, respectively. In the interviews,

mathematics was not the only subject mentioned to have this problem, but also subjects such as “Art” and “Handicrafts”, as S3 and S4 state.

- From the perspective of P1, many students do not show personal responsibility to improve in their performance at school. For example, they do not come after class to ask the teachers when they do not understand a problem. P1 believes that their social life at school is more important or interesting than their school performance.
- During the brainstorming session, three methods for increasing the feeling of relevance have been discussed. Firstly, to give math problems from the first-person perspective. Secondly, to let students understand why they should learn about certain topics. Thirdly, the math problem should be relatable to the students’ daily life.

7.5.1.1.3 Different Ways of Explanations and Differently Formulated Problems

Students wish different ways of explanation when they did not understand a certain way of explanation. Also, students find it easy when math problems are asked in one certain scheme but have difficulties to solve a differently formulated task.

S1, S2, S3, S4 and S6 stated that if they do not understand an explanation, they wished that their teachers used different words or different ways of explaining a math concept. S1 stated that her teacher tends to explain a concept “10-times the same way”, while S2 said, that she thinks the explanations her teacher gives are not good in general, because the teacher only reads out definitions from books. Also, S3 stated that it can be difficult when one must filter the information that teachers says. P1 believed, that many students often do not understand the core concepts, but only try to learn a “recipe” to solve math problems. Therefore, many students have difficulties when a math problem is formulated differently than the ones they are used to.

7.5.1.1.4 Language

Often, students do not understand the explanations in the books. Students criticised when teachers explain concepts “too scientifically”, while P1 warned that certain things could be seen as “too childish” for teenagers.

S1 stated, that her teacher always uses the “scientific language”, and S2 claims that her teacher only reads definitions from the books. S3 mentioned that mnemonics are helpful for topics which must be learnt by heart. Nonetheless, P1 said that, especially teenagers do not want to be treated like children, which is why it can be difficult to find methods “that are still cool” for them.

7.5.1.1.5 Variation of Teaching Methods

A teacher-centric teaching approach has often been criticised by the students, while varying teaching techniques (e.g. going to computer room) result in a positive attitude of the students.

S3 and S6 wished that the teachers used more interactive teaching methods. S3 and S4 stated that visualisation and graphical calculator helped them a lot during classes. S6 stated that revising old chapters helps him too. S4 would rather work independently than having the teachers calculating for them in front of the board. P1 indicated that the preference of the students regarding used teaching methods are varied. Especially students who are confident with their mathematics skills enjoy working independently, others simply want to listen to the teacher, while others prefer group work and interactive learning. Additionally, P1 stated, although a teacher-centric teaching approach is the easiest, she tries to bring diversion into class, by playing introductory quizzes or going to the computer room. The brainstorming session indicated that P1 also liked a variation of teaching methods when she was a student.

7.5.1.1.6 Self-efficacy

In the brainstorming session, P1 stated that she has an acquaintance whose teacher would say that this person will never understand maths, which led her acquaintance to be afraid of mathematics until today. S5 believes, that there is nothing one could do when one does not understand a certain concept, especially when one must solve a math problem independently. S6 added that he believes that he only understood a math concept completely when he sees the problem and can solve the problem immediately without thinking much.

7.5.1.1.7 Situations to Use eLearning Apps

When asking the students whether they could think of situations, where they would use eLearning apps, the answers were diverse.

S1 stated that her teacher was never at school, and remedial lessons did not come about. S2 said that they never had time to revise during class. S4 indicated that his class is very loud, and the teacher then talks silently to herself and writes very fast. S6 would use eLearning apps in situations when he was sick and therefore missed something at school, when he did not understand a certain concept at school, or shortly before a test for revision purposes in a 5-minutes break.

7.5.1.1.8 Ease-of-use

When using an eLearning app, S6 stated that the interaction needs to be flawless, and he would like to find certain topics very fast. P1 stated, that a tool must be

easy to use for students, for example to include a possibility for students to easily hand in their home exercises, without having to switch to another platform. During the brainstorming session, P1 highlighted the examples as her favourite ones which quickly explained the concepts.

7.5.1.2 Test

7.5.1.2.1 General Thoughts on the Prototype

P1: 4* with bugs 5* for students' understanding

> P1 liked the interactivity, and that the coordinate system changes immediately, however, she wished that the animations of the 3D objects would change too. She highlights that this example would help her students with their understanding.

P2: 3* with bugs, 2-3* for students' understanding

> P2 likes the visual representation and the story of this math problem, however, she thinks that this prototype would confuse students because she would explain certain parts differently. Especially students who already have difficulties in math, would face difficulties understanding the content of the prototype.

S2: 2* with bugs, 4,5* without bugs

> S2 liked that he understood the topic of linear functions, although he did not deal with this topic for quite a while. Moreover, he liked the idea of exploring maths in AR. Nonetheless, he criticised the usability, in terms that the island was "too big", and he had to stand on tiptoes to see everything; that it was not possible to stop the narrator from talking; and that he had not been able to see the coordinate system in one scene, because it was hidden behind the island. The usability problems would make him to "not use the app". Also, he wished that the 3D objects on the island were animated, and he hoped that more complex topics are going to be visualised in the future.

S7: 4*

> Said she liked the overall experience, and that this example was very immersive. However, she already knew the basics of linear functions, which is why, she would like to have more complex topics visualised, and asked whether there will be also exercises where solving and calculating the math problems are needed. She liked the story and the hands-on part the most.

S8: 4,5*

> Enjoys the novelty of the concept, and that one can interact with the prototype, however, she found the onboarding process cumbersome, and needed some time to understand the interactions. Additionally, she did not like the 3D model of the island, but said the experience was like a “fairy-tale”.

7.5.1.2.2 Content

- Scenario & Story

The scenario was well-received by all testers. For example, P1 stated, that it this example could show students that math problems can solve problems with personal relevance too. S7 and S8 said they enjoyed the story about ice cream and meeting up with friends.

a. Content should be more precise and clearer

P2 stated that she assumes that her students “will get confused”, because in the explanation of the prototype, the linear function is changed through moving the function on the x-axis, and not on the y-axis. Usually, Austrian students learn it the way, that the y-axis is changed, because the formula “y = k * x + d” moves the function along the y-axis by changing the variable d. Moreover, the narrator did not explain the formula or the components of y = k * x + d, but the information was shown in the graphs. P1, however, stated, that she liked the fact that the slope was well visible in the graphics. P2 suggested to focus on the key-takeaways, and not to integrate too much information into one exercise.

b. Helping students to reflect

P1 stated that the question in the end helped to actively reflect on the taught topic. Therefore, she would recommend an entire quiz in the end, for example to test, whether the students understood the core concepts e.g. paying attention to the axis labelling. S7 also said that it might be more effective if there were more exercises where she can solve math problems by herself.

7.5.1.2.3 Understanding

The teachers had different opinions, on whether this prototype would help their students. For example, P1 stated, that she expects a great impact, while P2 believed that the prototype would confuse her students, because of the reasons mentioned in the category “content”. For the students, who already have learnt about linear functions, the prototype seemed to be helpful for revising. S2 stated that the example was great for revising this topic, although he had not dealt with

the topic of linear functions for quite a while. S7 said that the topic of linear functions is way bigger than this example covers, which is why she did not think that this exercise alone improved her understanding on this topic that much. S8 stated at the beginning, she would rate her understanding about linear functions with 2*. Afterwards, she gave herself 4*.

7.5.1.2.4 Visual Design

The visual design aroused mixed feelings in the participants. For example, P2 stated that she liked the visual appearance of the example and could imagine this to be appealing for her students too. S7 said that she enjoyed seeing the 3D representation and thought the cyclist was animated, which was, however, not possible due to the constraints placed by *Torch AR*. S2 stated that the street was curved strangely, and S2 and S8 both did not like 3D model of the island. S8 said she was quite confused, what the bottom part of the island should represent.

7.5.1.2.5 Interactive Parts

P1 and S8 stated that they enjoyed the interactive parts because the prototype gave immediate feedback, what changes when e.g. the velocity changes. P1 also said she would like a comparison to e.g. cars and that the changes should not be too small, so students immediately see an effect of their actions.

7.5.1.2.6 Usage of AR

P1 states that she was surprised that the first scene in the environment had nothing to do with mathematics. She highlights that her students might like this kind of representation, because “it does not remind them of mathematics”. Nonetheless, she stated that the set-up process might be too complex, and students might only find this process interesting in the beginning.

> P1: “I do not know, if it is worth to go through the entire set-up process to only see the island placed into the room. Still, it is cool, and it is a difference to the things that the students usually see.” (Translated from German)

P1 suggested to go to a bigger place (e.g. street), and to implement this scenario into the real world.

P2 also said, that her students tend not to like components that reminded them of math classes.

> P2: “I think my students will like the representation, because they have not seen this kind of representation before.” (Translated from German)

However, P2 does not see that much of an added value in the first prototype. She gave an example for improvement: For linear functions, P2 believes the 3D representation of AR in combination with the graph might help students to understand the relationship between a walked way and a linear representation. She gave the example, that students believe, that when a person walks an uneven way, the graph must be curved as well. However, this is not the case when the person walks in a constant velocity, or the average velocity is taken. Therefore, she would find it interesting to convey this kind of understanding with the prototype. Also, P1 stated that she liked that this example shows that the path is fixed, and one does not try to calculate the path in this type kind of math problem.

All testers said that they could imagine AR to be helpful when more complex topics are visualised using AR. They suggested more levels, and to integrate the real-world environment more into the application. Moreover, both P1, and P2 suggested to add a reward system in the end.

7.5.1.2.7 Usability

- Starting Torch AR

When P2 started the *Torch AR* scene, the scene reacted very slowly and needed around seven minutes to load completely. Therefore, she was asked to share her thoughts. She stated that she thinks that the slowness of the app is caused by the test version. In real life, she would only explore new apps, when she has a lot of free time available. Therefore, she would put the phone aside and do something else until the scene is loaded. Other testers did not face any problems when starting *Torch AR.*

- Scanning the Room & Placing the 3D Scene

When scanning the room, S2, who has experience with AR development, immediately knew, how to scan the room and place the island, while all other participants, who only had little experience with AR, faced difficulties. For instance, S7 faced the problem that she tried to scan a table with very little feature points, P2 and S8 had the problem that they placed the island too high or too low, while P1 had the problem that she placed the island too close or too far away. Therefore, they did not see immediately, where the arrows below the island were located, which is why the interviewer needed to explain where to click, or whether they must relocate the augmentation. Later, S2 stated, that the island was also scaled too big, and he wanted to adjust its size. According to the mimic of the users (P1, P2, S7, S8) the scanning process seemed to be cumbersome, but their faces relaxed, when the scene was placed in a convenient place. For example, S8 said, after

successfully placing the island, “Ha, this is so cool!”. S7 stated, it would have been helpful to introduce users with low AR experience with a tutorial.

- Placement of Buttons & Feedback

Most of the testers could not find the interactive buttons below the island and some buttons did not give immediate feedback. For example, S2 and P2 reported, that they clicked on the phone or button, but they did not react properly, or P1 repeatedly clicked on the phone with the hope to continue the scene. Moreover, because the 3D scene was shifted in some set-ups, the testers were not able to see the buttons (P2, S7, S8). After initial problems, the users were able to continue without any interaction issues.

Furthermore, S2 recommended to place the buttons closer to the whiteboard, where the functions are visualised, so one does not need to jump with the eyes.

- Voice, Video & Animation

The users liked the explanation and the voice; however, the audio was levelled too loudly. Additionally, due to the *Torch AR* constraints, the video and the audio were played in a continuous loop, which was stated to be annoying by the testers. Another problem was that it was not possible to animate the 3D objects in *Torch AR*, which is why the testers recommended to animate the cyclist and the walker according to the graphs in the video and the narrator. Despite the usability problems, P1 stated, that she liked that the smartphone is reading everything out loud.

- Possible Situations of Usage

The professors might show this prototype to students during classes as a variation to normal lessons. P1 would use it either to introduce the topic of two linear functions, to show the relevance of this math concept, or give the prototype to students to try it out prior to the class. P2 would give it to students during a practice lesson with other learning materials where students can explore different examples on the impact of changing the parameters.

The students would use it either for revision purposes or when one is stuck when doing the homework (S2). S7 could imagine using it to revise for (final) exams and for practicing purposes, especially when being in quarantine (e.g. COVID-19). S8 would use it to revise at home, after having learnt the topic at school, or use it as a personal support when doing homework. Additionally, she would also like to talk with friends about the exercise, and to interact more with the prototype. If more

levels existed for topics which allows integrating the environment, or if geocaching were integrated, she would go around and explore.

7.5.2 Iteration 2

7.5.2.1 Interviews

For the analysis of the test, Kuckartz's (2016) method for qualitative content analysis was used (Kuckartz, 2016). The categories created were "Introduction & Ending Screen", "Scanning Process", "Usage of AR", "Visual Representation", "Usability", "Self-Efficacy", "Realism and Relevance", "Story", and "Technical Problems".

7.5.2.1.1 Introduction & Ending Screen

The introduction screen seemed not to be appealing or motivating to everyone. S9, S11 and S14 did not read the introduction and clicked on "START AR" right away. However, S10 stated that she liked that she was reminded of the formula y = k * x + d. While S11 and S14 stated that they liked the end-screen and that there is a summary of all gained competencies. However, S9 said that she doubted that she understood everything.

7.5.2.1.2 Scanning Process

The scanning process seemed to be straight forward for all testers, and they enjoyed the immediate feedback from the system. When S9 was asked about the scanning part, her face lightened up and said she thought "it was so cool" to see how easy and fast it was, and that she liked that she did not need further materials, such as a pencil or a ruler, only the phone and the sheet. S11 also said "it was so interesting that it worked immediately", and S12 said "I like that kind of stuff, it works like Snapchat filters!". S14 said during the test "Uh, that's fascinating" and "I already think it's (the prototype) cool!". S14's face was very surprised when the 3D scene appeared.

7.5.2.1.3 Usage of AR

The opinions on the necessity of the usage of AR are varied.

S9, S10 and S11 all said that they liked that the animation appeared easily. S9 stated that she had never seen that kind of math representation before, and she wished there were more exercises, because usually, it takes a lot of effort to visualise math problems in one's head. S10 described the augmentation as "generally cool" but she has doubts that she could write and take notes with the phone in her hand. S11 and S12 liked how AR is used in this prototype, offering a

new learning approach for students. Moreover, S12 liked that the virtual coordinate system is the same as the physical one and that the labelling of axis is virtual. Also, he mentioned that other topics might profit more from AR. Also, S9 and S12 liked that they do not need additional equipment or material, only a sheet of paper and their phones. S13 stated that she believes that, for her, it would be sufficient to visualise everything without AR, but that this technology adds a possibility for students to learn differently. However, she also added that she probably cannot give much feedback on AR, because she does not know much about this topic. S14 said that she really enjoyed that she was able to see her desk in the background, which gave her a sense of realism and immersion. Sometimes, she thinks that math problems are too encapsulated, which is why they are not relevant to her. This set-up made her believe that the entire story took place in her own room. Also, if the coordinate system did not jitter, she could imagine taking notes on the sheet of paper.

7.5.2.1.4 Visual Presentation

All testers liked the design and the visual presentation of the application. For example, S11 enjoyed that she recognised familiar components, e.g. the chat-history. She also highlighted positively that the colours are coherently used. Also, all testers adored that the 3D objects and the graphs moved synchronically with the narration. S14 stated, that, in the beginning, she thought that there was too much happening simultaneously, and did not know exactly, which part to pay attention to.

7.5.2.1.5 Usability

- Tracking, Hand Positioning & Arm Fatigue

Jittery tacking was mentioned to be problematic by every tester apart from S9, although the tracking was lost once too when she used the prototype. Additionally, her hand positioning seemed uncomfortable, as if she wanted to stabilize the constant shifting. S10 stated that she usually puts her phone onto the table, which is why it was strange for her to hold the phone up-right above the paper. Also, she stated that she believes that she her hands were shaky, which caused the jittering. S13 also wanted to take a screenshot of the scene, so she could relax her hands. S11 wanted to explore the scene more closely, but when the marker was not in the camera, the coordinate system would shift, causing her to stop exploring. Although S14 liked that the virtual coordinate system was overlaid above the drawn coordinate system, she wanted to give the physical one away because it jittered too much. S10, S11 and S13 reset the augmentation once or twice after the interviewer told them where this button was located. During observation, it seemed

that the graph paper caused the jittering, because the scene would often jump one, two or three units. Also, tracking seemed to be more stable on the phones Samsung Galaxy S9, Samsung Galaxy S10, and Samsung Galaxy A50 than on Samsung Galaxy J5 and Samsung Galaxy A7.

- Zooming

S12 attempted to zoom in with pinch gestures. After the interviewer said that he could go closer with the phone, he would explore the scene by moving the phone. S14 explored the scene by moving the phone closer to the scene, but almost missed the message at the end of the exercise. S11 wanted to explore by moving the phone too, but did not continue, because the tracking shifted after the marker was out of the vies. S10 and S13 gave the impression that they did not want to explore. This could be because S10 generally likes to put her phone on the table and S13 wanted to relax her arms. S9 seemingly tried to hold the phone straight to stabilize the jittering.

7.5.2.1.6 Buttons

The control buttons “play”, “stop”, “replay”, “back” and “forward” seemed to be straightforward for all testers. S10 stated that she enjoyed that, compared to normal videos, she was given enough time to process the information bit by bit and that she was able to control by herself when she was ready for more information. All testers, except from S13, used the replay button at least once.

For the icons in the interaction scenes, only P12 and P14 understood they were clickable. Additionally, all testers, except from S14, did not understand what “-2m/s icon” should represent, while all other icons were understood correctly.

7.5.2.1.7 Guidance

S14 stated that in the beginning, she did not know which part of the scene to concentrate on. She suggested, that at first, only the 3D scene should show up, and later the coordinate-system should be introduced. Also, in the last scene, she stated that she almost missed out on the chat-history, which is why it would be nice if one implemented a visual guidance system to make sure one does not miss out on important information.

7.5.2.1.8 Self-efficacy

Regarding self-efficacy, the answers varied as well. For example, S9 did not know if she understood the math problem correctly and blamed herself by saying, “maybe it’s because of me”. She also said that she does not think that she understood all three requirements in the summary page. However, she mentioned

she knows now what intersection points are used for. Nonetheless, she showed insecurities regarding the basics of linear functions (e.g. what the slope exactly means). S10 stated that she would “really love to learn with this app again, because I feel well-prepared now for a test on intersection points”. S12 stated that he liked the summary page, because he could test himself, whether he understood everything. S11 said that she has learnt that the intersection point can easily be changed, depending on the slope and a different starting-point. S13 stated that, if it were her first time dealing with linear functions, the app would not contribute much to her theoretical understanding but would answer the question “why do I need this”. She “definitely” believes that this app could help her tutor students. S14 stated that, the app showed that the linear function can simply be changed with a button click. This gave her the confidence, that she could also solve the math problem easily as well.

7.5.2.1.9 Realism & Relevance

Most of the testers highlighted the realism and relevance for daily life positively (S10, S11, S12, S13, S14). For example, S11 stated that she believes that she could reuse the leant concept one day.

S11 and S12 stated that she liked the chat-history looks, and that the scanning process with the QR code reminds him of face-filters in other apps, respectively. S13 liked the most that one was able to, not only see the coordinate-system, but also the real-world scenario. S14 stated that the story is “very realistic and relatable”, that she “would not pay attention to the phone either”, “I don’t even know where my purse is at the moment” and that “yes, my mum would definitely tell me to eat something before going out”. Additionally, during the second interactive scene, she put on a worrying face stating “What, it’ll take me so long for eating? Then I’ll never be able to catch him up!”. She also stated that it makes more sense to her when she might need linear functions in her daily life. Only S9 stated that she thinks that one cannot know that exactly when a person arrives, because there might be some delay due to unforeseen factors.

7.5.2.1.10 Story

Most parts of the story appeared to be understandable for all testers. S10 for example, laughed at the part, that she would eat something before going to an ice cream store. Also, the interactive icons seemed to contribute to their reflection process. Only the icon for “-2m/s” was problematic and was only understood correctly by S14. S11 stated that she would have expected this to be explained in later scenes. S13 thought that it would portray the way back home.

7.5.2.1.11 Technical Problems

Before and during the test, a couple of technical issues occurred. For example, S9 needed to deinstall an app before being able to install the prototype. S10 did not have a smartphone which is able to run *ARCore*, which is why the test needed to take place in person, with her using the researcher's phone. S11's first tried to run the app with Samsung Galaxy A5, which is not supported by ARCore, which is why she needed to switch to Samsung Galaxy J7. Initially, her J7 crashed three times, which was resolved by a re-start. S12's J7 was not able to install the app beforehand because of a lack of storage, which is why the test of the prototype was conducted in person, using the researcher's phone.

7.5.2.2 RIMMS Test

For both, the pre-test and the post-test, the students were asked to fill out the RIMMS query, which can be found in the appendix (Appendix B - RIMMS Pre-Survey, adapted (N. Loorbach et al., 2015)). Figure 25 shows the scores of the RIMMS test. When comparing the results of both tests using the ARCS model, the biggest positive difference can be seen in the categories satisfaction and attention. S13 found the narration and the content of the prototype less relevant than the book page. In the confidence category, S9 and S13 both felt less confident that "they could learn the content while working through the book page / prototype". All in all, the users were more motivated to use the AR prototype than learning with the book-page. The following chapter will discuss those scores more closely.

a)

Student & Question	A - Pre	A - Post	Difference	Student	R - Pre	R - Post	Difference
S9 A1	3	4	1	S9 R1	2	2	0
A2	2	5	3	R2	2	4	2
A3	3	5	2	R3	1	4	3
S10 A1	3	5	2	S10 R1	4	4	0
A2	2	4	2	R2	3	4	1
A3	3	5	2	R3	2	5	3
S11 A1	2	5	3	S11 R1	4	4	0
A2	2	4	2	R2	1	3	2
A3	1	4	3	R3	3	3	0
S12 A1	4	5	1	S12 R1	3	4	1
A2	3	4	1	R2	2	3	1
A3	4	5	1	R3	2	3	1
S13 A1	5	5	0	S13 R1	4	5	1
A2	3	4	1	R2	4	3	-1
A3	3	5	2	R3	2	4	2
S14 A1	2	5	3	S14 R1	4	5	1
A2	5	5	0	R2	5	5	0
A3	4	4	0	R3	5	5	0
Sum	54,00	83,00	29,00	**Sum**	53,00	70,00	17,00
Avg	3,00	4,61	1,61	**Avg**	2,94	3,89	0,94
Median	3,00	5,00	2,00	**Median**	3,00	4,00	1,00
Std. Dev.	1,05	0,49	1,01	**Std. Dev.**	1,22	0,87	1,08

b)

Student & Question	C - Pre	C - Post	Difference	Student	Sat - Pre	Sat - Post	Difference
S9 C1	4	3	-1	S9 Sat1	2	4	2
C2	1	3	2	Sat2	2	4	2
C3	3	3	0	Sat3	3	4	1
S10 C1	4	4	0	S10 Sat1	4	5	1
C2	1	5	4	Sat2	2	5	3
C3	3	5	2	Sat3	3	5	2
S11	4	5	1	S11 Sat1	1	4	3
C2	3	5	2	Sat2	2	4	2
C3	2	4	2	Sat3	1	5	4
S12 C1	3	4	1	S12 Sat1	2	3	1
C2	4	4	0	Sat2	3	4	1
C3	3	4	1	Sat3	3	4	1
S13 C1	4	3	-1	S13 Sat1	2	3	1
C2	1	2	1	Sat2	1	5	4
C3	4	5	1	Sat3	3	5	2
S14 C1	5	5	0	S14 Sat1	4	5	1
C2	3	4	1	Sat2	4	5	1
C3	5	5	0	Sat3	5	5	0
Sum	57,00	73,00	16,00	**Sum**	47,00	79,00	32,00
Avg	3,17	4,06	0,89	**Avg**	2,61	4,39	1,78
Median	3,00	4,00	1,00	**Median**	2,50	4,50	1,50
Std. Dev.	1,21	0,91	1,20	**Std. Dev.**	1,11	0,68	1,08

Figure 25. RIMMS scores; the questions can be found in the Appendix B - RIMMS Pre-Survey, adapted (N. Loorbach et al., 2015)

8 Discussion

This chapter provides a discussion to answer the research questions, using the literature research and the results of the empirical study. As a recap, this thesis aims at answering the following research question:

How can AR learning exercises for a math learning app be created to foster the motivation of upper secondary school students, especially for remote or blended learning situations?

According to Edelson (2002), DBR can create three types of theories (Chapter 2 - Design-based Research), which are domain theories, theories on the design framework, and theories on the design process (Edelson, 2002). Therefore, the sub-questions of this thesis acquire findings in those three categories.

- Which main benefits of using an AR mathematics learning app for upper secondary school students can be found during research? (Domain Theory)
- Which elements should a motivational AR learning experience contain? (Design Framework)
- How should a creation process look like to effectively create motivational AR math learning experiences? (Design Methodology)

This chapter shortly discusses the domain theory, then focusses on the theoretical frameworks to design motivating AR exercises for a mathematics learning app. Additionally, recommendations on the process to create such experiences will be given. In the end of this chapter, a combination of design frameworks and design methodologies will be suggested. Also, hypotheses for further research will be provided.

8.1 Which main benefits of using an AR mathematics learning app for upper secondary school students can be found during research? – Domain Overview

During the process of answering the first sub-question, an overview on the state-of-the-art research landscape on AR in educational settings was generated. The combination between the literature research (Chapter 4 – AR in Educational Settings) and the results of the first iteration (Chapter 7.5.1 - Iteration 1) made evident that the main benefits of AR in educational settings are its motivational effects and its ability to visualise invisible concepts differently. Additionally, the situation caused by the COVID-19 outbreak showed that motivational tools for remote and blended-learning situations are needed to support students with self-directed learning. Literature research (Chapter 4.1.2 - Effects & Conflicting Insights, Chapter 5 - Multimedia Learning Theory), interviews and both tests (Chapter 7.5 - Analysis & Results) show that AR exercises can either be highly motivating, or discouraging and annoying (Chapter 6 - What is Motivation).

Therefore, the following research questions focus on discussing a design framework and provides a design process to create motivational AR exercises for a mathematics learning app.

8.2 Which elements should a motivational AR learning experience contain? – Design Framework

The results show that AR exercises can be highly motivating. However, there is also a risk of AR being discouraging or annoying for students when the instructions do not meet the learner's expectations or when technical difficulties, usability issues or cognitive overload occur. In the course of the study, it became clear that both created prototypes can be either created with or broken down using the ARCS model and the multimedia learning theory. While the ARCS model contains the motivational factors, the multimedia learning theory attempts to reduce cognitive load. Therefore, a discussion on each of those two models will be given using the research results.

Design frameworks provide theories on creating certain designs and experiences. In the case of this study, the multimedia learning theory, the ARCS-V model, and

the combination of them are being discussed. In the end, the cost-benefit factor will be considered as well.

8.2.1 Multimedia Learning Theory

This section focusses on discussing the findings of the first and second prototype, using the multimedia learning theory (Chapter 5 - Multimedia Learning Theory).

8.2.1.1 Coherence Principle

According to P2, the coherence principle in the first prototype (Chapter 7.3.2) was disregarded when the prototype showed the equation y = k*x + d, although the narrator never explained the equation. P2 stated that it could be confusing for her students, while P1 highlighted positively that the equation and the slope were well visible. For the second prototype (Chapter 7.3.3), S13, an A student in mathematics, stated that she would have liked more theory and scientific terms implemented to the prototype. Since both prototypes only contained one AR exercise, it was not possible to cover all relevant information about linear functions in one exercise without disregarding the coherence principle. Therefore, for the creation of a mathematics learning app, it is recommended to analyse all course elements (step 4 of motivational design steps), and then to set a clear goal for one (step 5 listing objectives and assessments), so one complete course covers all relevant information, but one exercise does not try to convey too much information. Estapa & Nadolny (2015) have observed that AR applications are more prone to be cluttered and have a higher risk for cognitive overload than websites (Estapa & Nadolny, 2015). Therefore, it is suggestible to put even more effort on applying the coherence principle when designing AR learning experiences.

8.2.1.2 Signalling Principle

The testers of the first prototype (Chapter 7.3.2) liked that important information were highlighted with a ring when the narrator talked about it. However, P2 stated that her students might get confused because she would explain linear functions by moving the function along the y-axis and not the x-axis. This is because, when d in the linear equation y = k * x + d is changed, the function would move along the y-axis. In the post-interview after testing the second prototype (Chapter 7.3.3), S14 stated that the interactive part helped her understanding which parameters she could change to manipulate a linear function. Since the second interactive part was about shifting the zero point, there might be a risk that new learners mistakenly mix up zero point and d. Therefore, one needs to carefully consider which parts of the instructional materials are highlighted and done interactively, since those are

probably the parts the students most likely take away from an interactive AR experience.

8.2.1.3 Redundancy Principle

For the first prototype (Chapter 7.3.2), the redundancy principle was considered by adding the chat history to the narration. Both conveyed the same information but were worded differently This was reused for the second prototype (Chapter 7.3.3), which made some testers smile (e.g. S11). Another factor which needs to be considered is that S14 said that she was stressed in the beginning, because she did not know whether to look at the coordinate system or the 3D representation first. She suggested to first, only show the 3D scene, and then the coordinate system. Later, she stated that she got used to the format and concentrated more on the mathematical representation on the coordinate system.

What is more, during the tests, almost all icons in the interactive part seemed to be understood by the students. However, for more tricky concepts, e.g. the -2m/s button, it might be recommendable, to add an optional auditive channel which explains the interaction.

8.2.1.4 Spatial Contiguity

In the first prototype, the control buttons were placed relatively far away from the whiteboard. This was criticised by the testers. Therefore, the position was changed to the UI space for the second prototype. Although the control buttons were still not placed directly next to the coordinate system, the testers seemed to like their position. This is because, in the second prototype, not only the coordinate system had animations on it, but also the 3D scene. Consequently, the control buttons would influence the entire scene, not only one part of the scene, like in the first prototype. However, it is recommended to place buttons and information right next to one element, if only this element was influenced.

8.2.1.5 Temporal contiguity

Since the prototyping software of the first prototype did not allow to sync the 3D objects with the narration or the video, it was stated by the testers that adding animations would improve the prototype. P2 stated that some of her students have difficulty in understanding that going a curved path does not result in a curved function. After syncing the narration, the graphs, and the 3D objects in the second prototype, the testers highlighted this feature as very helpful to understand the connection between a real-life situation and a linear function. These observations support that the temporal contiguity principle for multimedia learning also applies for interactive AR experiences.

8.2.1.6 Segmenting

Although the narration was segmented in both prototypes, users of the first prototype faced the problem, that they could not control the narrator, since videos in the prototyping software were played in a constant loop. This seemed to annoy the testers, although they did not say it directly. In the second prototype, the narrator would stop talking after one scene. S10 preferred this kind of segmenting over e.g. normal videos, because the prototype would give her the time to digest the information. She liked that she was able to decide on her own whether she was ready to continue with the explanation. This finding supports that the segmenting principle helps learners to process the given information.

8.2.1.7 Pre-training

Pre-training or an onboarding would have been necessary to set up the first prototype, because most testers were not familiar with the room scanning process. For the second prototype, pre-training was not needed for the scanning and placing process and using the control buttons. This is because the testers were all familiar with smartphone camera scanning processes, and video buttons. Additionally, the testers of the second prototype were satisfied that they were able to scan and place the scene immediately. However, a welcome tutorial would have probably been helpful for functionalities such as re-locating the augmentation and the interaction buttons.

For further development of the app, it is recommended to revise needed previous knowledge in the app before entering the AR exercise. Since many students in the second prototype skipped the introduction screen without reading it, pre-training should also be designed interestingly, although they are not a part of the AR experience.

8.2.1.8 Modality

The modality principle was perceived as important by the testers. By syncing narration, 3D animation and graph animation, the testers stated that they now understand how linear functions could be used in their daily life. Additionally, during the tests of the second prototype, especially students with low prior knowledge liked that the sheet of paper was augmented, however, S13 stated that she would forgo the AR functionality, supporting the insight that the modality principle mostly appeals to learners with low prior knowledge.

8.2.1.9 Personalisation

For the prototypes, an informal style of conversation using the first- and second-person perspective was chosen, to foster the sense of personalisation. All students appeared to enjoy the informal style of conversation, except from S13. She would have preferred a more formal style of language. This is because the personalisation principle is especially effective for students with low prior knowledge. Since S13 already knows a lot about linear functions, and strives to become a mathematician, this principle did not appeal to her. Therefore, it can be suggested to consider user's goals, prior knowledge, and preferences when applying the personalisation principle. Additionally, it is recommended to put more effort to personalise the experience when introducing a new chapter or concept to students.

8.2.1.10 Voice

The voice was spoken by a human, and not a machine. The testers seemed to like the explanations and the voice. S14 highlighted that the voice was her favourite part of the prototype. However, the first prototype was levelled too loudly and was played in a loop, which is why some testers seemed to be annoyed by it. Therefore, not only the quality of the voice, but also its volume and the control should be considered for future prototype designs.

8.2.1.11 Embodiment

Humanoid 3D objects were used for the narration. During and after the tests, S2 and S12 stated that they would like to have more realistic 3D characters, however, this did not seem to affect their motivation or understanding. Combined with the factor that the embodiment principle is the least effective principle, the amount of realism and embodiment used in the prototypes seem to be sufficient for these two scenarios.

8.2.1.12 Guided Activity

Guidance was clearly missing during the setup of the first prototype, because almost all users had difficulties with scanning the room. For the second prototype, the testers were asked to scan a marker. When they did, the app would give immediate feedback that it worked. Additionally, since the augmentation of the first prototype was not entirely visible on their screens, visual guidance would have been necessary to assure the users would know where to click to proceed. For the second prototype, the control buttons (e.g. "play", "pause", and "forward") were understood by all tester because they resemble symbols which they already know. However, the testers did not understand that the follow-up emojis (e.g. pedestrian,

cyclist, and car) in the first interactive scene were clickable. After indicating that they are clickable, they also understood that the icons in the second interactive scene were usable.

Another missing guidance was the possibility to explore by moving the device. S12 wanted to pinch-zoom, which did not work. After indicating that he could zoom and explore by moving the device, he would do so. S14 who already tried out multiple AR experiences understood that she could explore by moving her device. However, because she was exploring, the feedback message, indicating whether she answered correctly, was cut off. Consequently, she did not immediately notice it.

Due to the above-mentioned observations, it can be concluded that guidance is essential to encourage people to explore or to understand unfamiliar interactions and functionality. Additionally, when users are encouraged to explore, their vision should be guided when something important happens that is outside their vision range.

8.2.1.13 Reflection

In both prototypes, active reflection was needed during the two interactive parts and the question in the last scene. For insecure students, it might be more helpful to implement more questions in between to provide more feedback is whether they understood something correctly. Another possibility could also be to implement a quiz in the end of an exercise, as P1 suggested, since interim questions might be immersion breaking.

8.2.1.14 Feedback

Immediate feedback is important for the testers. For example, in the first prototype, the buttons did not react properly, which confused and annoyed the testers, which was fixed in the following iteration. In the second iteration, the testers started the test with a positive attitude because the markers were scanned immediately. However, it is suggestible to implement more feedback for students with low self-confidence, to response to them whether they have understood a concept correctly or not.

8.2.1.15 Multimedia Learning Theory for AR

It can be concluded that the multimedia learning theory is also important to be considered for AR learning experiences. However, there is the possibility to extend the multimedia learning theory specifically for AR learning materials. For instance, when taking the created prototypes of this study into consideration, it would be

interesting to see whether there is a difference between augmenting a coordinate system on a sheet of paper or placing a whiteboard into the room. Since students mostly have to write and sketch on a sheet of paper during their homework and written exams, it would be interesting whether students performed better when receiving a lecture with an augmented sheet of paper, with e.g. a coordinate system on it, compared to a lecture with an augmented whiteboard.

8.2.2 ARCS – V

This section discusses the results after testing the second prototype (Chapter 7.3.3 - Prototype 2 – Augmentation of a coordinate system), using the ARCS – V model (Chapter 6 - What is Motivation). The scores of the RIMMS test can be taken from Figure 25.

8.2.2.1 Attention

The results of the second test show that the score on the post-test in the category attention is the highest compared to other categories. The translated statements the testers replied to, were the following (Keller, 2010, pp. 283–284; N. R. Loorbach, 2013):

- A1: The quality of the content of the app helped to hold my attention.
- A2: The way the information is arranged in the app helped to keep my attention.
- A3: The variety of reading passages, exercises, animations, narrator etc, helped to keep my attention on the lesson.

According to the results, the usage of different channels seemed to work well for testers. Although the novelty effect[38], might have played a role in the high score in the attention category, S11 stated that she was surprised that the representation worked so well, and was always curious what would happen in the next scene. It seems that using different sensory channels and techniques within one exercise worked well to grab and maintain the user's attention. For instance, the testers stated that they enjoyed that there was a narrator explaining and guiding them through the exercise. For future research, it would be interesting to see the differences in this category compared to other multimedia learning materials, such as videos or interactive 3D visualisations. Therefore, it is recommendable to A/B

[38] The novelty effect explains that media and emerging technologies do not have any influence on learning in the long run. The positive effects which come alongside with the usage of new technologies, are only by the initial curiosity of the users, and fade after an amount of use (Clark, 1983).

test a complete chapter of a math learning app with only AR exercises versus a complete math learning app with different techniques (e.g. video, interactive exercises, 3D visualisations).

8.2.2.2 Relevance

The difference of the scores in the relevance category were lower than the scores in the attention and satisfaction category. Additionally, the absolute score for the post-test was the lowest throughout all categories. The statements in the questionnaire were the following (Keller, 2010, pp. 283–284; N. R. Loorbach, 2013):

- R1: It is clear to me how the content of this exercise is related to things I already know.
- R2: The content and preparation of this lesson convey the impression that its content is worth knowing.
- R3: The content of this AR exercise will be useful to me.

Especially statement R1 did not result in a big difference, which could have been caused by the design of the introduction page (Figure 18a)). This screen was not designed considering the motivational guidelines and did not grab the attention of the testers. Many testers have skipped the introductory page without reading it. Therefore, it is recommendable to also well-design pre-information and pre-training using motivational design guidelines, although they are not part of the AR experience.

The statement R2 for the prototype resulted in either equal scoring or higher scoring compared to the book-page, except from S13 who wished that more theory would be covered in the prototype. This is because S13 is already highly motivated towards mathematics and strives to become a mathematician. Keller stated that it is recommendable to focus on efficiency, when it comes to already highly motivated students (Keller, 2010, 2016). Consequently, it is important to define the target group and to make sure that the exercises support the student's motives and help them achieving their goals.

8.2.2.3 Confidence

The confidence category had the lowest score difference and resulted in a negative score for S9 and S13 for the statement C1 (Keller, 2010, pp. 283–284; N. R. Loorbach, 2013):

- C1: As I worked on this AR exercise, I was confident that I could learn the content.
- C2: After working on this AR exercise for a while, I was confident that I would be able to pass a test on it.
- C3: The good organisation of the AR exercise helped me be confident that I would learn this material.

When comparing the results of the pre- and post-test of statement C1, the post-test results of S9 and S13 reported a lower score than the pre-test. During the interview S9 stated that she did not understand the content completely and was not sure whether it was her own fault. Before the test, she stated that she had only learnt about linear equations and was expecting to understand the complete theory after using the prototype. Additionally, during the test, S9 skipped the introductory page and stated insecurities whether she understood certain animations and explanations correctly. Therefore, it would be suggestible provide more feedback by implementing more interim questions to provide feedback whether the users understood certain parts correctly. Moreover, in the last screen, where the conclusion about what the learner should know after using the prototype was provided, S9 stated that she was not sure if she understood all three points mentioned. S12, however, thinks that the page was very helpful, because he was able to check himself, whether he understood everything. Therefore, it would be suggestible to make the conclusion more interactive, either by making a quiz, so the students receive feedback on their understanding, as P1 recommended, or to give them the possibility to jump back to a certain point of explanation in case they did not understand a part.

S13 stated that she wished that the prototype covered more theory. The lack of theory in the app affected her confidence too. This is because she knew about the amount of existing theory behind linear functions, which were, however, not mentioned in the exercise. At this point, it is important to define which key-takeaways one specific exercise is focussed on conveying, and not to integrate too much distracting or confusing information as P2 suggested.

Another important factor is the confidence to use innovative technology. Although S10 stated that she enjoyed learning with the app, and her IMMS results in this category are relatively high, she was not sure if the jittering was caused because her hands were shaky. Therefore, it is important to reduce usability and technical problems to boost confidence in using new technology.

8.2.2.4 Satisfaction

The satisfaction category in the pre-test was the lowest of all, and the second highest in the post-test. The difference in this category was the greatest (Keller, 2010, pp. 283–284; N. R. Loorbach, 2013).

- Sat1: I enjoyed this AR exercise so much that I would like to know more about this topic.
- Sat2: I really enjoyed studying with this exercise.
- Sat3: It was a pleasure to work on such a well-designed AR exercise.

The results show that the prototype was perceived as satisfying by the testers, although the coordinate system was jittery. S9 stated that she wished to learn more about linear functions using the app, but with other contexts and explanations. S10 stated that she “really wants to continue learning with this app”.

The design of this prototype and its total package has satisfied every tester. Nonetheless, S13 suggested a snapshot functionality, so one need not hold the phone unnaturally. This idea could have multiple advantages. After snapshotting the sheet, it would give students the possibility to place their device next to themselves and take notes on the sheet, and still see the connection between their physical sheet and the augmentation. S10 also wished that placing the phone onto the table was possible. Another feature could be implemented where learners could draw their functions on their graph paper and compare it using the augmentation. Moreover, the summary could contain pictures and videos of their own snapshot, giving the learners a greater sense of personalisation. Another advantage of this recommendation would be, that the app would not be as battery draining, resulting in a higher satisfaction in the long run.

The high score of the post-test could have also been influenced by the test-design. Since the app was not on the Google Play Store yet, the learners had to allow unknown sources on their phones, which gave the students the feeling that the application was unfinished or still low fidelity. S11 an S12 stated that they were surprised that the augmentation worked so well, and S12 stated that he thought that the app would contain many bugs in the beginning. However, this statement could have also been caused by the fact that the app did not run on two of his phones, which is why the researcher had to schedule a personal meeting with him to test the app.

8.2.2.5 Volition

Since volition is not covered in the IMMS scale and the app was only used for a short time by the testers, it was not possible to generate findings for this category.

However, self-regulation and persistence are essential parts for successful remote and blended-learning situations, which is why more studies focussing on the effects of AR on volition should be conducted in the future.

8.2.3 Combining Multimedia Learning Theory and ARCS – V model

This chapter discusses a combination of the ARCS – V theory and the multimedia learning theory as a design framework for future AR experiences for a math application. As seen in the previous two chapters, using an AR learning app with motivational instructional design elements can be highly motivating for learners. As reported in other studies, it is important to consider factors such as ease-of-use, technical issues, and cognitive load too (Akçayır & Akçayır, 2016; Bujak et al., 2013; Saltan & Arslan, 2016). Cognitive load can clearly be reduced by considering multimedia learning theories during the design phase.

As seen in the previous chapters, the multimedia learning theory also applies to AR learning experiences. Many problems concerning cognitive load mentioned during the test of the first prototype could have been avoided if the multimedia learning theories were followed, as seen in iteration 2. Nonetheless, since AR experiences have the possibility to convey invisible meta-concepts in new and different ways, as mentioned by multiple studies (Bujak et al., 2013; Pellas et al., 2019), it is necessary to explore more learning theories for immersive learning experiences. An example could be to study whether the augmentation of one's own physical graph paper result in better performance than watching a video where someone else draws on a sheet of paper.

Regarding the design of the prototype, it became evident that the design must be tailored to the target group. For example, students with high motivation and prior knowledge might find AR superfluous or annoying, while students with a lower motivation level are highly satisfied after using AR experiences. Moreover, the language, content, and technical setup need to vary for each target group as well. This study also confirmed that one should focus on efficiency when designing learning materials for motivated students (Keller, 2010, 2016).

Due to the answers and comments during the interviews and tests, it can be concluded that a mathematics app with AR can be motivating, but only when multiple aspects are considered. Nonetheless, it is not clear what effects AR would have on learners, when used through a longer period. Would AR still be considered as motivating, or would it be suggestible to integrate a variation of learning methods? When considering the cost-benefit factors, it is believed that a variation of learning, processing and reflection methods is needed to get the most out of an

interactive and immersive mathematics learning app. Nonetheless it is important that all elements are designed using the motivational instructional design framework and the multimedia learning theory. Additionally, for a fully functional mathematics learning app, P1 suggested to implement a learning management system into it, where students could easily hand in their home exercises.

Although a certain AR design is motivating for students, it does not imply that AR is the best choice to convey a certain concept. Additionally, there are multiple ways to use AR to convey certain concepts. The following chapter discusses how to best answer these questions during the process of creating AR learning experiences.

8.2.4 Cost-Benefit Factor

It is necessary to evaluate whether there are already effective ways to convey mathematical concepts without using innovative or modern technologies. Linear functions are mostly only seen to be complex for new learners. When it comes to interpreting a linear function, for new learners it is especially difficult to differentiate between the linear function and e.g. the actual path a person goes. As P2 stated, AR could help students understanding this difference better. Nonetheless, it was repeatedly mentioned by most testers in iteration 1 and by S13 and S14 from iteration 2, who have a high understanding of linear functions, to cover more complex topics. This leads to considering the cost-benefit factor of creating AR exercises for simpler topics.

First, the questions “Which topics and concepts are difficult for teachers to explain?” and “What is easier to convey using AR?” must be considered before creating an application. It is recommendable answer those questions in brainstorming sessions with experienced teachers. Secondly, is it worth the time and effort to create an AR prototype when the main benefit of the AR experience is its novelty, like it is in the first prototype? Or could a created system be reused to convey more complex concepts, like the second prototype does?

The second prototype proposes a reusable design, with the coordinate system and the 3D scene, for multiple topics. For instance, it can be applied on topics such as polynomial functions, unit circles, or 2D vectors. Also, it could be reused for the third dimension when another axis is added, such as for solids of revolution, 3D vectors and matrices; or geometry. However, the second prototype was only tested by actual practitioners, which are students who are currently learning the topic of linear functions or revising of it. For future research it would be interesting, if the structure and the system of the second prototype is found to be effective by professors too. For this purpose, one should also mention more complex topics,

and whether they see an added value in this type of augmentation. If those AR designs were found, authoring tools could be created for teachers and more students could benefit from AR technology. This leads to the suggestion to research more on effective, cost-efficient, and reusable systems for multiple math concepts.

8.3 How should a creation process look like to effectively create motivational AR math learning experiences? – Design Process

The development of the first and second prototype were created using a design sprint and a more analytical approach, respectively. While design sprints enable fast creation of testable prototypes, systematic approaches create more sophisticated prototypes. This chapter will suggest how to combine those approaches, with the goal to improve the creation process.

8.3.1 Different Types of Feedback

The prototype of the first iteration (Chapter 7.3.2) was created during a design sprint (Chapter 7.2.2 - Design Sprint – Iteration 1). The design sprint method was chosen because the goal was to generate general ideas about the possibilities to use AR for upper secondary school students. After testing the first prototype the results suggested that design sprints seem to be effective to create initial prototypes and to collect general insights on which direction a design of an AR experience should go, within a short amount of time (one to two weeks). For the second prototype, a more analytical approach was selected since the information collected during the first sprint needed to be considered and implemented. Both approaches have advantages and disadvantages.

The first prototype was not as sophisticated and as thoroughly designed as the second prototype. Nevertheless, a lot of feedback on the possibilities to use or improve the usage of AR were given by the testers. During the second prototype, the users focussed much more on the effects which the application had on themselves. This effect could be caused by the level of fidelity of the prototypes. It indicates that users potentially give more creative and visionary feedback when testing low fidelity prototypes.

However, another factor which could have influenced this effect is that the chosen testers in the first iteration had more prior knowledge on linear functions than the testers in the second iteration. Due to their prior knowledge, the testers might not

be as concentrated on the delivered content as unexperienced testers. Therefore, they might be able to give more feedback on other aspects than the content. In the second iteration, testers could have been more concentrated on the content which is why they gave more feedback about the effects of the prototype on them.

Subsequently, depending on the goal of an iteration, one should create prototypes with different levels of fidelity and test the prototype with according target groups. For instance, to explore the possibilities of AR, it is recommended to test low fidelity prototypes in cooperation with someone who is knowledgeable about linear functions and/or is an actual practitioner. Additionally, it is helpful when the testers are experienced in using AR. However, in the case of this thesis, most of the target group are not very experienced with a variation of AR systems yet. Consequently, it would be more helpful to integrate actual practitioners in the design process and conduct a hands-on workshop beforehand, so they get familiar with the possibilities which AR provides. This was the initial plan but was not feasible due to the COVID-19 situation. Nonetheless, this should be considered in future iterations.

8.3.2 Motivational Design Steps

For further iterations, it is recommendable to consider Keller's motivational design steps too (Keller, 2010, 2016). Keller suggested a motivational design with 10 steps and highlighted step 3 – analysis of the audience, step 6 – listing the potential tactics, and step 7 – selecting and designing tactics to be the most essential ones. However, to create a coherent mathematic learning app that covers all important information, step 4 – analysis of other course elements and 5 – listing objectives and assessments need to be considered as well. This conclusion is drawn because the conducted design sprint in the first iteration did not analyse the other elements about linear functions and did not list the objectives of the exercise beforehand. This was shown to be problematic during the first test, where P2 stated that it is necessary to consider certain standards, so students do not get confused by the application. Therefore, it is important that the course material is created according to the student's curricula.

While the first prototype was created during a one-week design sprint with three practitioners, the second prototype was created by only the researcher. The second prototype was created using a more analytical approach, using the findings of the first test and systematic models, such as the ARCS model and the multimedia learning theory. For future iterations, it is recommendable to combine design sprint methods and analytical methods within one iteration.

Phase	Motivational Design Steps	Approach
Analysis	1. Obtaining course information	Analytical approach
	2. Obtaining audience information	Analytical approach
	3. Analysis of audience	Analytical approach
	4. Analysis of other course elements	Analytical approach
	5. Listing objectives and assessments	Analytical approach, result of this step is the starting point for the design sprint
Design	**6. Listing potential tactics**	Design Sprint
	7. Selection & design of tactics	Design Sprint
	8. Integration with instructions	Design Sprint
Develop	9. Selection and development of materials	Design Sprint / Analytical Approach
Implementation & Evaluation	10. Evaluation and revision	Design Sprint / Analytical Approach

Table 14. Motivational design steps with suggested approaches

Table 14 shows the motivational design steps and newly added suggested approach. It is recommended to use a more analytical approach for step 1 to step 5 because information retrieval should be done thoroughly. The listed objectives and assessments in step 5 become the starting point for the design sprint. Step 6 to step 8 are suitable to be done within a brainstorming session or design sprint, including interdisciplinary practitioners. Step 9 and step 10 can either be conducted using a design sprint or an analytical approach. This depends on the goal of the iteration. In case one wants to create multiple prototypes and one wants to gather information on the possibilities of AR, it is recommended to use design sprints, like in iteration 1. If the goal is to create a polished prototype, then developers will need more time to consider multiple design and technical factors. The method to use for the 10th step – evaluation and revision, is also dependent on the goal of the iteration. Testing a prototype in design sprints allows to gather quick insights and enables idea generation, while an analytical approach gives more information on the effects of a prototype. The evaluation of the test data should, however, be done using an analytical and systematic approach.

9 External Influences & Limitations

This chapter discusses three factors which might have influenced the outcomes of this thesis. Furthermore, limitations of this thesis will be stated.

9.1 COVID-19

The COVID-19 pandemic has caused a shift in the needs for education. Since this research was conducted between 2nd February 2020 and 30th June 2020, the students and the teachers reported different difficulties and needs before, mid-lockdown and the time after the lockdown.

This situation has revealed the lack of proper remote or blended learning tools, adjusted to the Austrian curriculum. Although some students find home-schooling comfortable, many students reported the lack of self-motivation, and self-regulation to learn the materials. Since the tests were conducted during or right after lockdown, this could have manipulated the scores to be higher than it would be during usual situations. S12 and S14 stated that they would not use similar apps at school, but at home or in their holidays.

When designing mathematics learning app for blended-learning situations, it is necessary to integrate a learning management system, since it became evident that having the choice between multiple learning tools, apps, and websites, students reluctantly use any digital tools at all, as reported by P1.

Additionally, adjustments of the research design were done. Initially, in-person workshops and brainstorming sessions with professors and students would have been planned. Due to the need of social distancing, the initial plan was changed and almost everything was conducted remotely.

9.2 Participants & Duration

This study was conducted with a small sample size. For future iterations it is recommended to include more practitioners (students and professors) to the actual creation phase and to test the prototype with them.

Another factor would be that the testers mostly had little experience with AR. Therefore, the novelty effect could have caused the positive attitude of the testers towards the prototypes.

Moreover, due to the lack of experience with AR, the testers faced multiple issues during set-up when testing the first prototype. It is expected that students will get familiar with AR after a while and more complex levels with more interactions can be integrated to the maths learning app in the future, as suggested by P1.

Due to the above-mentioned factors, it is recommended to conduct long-term studies with AR exercises with increasingly difficulty to see the effects of a motivational AR math learning app during and after a longer timeframe.

9.3 Realism & Technical Issues

Although DBR is usually being conducted without manipulating the environmental variables, it was necessary to do so in both iterations. This is because, for example, the students needed to pre-install the prototype. Also, the app was not integrated into a real remote or blended-learning situation since it only covered one small chapter. Additionally, some students had technical difficulties installing and starting the app, which is why the researcher had to schedule a personal meeting with them. However, technical issues and more realistic scenarios will affect the attitude and the motivation of the testers, it is highly recommended to conduct the following iterations within a more realistic scenarios and without filtering the technical issues.

10 Conclusion

How can AR learning exercises for a math learning app be created to foster the motivation of upper secondary school students, especially for remote or blended learning situations? To answer this question, two design-based research iterations were conducted, for which two AR prototypes were created and tested. The goal of the first iteration was to generate an overview on the main benefits when an AR mathematics learning app is used by upper secondary school students. The aim of the second iteration was to research on the elements which a motivational AR math learning experience should contain. After combining the findings, suggestions for a design framework and recommendations to improve the creation process of motivational AR math exercises were provided.

Which main benefits of using an AR mathematics learning app for upper secondary school students can be found during research? To answer the first sub-question, the initial literature research included studies on AR technology (Chapter 3), and state-of-the-art research (Chapter 4) on using AR in educational settings. The findings show that the main benefits of AR for upper secondary school students are its motivational effects and its ability to visualise abstract concepts. However, to achieve those effects, multiple aspects need to be considered to create such an AR math learning exercise. Therefore, theories to create motivational learning experiences were researched on, including the multimedia learning theory (Chapter 5) and the ARCS-V model (Chapter 6). Additionally, due to the COVID-19 outbreak and its remote-schooling consequences, the prototype tests with the students showed that motivational AR learning apps have high potential to encourage students to learn in a self-directed manner.

In the empirical part (Chapter 7) two prototypes were created, refined, and tested on the target group within two DBR iterations (Chapter 2). Both prototypes were developed using different methods. While the first prototype (Section 7.3.2 - Prototype 1 – Indirect Augmentation with an Island) was created relatively fast within a design sprint, the second prototype (Section 7.3.3 - Prototype 2 – Augmentation of a coordinate system) was developed considering the outcomes of the first iteration and existing theories, including the multimedia learning theory (Chapter 5). Both prototypes were tested with Austrian math professors and/or upper secondary school students. The test of the first prototype generated insights on the possibilities to use AR in math education. The aim of the second prototype test was to assess its motivational effects on the students by using the RIMMS

query (Section 7.5.2.2 - RIMMS Test). Those results were compared to the RIMMS scores of the students after learning with a page in their textbook.

After the analysis of the gathered data, the multimedia learning theory and the motivational ARCS-V model were used to discuss the results. In Chapter 8 - Discussion, a suggestion was made to combine those models. This was done because motivational design work more effectively when cognitive theories, on which the multimedia learning theory is based on, are considered.

Firstly, to answer the sub-question "*Which elements should a motivational AR learning experience contain?",* the findings of the empirical research were broken down to the 14 principles of the multimedia learning theory (Chapter 5 - Multimedia Learning Theory). These principles apply to AR instructional material as well. After implementing those theories, users' attitude towards the tested math exercise became more positive. For future research, it would be interesting to see whether more principles could be found specifically for AR. For instance, one could research on the differences between students' performance when a math problem is conveyed using a marker-based AR system which augments a coordinate system on a sheet of paper, versus a system where a coordinate system is placed into the room.

Secondly, the RIMMS scores after testing the second prototype (Section 7.3.3 - Prototype 2 – Augmentation of a coordinate system) were discussed, using the ARCS-V model. The main findings are:

- Using multiple sensory channels and techniques within one exercise helps students to maintain their attention. Students enjoyed that they were guided by a narrator, were able to see the animated scene, and were able to interact with the augmentations and functions. For future research, it is recommended to compare the motivational effects of AR exercises with other multimedia learning materials, including interactive 3D visualisations or videos.
- The discussion of the attention and relevance category suggests that all important information of an app should be designed using the motivational theories, although they are not part of the AR experience. This is based on the observation that the introduction scene, which does not support AR and was not designed according to the motivational theories, was skipped by some testers. Consequently, they missed out on relevant information for the subsequent AR exercise.
- In the confidence category, it seems that users with low prior knowledge about the conveyed math concept needed more feedback than students

with high prior knowledge. Feedback for conceptual understanding could be provided, for instance, by asking interim questions. Previous studies have shown that AR learning experiences reduce math-anxiety due to their perceived playfulness (Y. Chen, 2019). Therefore, future prototypes should be tested with more high-anxiety learners, to see the effects on their confidence level and mathematical self-efficacy. Moreover, future studies should cover the possibilities to provide feedback to students about their conceptual understanding within AR experiences, without their breaking immersion.

Although the numeric results only reflected the confidence scores about the instructional materials, the interviews showed that the user's confidence level with technology need to be considered as well. This is especially important when using new technical features.

- The scores in the satisfaction category shows that the users were pleased by the exercise. Students who tested the second prototype reported that they would continue to learn with more exercises within the app. However, continuously holding the smartphone in a specific position was reported as cumbersome by multiple students, which is why this prototype could be refined by adding a snapshot functionality.
- Overall, future research can be conducted on the motivational differences of AR compared to other multimedia learning materials, such as videos or interactive (3D) visualisations.
- Moreover, self-regulation and persistence are essential components for successful remote and blended learning. Students reported that they enjoyed learning with the prototype and would use it in the future as well. Nonetheless, long-term studies need to be conducted to understand the volitional effects when using AR supported math exercises.

The results show that the combination between the ARCS-V model and the multimedia learning theory are effective for short-term motivation. Long-term effects still need to be studied in future iterations. Additionally, it is recommended to research on reusable, effective and cost-efficient frameworks for AR exercises. The second prototype is a suggestion for such a framework, because it can be reused for further math problems. However, professors and teachers still need to be interviewed, whether they see an increased value in using this framework for other math problems as well.

Next, to answer the last sub-question: "*How should a creation process look like to effectively create motivational AR math learning experiences?*", a suggestion to improve the creation process was given in Chapter 8 - Discussion, considering

motivational design steps, design sprints and analytical approaches. The first prototype was created in a design sprint within a short amount of time. Although the first prototype (Section 7.3.2 Prototype 1 – Indirect Augmentation with an Island) was not as sophisticated and thoroughly designed as the second prototype (Section 7.3.3 - Prototype 2 – Augmentation of a coordinate system), more feedback on the possibilities to use AR in math education and to improve the prototype was given. The second prototype was developed taking systematic theories into account (Chapter 5 - Multimedia Learning Theory & Section 6.2 - ARCS - V Model). This test provided more insights on the effects of the prototype. Therefore, depending on the goal of one iteration, one should use a different mix of methods. Section 8.3.2 - Motivational Design Steps shows Keller's 10-steps for motivational design (Keller, 1987, 2010, 2016), enhanced with suggestions on which approach should be used in which situation. For instance, in this thesis, it was found to be effective to use a more analytical approach during the analysis phase and to conduct a design sprint during the design phase. For the development, implementation, and evaluation phase, one could either include those steps into a design sprint, or use more analytical approaches, depending on the goal of the iteration.

The results of this thesis demonstrate that AR supported math exercises have high potential to solve current problems in education. Since this thesis was conducted during the time of the COVID-19 outbreak, changes to the initial research design were made, as described in Chapter 9 - External Influences & Limitations. Additionally, student's motivation might be higher or lower under other circumstances, especially since the situation of a lockdown showed a lack of proper motivational blended- and remote learning tools. Therefore, more long-term studies with more practitioners should be conducted, especially focussing on AR learning materials, to foster student's self-regulation in remote learning situations, to affirm the positive effects found during this thesis. Furthermore, future research should also focus on the effects of AR on high-anxiety learners, and which components are needed to effectively design AR learning experiences for those. Lastly, it is highly recommended to conduct research on cost-efficient, effective, and reusable motivational AR designs, so students, professors, and math educators can profit from the potential which AR technology provides.

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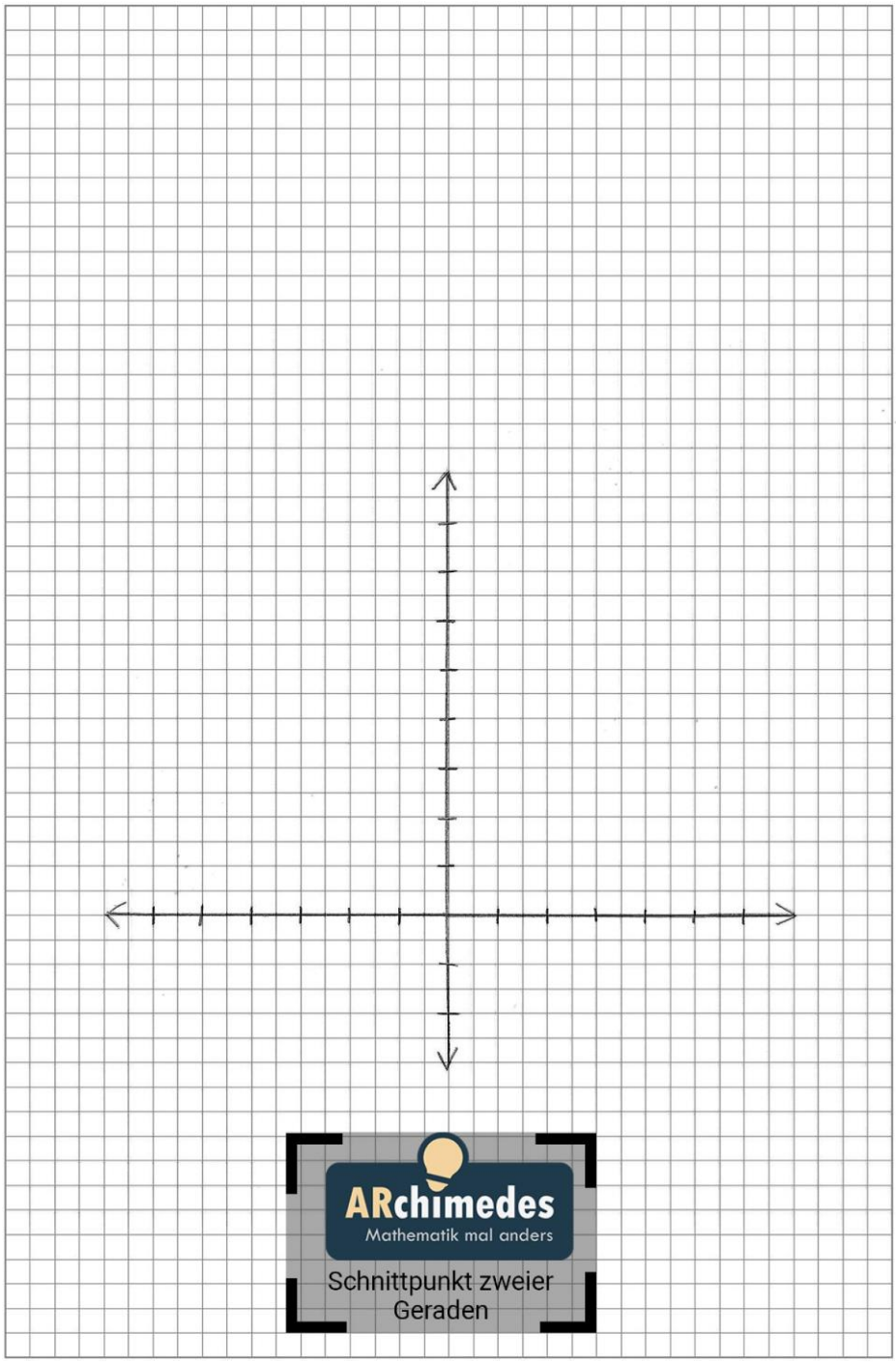
Table 13. Software used for testing the second prototype 69

Table 14. Motivational design steps with suggested approaches 99

Appendix

A. Graph paper with coordinate system and marker



B. RIMMS Pre-Survey, adapted (N. Loorbach et al., 2015)

Because all students who participated in this study spoke German, the statements in these tests were stated in German as well. The English statements of the pre-test are placed below for clarity purposes, in order to understand the scoring results in Chapter 7.5.2.2. - RIMMS Test. The post-test and the original version can be found in the appendix SD.

1. R1: It is clear to me how the content of this book page is related to things I already know.

2. A1: The quality of the writing helped to hold my attention.

3. C1: As I worked through the book page, I was confident that I could learn the content.

4. Sat1: I enjoyed this lesson so much that I would like to know more about this topic.

5. A2: The way the information is arranged on the page helped keep my attention.

6. Sat2: I really enjoyed studying with this book page.

7. R2: The content and style of writing in of this book page convey the impression that its content is worth knowing.

8. C2: After working with this book page for a while, I was confident that I would be able to pass a test on it.

9. A3: The variety of reading passages, exercises, illustrations, etc, helped keep my attention on the lesson.

10. R3: The content of this lesson will be useful to me.

11. C3: The good organization of the content helped me be confident that I would learn this material.

12. Sat3: It was a pleasure to work on such a well-designed lesson.

C. SD

On the SD, the used interview guidelines, test designs, questionnaires, and checklists can be retrieved in their original language. Additionally, following objects can be found:

- Scientific poster
- Text file with the links to the prototypes
- Semi-structured and problem-centred interview guideline (Phase 1 – Iteration 1)
- Design sprint checklists (Phase 2 – Iteration 1)
- Problem-centred pre-interviews guidelines & presentations (Phase 1 and 2 – Iteration 2)
- Testing guideline (Phase 3 – Iteration 2)
- Pre- and post RIMMS statements in German
- Page of the textbook