SCHOOL OF COMPUTATION, INFORMATION AND TECHNOLOGY - INFORMATICS

TECHNICAL UNIVERSITY OF MUNICH

Bachelor's Thesis in Informatics: Games Engineering

Developing a Serious Game to teach Mathematics

Laura Marsoner

SCHOOL OF COMPUTATION, INFORMATION AND TECHNOLOGY - INFORMATICS

TECHNICAL UNIVERSITY OF MUNICH

Bachelor's Thesis in Informatics: Games Engineering

Developing a Serious Game to teach Mathematics

Entwicklung eines Serious Game um Mathematik zu lehren

Author:	Laura Marsoner
Supervisor:	Prof. Gudrun Klinker, Ph.D.
Advisor:	Dr. David A. Plecher
Submission Date:	15.12.2022

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

Munich, 15.12.2022   Laura Marsoner

Acknowledgments

I would like to thank Lukas Pichler for helping me stay focused throughout the project and for giving me valuable feedback. Most importantly, he supported and motivated me during the challenging phases of the project.

Another thank you goes to David Plecher who guided me from the beginning to the end of this work and always provided me with helpful feedback.

Finally, I would like to thank my family, especially my sister Isabella, who always supported me during my years of study.

Abstract

Serious games have shown promise as a tool to enhance the learning experience by generating higher intrinsic motivation than traditional learning methods. In this paper, a serious game called *Kingdom of Math* is developed that aims to teach mathematics to secondary school students using proven design principles. To this end, essential terms and concepts are described, and related work is analyzed. The requirements for such a serious game are outlined, and the approach and design decisions made are discussed and implemented. A user study is conducted to evaluate the developed game, and the results are presented and discussed. In addition, possible improvements and enhancements for this project in the future are suggested.

Contents

1. Introduction

Digital games are very successful, and therefore this technology could be used not only for entertainment purposes but also in education (Dörner et al. 2016). This offers a new way of teaching, namely through serious games, which combine the concept of games with serious content to create an engaging learning experience. This approach is supported by several studies that demonstrate the benefits of serious games for playful learning, learning effectiveness, and learning motivation in education.

Usually, research-oriented serious games focus on the game's serious part and neglect the fun factor, which can lead to negative gaming experiences. For such serious games, it is hard to compete with normal games or other leisure activities because they are usually not that enjoyable. Therefore, this thesis takes a different approach, focusing on the entertainment aspect of the game. This approach aims to make the game intrinsically motivating so that it can compete with other free-time activities while also teaching the players something.

1.1. Goals

With this in mind, the goal of this thesis is to develop a serious math game called *Kingdom of Math* in which the mathematical content is immersively integrated in different ways and is designed to be completely optional, but rewarding for the players. This should make the game engaging and fun, which should increase motivation to engage with math topics and increase learning success in the long run. To achieve this goal, previously researched design principles for serious games are applied to enhance the game experience and thereby make the game more intrinsically motivating.

For simplicity, the research question is divided into four sub-questions that will be addressed throughout this thesis:

- What proven design principles can be applied to make the game more interesting and motivate players to engage with serious content?

- In what ways could math be integrated into the game to make it engaging and offer different options for different types of players?

- How is the game experience and the inclusion of mathematical content perceived by players?

- To what extent is this serious game, which incorporates mathematical content on a voluntary basis, able to motivate players to engage with mathematical topics?

1.2. Outline

Chapter 2 (Theoretical Background): In this chapter, the terms and concepts relevant to this thesis, such as serious games, flow, and design principles, are introduced. Furthermore, the challenges of serious games are discussed, and the mathematical content is described.

Chapter 3 (Related Work): In the first part of this chapter, Serious Math Games are analyzed, followed by other serious games whose components are of interest to this thesis. Lastly, inspirational Action RPGs games are also looked at.

Chapter 4 (Game Concept): In this chapter, a brief overview of the game concept is given, covering the story, the core progression of the game, and the gameplay. In addition, the design decisions made are discussed and the four ways in which mathematics is integrated into the game are described.

Chapter 5 (Implementation): This chapter describes the implementation approach, with a focus on the integrated mathematical content. For this purpose, the various features, how they work in the game and how they can be configured by the developer are explained, and corresponding examples are shown.

Chapter 6 (Evaluation): In this chapter, the user study conducted to evaluate the game, including the participants, the process, the questionnaire used, and the corresponding results are presented.

Chapter 7 (Discussion): This chapter discusses the results of the evaluation described earlier, the achievement of objectives, and potential problems.

Chapter 8 (Future Work): The purpose of this chapter is to propose future improvements and additions to the project, including more content, a multiplayer mode, adaptation and personalization.

Chapter 9 (Conclusion): In this chapter, a final conclusion to this thesis is given, as well as a brief summary.

2. Theoretical Background

2.1. Serious Games

Serious games are used in various fields, e.g. in healthcare, for training purposes, and especially in education. Therefore, there are several definitions for the term serious game. Dörner says: "*A serious game is a digital game created with the intention to entertain and to achieve at least one additional goal*" (Dörner et al. 2016). This goal, referred to as the characterizing goal, could be learning, for example. According to Michael and Chen (Michael et al. 2005), a serious game does not have fun, pleasure, or entertainment as its primary goal. Some definitions state that the intent of the player determines whether it is a serious game. For example, a shooter game could become a serious game if the players use it not only for entertainment but also to improve their reaction time or to train their motor skills. It should also be mentioned that a serious game can belong to any genre, for example, it can be a puzzle game or a role-playing game (RPG).

2.1.1. Serious Games vs Gamification

Not to forget that the term *Serious Game* should be distinguished from the term *Gamification*. The term *Gamification* means "*to make a game out of something that is not a game*". It is used to describe the use of game elements in non-gaming systems to improve the user experience and user engagement, as noted by Deterding (Deterding et al. 2011). For example, levels and a scoreboard are used to enhance the language learning platform *Duolingo* (Duolingo 2011).

2.1.2. Serious Games in Education

Digital games can be intrinsically motivating (Wong et al. 2007) and therefore could help to make learning an enjoyable experience where players are in the state of flow and time flies by (Dörner et al. 2016). In addition, there are also reports that serious games support sustained learning (Michael et al. 2005). In the book *Serious Games* (Dörner et al. 2016), other reasons given for using games for educational purposes are sensory impressions and narratives that create an entertaining experience.

Furthermore, games can be used to increase motivation and promote active engagement, as games offer challenges, empathy with characters, suspense, etc., and therefore users can become more committed to the game. Additionally, games offer immediate feedback and adaptation possibilities that allow players to evaluate their progress. As this is provided anonymously, negative feedback may be less stressful for the players than if it is given in front of the whole class. Moreover, not only Dörner (Dörner et al. 2016), but also Backlund and Hendrix (Backlund et al. 2013), Egenfeldt-Nielsen (Egenfeldt-Nielsen 2011), and Connolly (Connolly et al. 2012) point out the benefits of serious games for playful learning, learning effectiveness, and learning motivation in education.

2.1.3. Challenges

According to Dörner (Dörner et al. 2016), various issues need to be addressed when developing serious games, such as how the serious game can be made enjoyable and motivating, how to make it engaging on an emotional level, what mechanisms can be used to adapt the game to the individual user, and how it competes with other leisure activities. In addition, it is important to consider what goals can be targeted and to what extent the serious game achieves the intended goals. The question of how the development and production process differs from the development of an entertainment game must also be considered (Dörner et al. 2016).

It is also important to note that players may not want to play a game just because it is labeled a serious game. This could lead players to think that it is just an attempt to wrap the serious content in a nice package, but it is still serious content and just because it is a game does not mean it is fun (Wong et al. 2007).

Furthermore, it is difficult to find an appropriate balance between learning and game activities, as serious games have to consider the tradeoff between two goals, the one to entertain and the one to teach. For a game to effectively teach and maintain the player's interest, both learning and engagement are required. The problem is that educational games are perceived as either entertaining but educationally insufficient or educational but boring (Engels 2021), which may make the players not want to play the game. On the other hand, if the learning goal is neglected, this can have a negative impact on learning outcomes.

The fact that there are different types of players and different types of learners must also be taken into account. For example, not every player likes to play puzzle games, and not every learner likes to learn using serious games but may prefer a textbook. However, by providing the opportunity to learn with a serious game, a serious topic could be opened up to a new group of players and learners. How these challenges are addressed in this project is discussed in chapter 4.

2.2. Flow

Flow is a term from psychology that refers to the state of mind of the player. There are several definitions of flow. Nakamura and Csikszentmihalyi (Nakamura et al. 2002) describe the flow state in terms of the following characteristics: Merging of action and awareness, increased and focused attention on the current activity, sense of control over one's actions, distortion of the experience of time, loss of reflective self-consciousness, and experience of the activity as intrinsically rewarding. Jackson and Marsh (Jackson et al. 1996), on the other hand, define flow in terms of the following nine dimensions: Merging of action and awareness, clearly defined goals, balance of challenge and skill level, clear and immediate feedback, focus on the task, sense of control, loss of self-consciousness, transformation of time, and self-rewarding experience.

2.2.1. Game Flow

According to Dörner, *game flow* is one of the most important dimensions of the game experience (Dörner et al. 2016). *Game flow* is an experience that occurs during gaming when the players are immersed in the game, focused solely on the game, feel control over the game, face clear goals, interact socially, and receive immediate and consistent feedback (Sweetser et al. 2005). It occurs when the difficulty of the task matches the players' skills. Chen (Chen 2007) presented three conditions that must be met for flow to occur. First, the game must be intrinsically rewarding; second, it must provide the right level of challenge to match the players' abilities; and third, it must give the players a sense of personal control over the game.

2.2.2. Dual Flow

Serious games need to be not only attractive but also effective compared to normal games. For this reason, Sinclair (Sinclair 2011) has introduced the concept of *dual flow*, which is an adaptation of the *game flow* with effectiveness taken into account. The dual flow model focuses on two main objectives, attractiveness and effectiveness, by creating an appropriate balance between task difficulty and skill level, as shown in Figure 2.1. The attractiveness of a serious game describes that the game must be attractive so that players want to play the game in order to be motivated to engage with the serious content. According to Sinclair (Sinclair 2011), the attractiveness of a serious game is based on challenge, curiosity, and fantasy. Effectiveness refers to the achievement of the characterizing goal. This can be accomplished by considering the principles of adaptation, progression, and individualization.
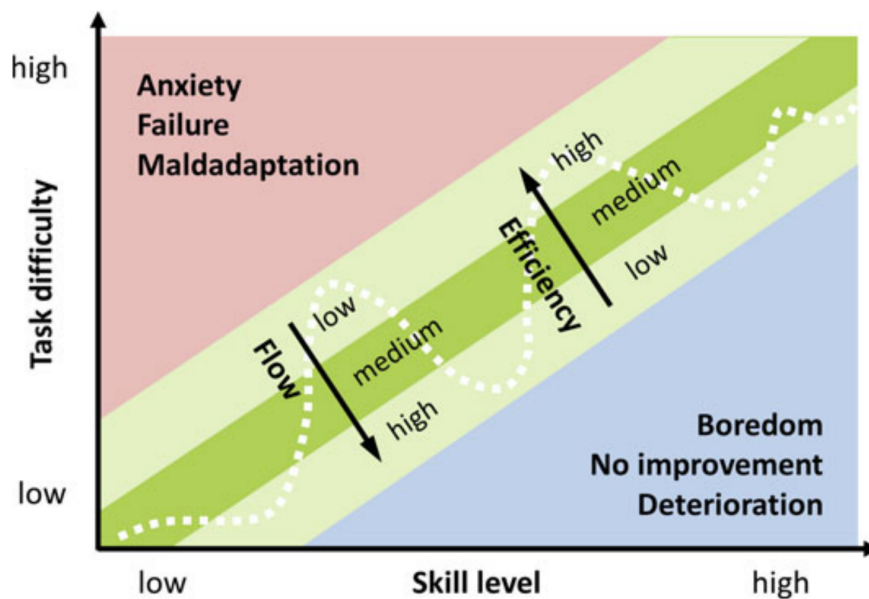
Figure 2.1.: Dual flow as a balance of task difficulty and skill level according to Dörner (Dörner et al. 2016).

2.3. Game Design Principles

There are many different design principles for serious games to motivate the players, provide a good game experience, and encourage learning. Two scientific publications were found that examine different design principles and their relevance, which are explained in more detail below. In addition, in this section, also the most relevant design principles of this project are described. How these principles are implemented in the project, on the other hand, is discussed in chapter 4.

2.3.1. Scientific Publications

In *Design Factors for Educational Video Games*, Engels (Engels 2021) conducted a multi-year study on how design features enhanced engagement and learning outcomes of educational video games for STEM (science, technology, engineering, and mathematics) subjects. The study discovered that 25 design features are relevant to the design of educational STEM games by analyzing 8 STEM games, applying the found features to 25 games, and evaluating the results. The results should serve as a guide for game designers to understand which design features enhance the engagement or learning

goals of serious games.

The result showed that *Subject Integration* had the highest positive effect on learning outcomes, but *Increasing Challenge* and *Visual Instructions* also had a positive effect. On the engagement outcomes, the features with the most positive effect were *Visual Cues*, *Explicit Learning Goals*, and *Immersion*. Also, *User Interfaces* and *Level Behavior* had a positive effect on engagement, but not as much as the previously mentioned features. In addition, engagement and learning outcomes were often found to be inversely correlated, meaning that no design feature had a strong positive effect on both outcomes (Engels 2021). It was also found that the outcomes supported many of Csikszentmihalyi's characteristics for an optimal experience (Csikszentmihalyi 1990) as described in section 2.2, including a challenging activity that requires skills (*subject integration*), merging of action and awareness (*visual cues*), clear goals (*learning goals, subject motivation*), direct and immediate feedback (*player progress*), focus on the task (*immersion*), and a sense of control (*level interaction*).

Chorianopoulos highlighted three design principles in *Design Principles for Serious Games in Mathematics* (Chorianopoulos et al. 2014) after reviewing previous scientific publications. The first principle is to engage players with a story and a hero, which is supported by the Kelleher publication (Kelleher et al. 2007). The second principle is to engage players with familiar game mechanics from popular video games, as noted by Rieber (Rieber 1996), and the final principle is to provide constructive gameplay for learning, which is supported by the findings of Gee (Gee 2009). In addition, it was found that the difficulty level must also be taken into account, because if players fail, their frustration might increase and their self-esteem might decrease, and vice versa (Seery et al. 2004).

2.3.2. Hero and Narrative

As mentioned earlier, heroes and narratives can be used to engage players in a game. Research has shown that a game's story can motivate students to use educational games (Bopp 2007). In addition, narrative in a learning environment is beneficial to game design (Kelleher et al. 2007; Malone 1981) because it provides opportunities for evaluation, illustration, exemplification, and inquiry, especially with arithmetic concepts (Chorianopoulos et al. 2014). It also has the advantage of facilitating faster comprehension and better memory (Graesser et al. 2014).

In addition, stories facilitate immersion in the game and promote emotional engagement with the game because they are often constructed in a suspenseful way. Furthermore, emotion and immersion can motivate players to continue playing and help achieve characterizing goals such as conveying a topic in serious games. Also, studies have shown the importance of emotional engagement for motivation and learning

efforts (Dörner et al. 2016).

Moreover, compared to other media such as books or videos, a game offers the players the opportunity to interactively influence the development of a story. Therefore, interactive storytelling is used, which allows the players to participate in actions and make decisions that shape the narrative which can lead to a non-linear story (Dörner et al. 2016). For example, this can be done by giving the player different ways to interact with an NPC, such as trying to attack the NPC and steal the item, or trying to persuade the NPC to give the player the item. The action can then lead to the hostility of an entire town against the player, or on the other hand possible discounts in the respective shops. This helps to ensure that every type of player can play the game the way they want and feel immersed in the story and the game.

2.3.3. Immersion and Flow

Other important concepts are presence, immersion, and flow. According to Dörner (Dörner et al. 2016), presence describes the feeling of "being there" as a specific experience, while immersion is more of a general term that encompasses presence and flow at specific points (Nacke 2009).

The style of the game also promotes immersion for the players. For example, if the content is created without a clear artistic direction, the game may seem cheap and not engaging because the different styles are distracting. Therefore, a clear artistic direction should be established before creating the game. The way UI elements are integrated into the world also contributes to immersion. For example, if players always have to open a menu to do certain things, such as save the current game state, this could break immersion. One idea to overcome this problem could be to integrate saving into the world, for example by having checkpoints where the game automatically saves so that the players only have to save the game themselves when they want to quit it and thus decide to end the immersion themselves.

In addition, the pacing of the game also contributes to game flow and immersion. A game can be fast-paced, such as an action RPG where players must react quickly, or slow-paced, such as a strategy game where players have enough time to think about their next move. It should be remembered that it would be counterproductive if a game designed to encourage players to think did not provide the necessary time to do so, and therefore the pacing of the serious content must be considered in advance (Dörner et al. 2016). To create an entertaining experience with serious content, the pacing could alternate between fast-paced entertainment content and slow-paced serious content to keep the players engaged but not overwhelmed.

There also needs to be a balance between fun and learning. In research-driven serious games, which are usually only prototyped and not used commercially, the game design

and quality are often poor. This is because they are mainly focused on the learning effect and therefore the serious content dominates the games (Dörner et al. 2016). On the other hand, if a game is developed just for fun and the serious elements are not designed properly, the players might find them annoying or do not learn anything at all. In addition, the game should be neither too complicated nor too simple, otherwise, players might become frustrated or bored, as explained in 2.2.

2.3.4. Intrinsic and Extrinsic Motivation

It is also important to motivate the players to continue playing, especially in serious games (Dörner et al. 2016). There are several ways to keep players motivated, including intrinsic motivation, such as using levels to give them a sense of progress, or extrinsic rewards, such as points or items.

The characteristics of learning can also be used as motivators, such as players being satisfied when they discover something new in a game or when they accomplish something that is considered difficult. Some players want to understand and practice the game to become better and faster, and therefore this intrinsic motivation could be used to learn something and achieve their goals (Dörner et al. 2016). This intrinsic motivation of players to play and progress in the game can be used to keep the players engaged. The way the game presents content can support players' intrinsic motivation to learn about a topic.

On the other hand, players can also be extrinsically motivated if they only use the game as a tool to accomplish their goals and then stop playing. This could be the case when a serious game is used as a tool to study for an exam because it is more fun than a book, but after the exam, the players stop playing because they are not interested in the game itself, but only in the tool. Therefore, a game could serve as extrinsic motivation to engage with a topic if the players do not have an intrinsic motivation to learn the do so (Dörner et al. 2016).

Furthermore, the characterizing goal could be either intrinsically or extrinsically integrated. An intrinsic game would be a firefighting game that serves to train firefighters or a flight simulator that serves to train pilots. An extrinsic game, on the other hand, would be a racing game in which, for example, questions have to be answered about a topic that has nothing to do with racing, such as astrology. This would then be an extrinsic game about astrology, where the racing game serves to create an extrinsic motivation to engage with the topic.

Whether a game should be designed intrinsically or extrinsically depends on where the game is to be played. If it is intended for classroom use, it may be extrinsic because the players already know it is a serious game and still want to play it because it is more fun than a textbook. On the other hand, if the game is to be played voluntarily,

it should be intrinsically motivating. If the content is not integrated subtly enough, it may have the negative effect that players will not want to play the game because it is a serious game. Therefore, an intrinsically motivating game should be designed to be entertaining, because then players may not mind if it contains serious content (Dörner et al. 2016).

2.4. Math Content

The mathematical content of the game is intended for students in the 6th to 8th grade, which in South Tyrol is called *middle school*. Since the study was conducted in South Tyrol in Italy, the content should correspond to the learning objectives in the curricula of these grades. The curriculum was created by the Autonomous Province of Bolzano, which is responsible for the administration of the province, including the schools. Therefore, this curriculum represents the official curriculum of the province and is the most suitable since it applies uniformly to all schools (Autonome Provinz Bozen 2021). It should also be noted that the South Tyrolean curriculum is very similar to the *LehrplanPlus*, the corresponding Bavarian curriculum (Staatsinstitut für Schulqualität und Bildungsforschung 2022), and therefore the game can also be used for students from Bavaria.

The curriculum details learning objectives for all subjects at each grade level, including mathematics. It also lists competency goals such as "*use concepts of the natural, whole, and rational numbers and calculate with them in writing and one's head*" or "*question mathematical statements and check them for correctness, recognize connections and develop conjectures, and comprehend justifications*". These competencies can be used as a general guide for the mathematical content of the game. In addition to the general competency goals, specific skills, abilities, and knowledge items are given that can be used as topics for the different areas in the game and the associated quests. "*Decompose numbers into prime factors, determine common multiples and divisors of two or more numbers*" and "*calculate with proportions and percentages in different contexts*" are two of the specified skills currently covered in the math riddles of the prototype level.

The riddles currently used for the chests were taken from the website *KleineSchule* (Artmedia 2004) and adapted where necessary. However, in the future, these should be created specifically, or an interface should be provided for teachers to add or modify the riddles individually.

3. Related Work

In this chapter, related work in the field of serious games as well as action role-playing games relevant to this project are collected and analyzed. This is important to avoid unnecessary false assumptions and to identify already established methods and design principles that can be applied to this project at a later date. The serious games will be analyzed in terms of how the serious content is integrated, what the gameplay is like, what worked well or not so well in these games, and what other aspects of the games might be of interest to this project. In particular, different math games are considered, since mathematics is the type of learning content that will be integrated into the game. Nevertheless, no specific mathematical game was found to meet the requirements of this project. However, since there are some games in the field of physics and physics is a STEM subject related to mathematics, related works in this field are also investigated.

3.1. Serious Math Games

Prodigy Math: One of the serious math games found, and probably the most relevant, is *Prodigy Math* since it uses many of the design principles explained previously and has had great success. It is an interactive adventure game with turn-based combat, where players can explore a fantasy world, solve tasks and play with friends. In addition, parents and teachers can help children learn by monitoring their progress and providing additional help through a separate interface. Also, the content complies with state curricula and automatically adapts to the players' strengths and weaknesses (Prodigy Education Inc. 2011).

   The game has been evaluated by both teachers and students, and they recommend Prodigy as a learning assistance (Cabalo et al. 2017). In addition, a research study showed that Prodigy can lead to an improvement in decimal and fraction skills (Lyons 2020).

Mage Math: Another very interesting serious game is Mage Math, a 3D fantasy adventure game for primary education where kids can explore the world, fight monsters, learn magic skills, and complete quests. The game separates the math part from the rest of the game by letting players practice math in a village with different math videos, while outside the village they can explore the world and fight enemies (Jason Skoubye

2019). The approach of involving the players in the game world and using mathematical problems to empower the players served as inspiration for the game developed in this thesis. No scientific work has been found that proves the effectiveness of Mage Math, but the videos that are used to teach math in the game have many subscribers on the YouTube channel and many views of the videos, which indicates the reliability of the videos and thus the math content.

Mathstation: One game worth mentioning is *Mathstation*, which is also a serious game. It was developed by Jonathan Borowski as part of his master's thesis, which had the same goal as this thesis, which was to develop a game that balances fun and learning. Unlike this project, it is a 2D pixel art math game for elementary grades and was used as a comparison to this project. The game features three different game modes with math problems to solve and a configurable math problem generator (Plecher et al. 2021).

Other: There are also many other serious math games, such as *Math Quest* (Afza Shafie 2011), which are declared as RPGs and are structured like *Pokémon* with turn-based combat, except that an attack requires solving a calculation. Most of these games are also only suitable for elementary school classes, since just simple arithmetic operations are used in turn-based combat. These games were used to illustrate the difference between the inclusion of mathematical content and the pacing of the combat, as in these games the mathematical content is not as immersive and the combat is slow-paced, while in the developed project it is immersive and fast-paced.

3.2. Serious Physics Games

Physikus: One of the analyzed games was *Physikus*, a serious game about physics, released in 1999 for the target audience of 9 years and older. It is an adventure game with puzzles and photo-realistic graphics for the time. According to the publisher, it is one of the best-selling educational games and has won several awards for the didactic concept of the game (Ruske and Pühretmaier 1999). The game was chosen because, as a point-and-click adventure, it is very similar to the genre of the game being developed as part of this project. The main difference between *Physikus* and the game to be developed is that in *Phyiskus* the serious part is separated from the game part. According to a study, this leads to the fact that the serious part is mostly skipped by the players to return to the game-like part (Bormann et al. 2008).

Ludwig: Another serious physics game is *Ludwig*, a 3D interactive adventure game for secondary education students featuring decent graphics. It teaches physics by allowing players to explore the world and giving them tasks consisting mostly of interactive 2D experiments. The emphasis of the game is on letting players learn, experiment, and explore on their own, which is in line with what this game tries to archive, as the game is designed to be fun while still being educational, and it also focuses on motivating students to learn and apply knowledge. The quality of the game is proven by evaluation studies (Wernbacher et al. 2012; Wagner et al. 2013) and by receiving several awards (ovos 2014).

Game of Physics: Also worth mentioning is the serious physics game *Game of Physics*, an RPG that teaches physics through narrative based on textbook chapters that is introduced to the players through quests. Although it does not have such good ratings, it takes an interesting approach to teach physics by using practical examples to explain to the players why a topic is important, thus encouraging active learning (Mind Design Marketing and Communication Pvt. Ltd. 2021). It also uses a leaderboard to stimulate competition between players. These are concepts that are also interesting for this game, as they provide an immersive way to deliver learning content, which is why the game was chosen.

3.3. Action-RPGs

Diablo Immortal: *Diablo Immortal* (Blizzard Entertainment 2022) is a famous new Massive Multiplayer Online Action RPG. It was released in 2022 and has been downloaded over 30 million times as of July 29, 2022. The game was very successful and earned $14.5 million in its first week. This makes it a good example of an action RPG to take something from. It has amazing graphics for a mobile game, a great story, and many different options to play the game. Besides, it offers many features such as Player-vs-Player (PvP) content, different rarities of loot, fast-paced combat, abilities, talent trees, shops, an inventory and equipment system, and many more. These features are common and well-known in this genre, so they served as a guide for determining what features should be implemented in this project. The only difference is that *Diablo Immortal* uses a static top-down camera and not a dynamic 3rd-person camera, which would make the gameplay more immersive.

Aron's Adventure: *Aron's Adventure*, on the other hand, is a third-person action-adventure game for single players. The art style is low-polygon, which corresponds to the art style of this project. The main features are combat, quests, boss fights,

exploration, dungeons, and various weapons (TiMer Games 2021). Besides, some nice animations and effects enhance the players' immersion in the game and make the game look prettier. Therefore, the game not only serves as an inspiration for the graphics, but also for the design and gameplay of this project.

Figure 3.1.: Screenshot of Aron's Adventure taken from it's website (TiMer Games 2022)

4. Game Concept: Kingdom of Math

This section first gives a brief overview of the game, including the target audience and design pillars. Then, the story and core gameplay are described. Finally, the design decisions made are discussed, and it is explained how the mathematical content is integrated to meet the previously mentioned requirements.

4.1. Overview

The game developed for this work is an action RPG with mathematical elements. It is a 3rd-person single-player game with a free-look camera. The PC was chosen as the main target platform, so the controls are the keyboard and mouse. The main target audience of the game are students aged 10-14. Since the mathematical content is designed for secondary education, the game might be interesting for math and RPG fans as well.

Figure 4.1.: Graphical style and theme of the game world.

The game is called *Kingdom of Math* because the whole kingdom contains math in various ways, for example, wizards who practice mathematics to discover secrets and improve their skills and spells. Also, the story of the game revolves around the use of math to become the strongest magician and save the world, as described in section 4.2. A medieval fantasy world was chosen as the setting, and low-poly assets were used because they fit the fantasy theme very well, as shown in Figure 4.1.

The main design pillars that were followed were that the mathematical content should be included in an immersive way, playable voluntarily and that the game, especially the combat, should be fun.

4.2. Story

The story begins with the main character waking up in the forest without knowing who he is and how he got there. An old hermit finds him on one of his walks and takes the main character to his house, a small hut, and gives him food and a place to sleep. Since the main character has lost his memory and does not know where to go, he befriends the hermit and helps him collect herbs, among other things. Soon he finds out that the hermit is secretly a wizard who has given up life in the city to find peace in the woods. He asks him if he can help him regain his memory, and the wizard begins to teach him secret math magic, for which the main character has a natural talent. Just before he can teach the main character the spell to restore his memory, he is kidnapped by an evil force while the main character is training in the forest. The main character now sets out on a journey to rescue his master and learn more about his past. On his journey, he has to defeat various enemies sent by the evil force. He finds out that his master was kidnapped to help an evil magician summon a demon, since he was once the best magician in the world and the only one with the necessary power and knowledge. On his way, the main character experiences great adventures, solves difficult riddles, finds friends, and becomes stronger and stronger, eventually fighting the evil mage, freeing his master, and saving the world. During the journey, it turns out that he is the child of the evil mage and that he tried to stop him, but something went wrong, and he was teleported into the forest and lost his memory.

4.3. Core Gameplay and Progression

The main gameplay loop of the game is that the player explores the world, opens chests, completes quests and upgrades items to become stronger, and then fights enemies. This means that the gameplay alternates between fast-paced combat for the fun part and slow-paced exploration, story, problem-solving, and optimization for the math part.

The players' main experience should be to have fun adventuring and fighting, and to feel smart and confident in their mathematical abilities while solving puzzles.

The game progresses in several ways, for one, the players can level up by killing enemies and completing quests, since both give them experience. With leveling up, the players can increase their stats, making them stronger in combat. Also, the players can collect better items from enemies, chests, quests, and shops, which can then also be improved by completing an equation by placing mathematical items such as numbers and signs in the equipped items in corresponding slots as described in section 4.5.2. In addition, when the players level up, they get trait points that also improve stats, and the stores offer more and stronger items. However, not only does the players' strength increase as the game progresses, but also the difficulty of the enemies and the mathematical content, for example, in the lower levels numbers between 1 and 10 are used for the calculations in the items and in the higher levels these numbers also become higher, and thus it becomes more difficult to solve the equations. Not to mention that the story also progresses through the levels and the players learn new abilities and get new weapons.

4.4. Design Decisions

The key design principles followed in this game to create an entertaining experience while promoting learning are based on motivating players using the design features and principles described in chapter 2. These include hero and narrative, familiar game mechanics, and constructive gameplay. However, the most important focus in the design of the game was to keep the players immersed and in the flow. As a brief summary, the game flow model proposed by Sweetser and Wyeth (Sweetser et al. 2005) includes the eight dimensions of concentration, challenge, player skill, control, clear goal, feedback, immersion, and social interaction. The design decisions made and the reasoning behind them are explained below, and the dimension of the flow concept covered is mentioned in the appropriate place.

4.4.1. Game Design

The first and one of the most important decisions made was the type of game. The choice fell on an action RPG, as this is proven to be fun and players are already familiar with the mechanics, which is one of the design principles mentioned in chapter 2. In addition, the game, being an RPG, offers the possibility of immersive content and story to make the players feel emotionally involved and therefore achieve better learning outcomes.

Fantasy was chosen as the theme for the world because it is very popular and magic offers a good way to combine learning with play. It provides the opportunity to tell a good story and to incorporate combat and magic skills. Also, there were appealing assets available that fit well with this theme, as seen in Figure 4.1, and nice-looking graphics are a good way to interest players in a game. The low poly style was chosen because it looks appealing, is easily expandable, and provides better performance, making the game potentially playable on platforms such as smartphones and tablets.

It was decided to use a third-person camera as this is usually used in Action RPGs, which was extended by a free-look component to support different play styles. It allows players to zoom in on one side when they want to look around the world and have an immersive feeling, and on the other side they can zoom out to get a better view in combat and move around more easily.

As already described in chapter 2, the narrative of a game is very important, as it contributes to the immersion of the players and can motivate them on an emotional level, which in turn contributes to learning success. To achieve this, the main character and the possible dialogues with NPCs were designed in such a way that players can identify with the character and can understand the decisions. To support different styles of play or characters, the story is partly dynamic, so that at certain points the players can make decisions that affect the game, as described in more detail in section 5.4.1. In turn, the inclusion of the players and their individual decisions in the story promotes immersion and the emotional connection of the players to the game.

Since there are different types of players who have different preferences and approaches to playing, this has also been taken into account. To this end, various contents have been developed that allow players to play the game in their way and still progress. Among other things, chests hidden in the world offer players who like to explore and solve puzzles the possibility to do so. On the other hand, players who prefer more action-oriented content will have the possibility to fight enemies and advance this way. Also, for players who like to involve themselves in the game world and story, quests and NPCs will provide the possibility to do so. In addition, the mathematical contents are integrated in different ways to give players multiple ways to engage with them, which will be described in section 4.5.

As described in section 2.2, clear goals are an important part of the flow concept, which means that the game must give the players clear goals at appropriate times. This is realized in the game through quests and their respective objectives, which guide the players through the game by sending them to certain places and giving them tasks so that they do not get lost somewhere without knowing what to do. Quests are also used to control the pacing of the game a bit, encouraging the players to switch between slow-paced content and fast-paced combat by going from one place to another, along

the way of which side quests and chests may appear or enemies may cross the players' path.

To provide the players with challenges that match their skill level and new challenges at a reasonable pace, which contributes to the flow of the game, different difficulty levels of content are offered. This includes that the enemies get stronger as the game progresses and that there are different difficulty levels of math problems, as described in section 4.5.

Since there are many different mechanics implemented in the game, some of them very complex, a tutorial was created to teach them to the players step by step. This way, the players are not thrown into the game right at the beginning, where they do not know what to do and might be overwhelmed, as this could lead to frustration and quitting the game. The tutorial is designed to be interactive, so that the players can have fun trying out the individual mechanics one by one and thus get into the game, instead of just having to read text explanations and getting bored. This contributes to the part of the game flow called player skill, which means that the game interface and mechanics should be easy to learn and that the players should not require a manual to play the game.

To increase the performance of the game, fog was also added, which envelops the environment from a certain distance and thus no longer needs to be rendered. In addition, the fog ensures that the players do not immediately see the whole area and can thus make them curious and encourage them to explore places.

4.4.2. Serious Content

The next important decision concerns the incorporation of mathematical content into the game. As discussed in chapter 2, serious games usually have a deterrent effect on players because they are associated with learning and less with fun. In addition, most serious games focus on the learning content, and thus the fun of the game is usually neglected. Therefore, in this project, a different approach is taken, namely to focus on making the game fun in the first place and to include the mathematical content in such a way that it is completely voluntary. Of course, this does not mean that there is simply an option in the menu where the players can learn math, but that the content is still immersive and part of the main gameplay loop as described in section 4.5.

The idea is that the players do not feel forced to deal with the math content, because they know that they does not have to, but that they see an advantage in doing it anyway. This can motivate players to engage with math because they associate it with something positive rather than something negative, allowing them to learn something and have fun in the process. To engage the players in the serious content of the game, the content was designed to be both intrinsically and extrinsically motivating, which is explained

in more detail in the 4.5 section.

The mathematical content and the game were designed for students aged 10 to 14 years since there are already many games for primary education but few for secondary education and this area is therefore particularly interesting because there is little research on it. However, the game can be played not only by students of this age group but could also be interesting for RPG and math enthusiasts.

It was also an intentional decision not to include math directly into the combat, as other games described in chapter 3 have done, for example through turn-based combat or a timer. This was to keep the combat itself fast-paced, immersive, and fun, as it would have been difficult to incorporate math into the combat in a way that did not disrupt the immersion and pacing.

Also, the players have the option to switch between the slow-paced math content and the fast-paced combat. This ensures that if the players have had too much action and want to do something else that is not as action-packed, they have the option to do so and still progress in the game. If they no longer want to fight and fighting is the only way to progress in the game, the players would probably abandon the game because they have nothing else to do. However, since fighting is not the only way to progress in the game, the players can simply move on to another option, such as quests or chests, to get a break from fighting and still progress in the game. This contributes to the flow component of control, where players should feel a sense of control over their actions in the game.

As described by Sweetser and Wyeth (Sweetser et al. 2005), social interaction is also part of the flow concept. Due to time constraints, this part is currently only partially integrated into the game by offering the possibility to solve puzzles together. In the future, however, a leaderboard and a multiplayer mode will contribute to social interaction and allow the players to play or compete with others, which should motivate the players to get better, as explained in more detail in chapter 8.

Another point of the flow concept is that the players should receive feedback at appropriate times. In the game, this is implemented in different ways in both types of content. For example, when the players solve the riddle of a chest, they receive the corresponding reward, and when they enter an incorrect answer, they receive visual feedback by shaking the screen and removing the answer. In the game in general, feedback is built in through rewards from quests and enemies, answers from NPCs, etc., which indicate to the players whether they are doing something right or wrong. Also, achievements would provide another way to give feedback to the players in the future.

4.5. Math Content

The game focuses on incorporating the mathematical content in such a way that the players can do it voluntarily, but do not have to in order to progress in the game. Each way in which math is incorporated provides the players with the opportunity to become stronger by including items as rewards and increasing their stats. This makes the rest of the content easier, especially helping to defeat enemies more easily and complete the level without major problems.

Since the mathematical content is optional, the levels must be manageable without it, and each enemy must be defeatable without the items from that content. This is realized by the fact that also enemies drop items after they are defeated, which the players can use to get stronger. If the math content is not made, the enemies are much harder to defeat and the players must fight them as single targets and cannot fight several at once, which makes completing levels and progressing more difficult and should encourage the players to engage with the math content. This would make the game easier and the levels can be completed faster, although the players must invest time to engage with the math content. However, this time is less than if they have to complete the level without the rewards from the math content. This helps to intrinsically motivate the players to engage with the serious content if they want to get stronger and faster. There are four ways in which mathematical content is integrated into the game, which are described in more detail below.

4.5.1. Chests

The first way in which mathematical content is incorporated is through chests. To open a chest, a mathematical problem or puzzle must be solved. Chests have three different difficulty levels: easy, medium and hard, and contain corresponding loot. As shown in Figure 4.2, the difficulty level of a chest is visually displayed so that players can estimate the difficulty and decide whether to open the chest or not.

To solve the difficult tasks, players should make an effort and possibly take pen and paper to help them, because the loot inside is accordingly good. The different difficulty levels are meant to help players assess their mathematical abilities, and they offer appropriate content for each skill level so that even players who are not that good at math can at least solve the easy chests. Easy chests at the beginning of the game serve to lower the barrier of entry for interacting with the system, as they can be solved by anyone and players have an immediate sense of accomplishment, rather than trying to open a difficult chest at the very beginning, failing at it, and not interacting with chests again in the game.

Figure 4.2.: Different types of chests, from easy on the left to difficult on the right.

Also, it should encourage players to engage in more difficult tasks because the loot is better. It should be noted that players will not be penalized, however, if they enter a wrong result in order not to demotivate them. This allows players to decide for themselves if they want to open chests to get loot that makes them stronger or not.

The chests should also be a feature that encourages the players to explore the world, as the chests are usually hidden and need to be found first. It is intended that players will have to leave the main path to find the chests, as it should be a particular decision to search for them. This is also important for gameplay, as there are players who prefer to explore rather than fight. This allows those players to make the part they like, such as exploring, more exciting and help them with the part they do not like as much, such as fighting.

The inclusion of chests helps to implement the design principle of intrinsic and extrinsic motivation. Chests can be intrinsically motivating by allowing players who like riddles and math and do not like fighting as much to play the game the way they prefer. But they can also be extrinsically motivating by giving players the opportunity to get loot when they open chests by solving math problems. This extrinsic motivation is especially interesting for players who do not like to deal with math, but want to become stronger in the game and therefore solve the riddles to reach their goal and maybe learn something in the process. How exactly the chests are implemented will be covered in the next chapter in section 5.7

4.5.2. Item Upgrades

The second way in which math is integrated is through item upgrades, the implementation of which is described in detail in section 5.2.5. Item upgrades provide the players with the ability to increase a stat corresponding to the item they are upgrading. The bonus value has a corresponding number, for example in Figure 4.3 it would be 50 for

the *Mana* stat. The players can then assign numbers and signs to different slots to form an equation to get as close as possible to the maximum number, but not above it. In the example, 45 out of 50 is achieved, which then means that the *Mana* stat is increased by 45 points.

Figure 4.3.: Item Upgrade UI.

This type of mathematical content should motivate the players to practice mental arithmetic regularly, since the players can collect numbers and characters from chests and enemies throughout the level. It also provides the players with the opportunity to tweak the equation and change it each time they collect a new number or sign to

get closer to the number. For example, if the players collects the number 2 they can change the equation to *6*7+2*4* in Figure 4.3, to reach exactly 50, which would be the maximum. Also, the players have the option of moving the numbers back and forth between different items during the game to see if it might make them stronger. Thus, when the players get a new number or sign item, they immediately try to make the most of it and change the equations in different items to maximize their stats. Since this is optional and the players choose to do it voluntarily, it can be seen as an intrinsic motivation to engage with the content.

4.5.3. Shops

The third way in which math is embedded is with the use of shops, the implementation of which is discussed in section 5.8. In these shops, items are sold depending on the type of shop, for example, an armor shop sells different armor items. Some of these shops can also be seen in Figure 4.1, where a weapons shop can be seen on the left and an equipment shop on the right.

Players have the option to buy the items at a certain price and also to sell them, but usually for a lower price than the initial purchase price. Also, players can sell items they have collected in the world to earn money and buy better items when the old ones are no longer needed.

There are also shops that sell the same item at a higher price than other shops, for example, a shop in the mountains sells ice for 5 gold, while a shop in the desert sells it for 50 gold because this item is rare there. The players could use this principle and buy all ice items in the mountain store and sell them for a certain percentage of the 50 gold, for example, 40, in the desert shop and earn money that way. In this way, the players should get a feeling for how the economy works by buying and selling items and calculating the respective profits and discounts to earn money and become stronger.

The approach of integrating math in this way supports the design principle of the immersion of the mathematical content, since it represents a natural system that also exists in the real world. The players probably think they are smart, because they have the idea to buy the items cheaply at one place and sell them expensively at another, and thus earn money. It may not even occur to them that they are using mathematics for this and have possibly learned something.

4.5.4. Quests

The last way mathematics is included is through quests, the implementation of which is discussed in section 5.5. On the one hand, there is the main quest line, which does

not contain math but encourages the players to engage with the world and its story. In addition, the main quest line should encourage the players to take an interest in the respective locations and do side quests there to learn more about the different locations, the world, and themselves. In addition, these side quests also offer players the opportunity to become stronger, because they get rewards for them after they have successfully completed them.

The mathematical content of these quests is adapted to the respective topic of the level. If a level is designed to explain and practice for example percentage calculation, the side quests will focus on that topic. For instance, in a quest, a player might be tasked with bringing the quest giver a dress from one of the clothing stores that previously cost 1500 gold but is now 35 percent off, and the quest giver does not tell the players exactly which one and in which store. The players must then calculate how much the dress now costs and buy the appropriate dress from the appropriate store and bring it to the quest giver to get their money back and earn an additional reward.

In this way, quests are designed to help the players understand the mathematical topic of the level by confronting them with real-world problems. This type of mathematics serves to present problems to the players in a more interesting way than with pure text problems. It should also motivate the players to engage with math, because they have built up an emotional connection to an NPC through the quest, and it is important to them to help the NPC. Quests also help to keep the players immersed in the story and the world while they is dealing with the mathematical content, because there is nothing to prevent them from empathizing with it. It also shows the players that mathematics can be encountered in many situations in the real world and helps them to better recognize and understand them.

5. Implementation

The actual implementation of the game was the most important part of this project, which is why most of the time of this thesis was dedicated to it. In this chapter, the various features implemented in the game are described in terms of gameplay and configuration options for the developer, and brief examples are given.

5.1. Technical

Unity 5 version 2021.3.1f1 was used as the game engine, as it is a cross-platform engine with an easy-to-use editor that allows the game to be offered on different platforms, making it possible to reach the target audience more easily. The programming language C# is used because it is the default programming language in Unity.

For the creation of the icons for the number and character items, *Krita* (Krita Foundation, KDE 2005) was used. Due to the limited time available for this project and the need to find appealing assets, they were obtained from a variety of sources. The main assets, especially the environment and character models, were created by *SyntyStudio* (Synty Studios 2014) and the following packs were used: *POLYGON - Fantasy Kingdom Pack*, *POLYGON - Dungeon Realms*, *POLYGON - Dungeon Pack*, *Simple FX - Cartoon Particles*. Also, some of the VFX, tutorials, and icons for the cursor were taken from *GameDev.tv* (GameDev.tv 2014). The skyboxes used were taken from the package *FREE Skybox Extended Shader* by *BOXOPHOBIC* (BOXOPHOBIC 2019) and the GUI assets come from the package *GUI PRO Kit - Fantasy RPG* by *Layer Lab* (Layer Lab 2019). The animations were imported from *Mixamo* (Adobe Systems 2008) and modified to fit the character models.

5.2. Items

Items are one of the most essential parts of this RPG, since they are used in many ways for gameplay and math content. An item is an object that the players can collect in the world and then add to their inventory. This item can then be used for various things in the game, which will be explained in detail in this chapter.

5.2.1. Implementation

Items are implemented using scriptable objects, each of which has a name, a unique ID, a description, an icon, and a pickup. Also, for each item, its price in the store, its category, which is described in section 5.2.2 and is used to filter items in the store, whether it is stackable, its level and, if it has a bonus stat, what stat that is, its maximum value and its current value can be configured. In addition, there exist other configurations that depend on the type of item and are described in the corresponding section.

An item can be created by the developer by right-clicking on the appropriate folder and selecting [*Create*]->[*Inventory System*]->[*Item Type*]. The items that can be created in the current state are math items such as numbers or signs, action items such as consumables or quest items, abilities, equippable items such as armor, currency and experience reward items, and weapons. Abilities and weapons can be created under a separate tab called [*AbilitySystem*]->[*Ability*] and [*CombatSystem*]->[*Weapons*]->[*New Weapon*]. This gives the developer the ability to easily create a variety of different items that make the game more interesting and unique.

5.2.2. Types

There are different types of items: Equipment items, consumable items, ability items, weapon items, number items, sign items, quest items, currency items, and experience items. Some of these items, such as numbers, signs, consumable items, and quest items, are stackable, meaning they only take up one slot in the inventory, even if there are 20 of them. Others, such as equipment, ability, and weapon items, require a separate slot per item.

Equipment items are used to describe items that the players can equip in a separate equipment window, as shown in Figure 5.1a. They represent different armor types, including helmets, chests, gloves, boots, and shields. Each armor type can only be equipped in a specific slot, indicated by a grayed-out image. The items can be equipped by dragging them from the inventory to the corresponding slot in the equipment window. In addition, weapon items can also be equipped in the Equipment window, but they are a separate item type as they have extra configuration options, as explained in detail later in section 5.2.3.

All equippable items can have additive and percentage modifiers that increase a specific stat if desired. For example, if the player has equipped a shield that has an additive modifier for the defense stat of 5, this is then added to the player's defense stat, which is for example 10, resulting in an effective value of 15 for the defense stat. How exactly these values are calculated is explained in section 5.3.

(a)	(b)	(c)

Figure 5.1.: (a) Equipment window, (b) Character with equipped weapon, (c) Inventory with item tooltip

Ability items and consumables can be equipped on the action bar at the bottom of the screen and are explained in detail in section 5.2.4. There are also money and experience items that are consumed when they are picked up, which means that they are added directly to the player's money or experience balance as soon as they are added to the inventory, and therefore do not appear in the inventory. Lastly, there are items for various numbers and signs that are needed to enhance the other items. Furthermore, when hovering over an item, a tooltip appears showing details about the item, such as its name and description, as displayed in Figure 5.1c.

5.2.3. Weapons

One of the most essential item types are weapons, as they are the important for combat. At the moment there exist three different types of weapons: The unarmed weapon, which refers to hand-to-hand fighting, the sword as a melee weapon, and the bow as a ranged weapon. The selected weapon is displayed in real-time in the game on the character model and follows the character's movements as if they were holding it.

Weapons are implemented using scriptable objects where, in addition to the default item configurations, developers can configure weapon range, weapon damage, percent damage, a weapon prefab, which is the object that is equipped and displayed at runtime, an animator override controller with the appropriate attack animation, whether the weapon is right-handed, which is the case for swords, or left-handed, which is the case for bows, and possibly a projectile for ranged weapons.

The various animations for, say, a sword or a bow are controlled during runtime with an animator override controller, so that the weapons can be changed during runtime but still maintain the correct animations, as shown in Figure 5.1b. Also, a hit point can be set in the weapons' animations where the animation will call a hit function when passing that point so that enemies are hit when the sword hits them and not when the animation is started or stopped. This should contribute to more realistic combat behavior, as an enemy or player should not take damage if the sword has not yet hit them.

5.2.4. Abilities

Abilities are also essential to the combat system, as they can be used as an additional attack in combat alongside normal attacks, like with the sword or bow. Abilities can be equipped in the action bar at the bottom of the screen. The first four slots are reserved for abilities, the last two for consumables like health potions, and other action items like quest items as shown in Figure 5.2.

Figure 5.2.: Action bar with two abilities and a potion equipped.

Abilities can be used by pressing the key, that is indicated above the slot in which the ability is equipped. Some abilities take effect immediately, such as health potions, which are automatically cast on the player, while others, such as the *Super Mega Splash* ability, must first be activated by pressing the appropriate button and then clicking on the ground at the location where the ability is to be cast. The area in which the ability can be cast is usually indicated by a circle on the ground, as shown in Figure 5.3. Consumables can be used by pressing [*1*] or [*2*] and can be set to be removed from the inventory when they are used up, as is the case with health potions. In addition, each ability costs *Mana* and has a *cooldown* that indicates how long the player must wait before using the ability again.

Each ability is also implemented as a scriptable object that has additional configuration options on top of the normal items. For instance, it can be set as consumable, which is used for consumables such as health potions. Also, an equipment slot, meaning its place in the action bar, needs to be configured, which is important to help balance

Figure 5.3.: Target indicator of an ability.

the game. For example, if there were multiple ultimate abilities, and they could be equipped in all slots, that would be too advantageous to the players and therefore unfair, so the ultimate abilities can only be equipped in one slot, allowing the players to have only one ultimate ability at a time. In addition, for each ability, the *cooldown* and *Mana* cost must also be specified.

Moreover, a targeting strategy must be defined. This targeting strategy can be e.g. self-targeting, multiple-targeting, single-targeting, or directional-targeting. A filtering strategy must also be set, e.g. which characters are targeted, players or enemies, and how they should be filtered, e.g. by tag. It has also been implemented that dead targets are ignored when targeting. After the target is set, effect strategies must be added, such as an animation for the ability, that the player is facing the target and a particle effect. The effects are then executed in the order in which they are listed.

5.2.5. Upgrades

Some of the items can be upgraded with bonus stats, e.g. equipment, weapons, and abilities. To do this, the player can right-click on the item in question, which will open a window with the details of the respective item, as shown in Figure 4.3. The window contains the item's name, icon, description, level, type, and bonus stat. What a stat is,

is explained in more detail in section 5.3. For weapons, additionally, the base damage and range are displayed.

The bonus stat is marked with a * at the beginning of the name, and an additional field at the bottom contains the name of the bonus stat, preceded by the word "*Bonus*". The field also contains a slider that indicates how much of each bonus stat has been reached. The goal should be to get as close as possible to the indicated possible value of the bonus stat. This can be achieved by dragging numbers and characters from the inventory into the slots below the slider and forming a calculation with them. The result of this calculation should be as close as possible to the maximum bonus stat. For example, if the desired number is 50, it can be formed by dragging a five, a multiplication sign, and a 10 into the corresponding slots. In the example in Figure 4.3, only 90 percent of the maximum value was reached because the result of the calculation *6*4+7*3* was only 45 and not 50.

The numbers and signs can only be placed alternately, e.g. it is not possible to place two numbers next to each other to get one number, like 2 and 2 to get 22. There must always be a sign between these numbers, otherwise, they will not be taken into account in the calculation. Moreover, it is not possible to get a number that is greater than the possible number or less than 0. In this case, the numbers return to the inventory after being dragged and do not remain in the slot.

The value reached is then automatically updated and added to the respective stat, in the example case, the *Mana* stat. The numbers and characters can be changed at any time to achieve a larger number and optimize the stat of the item. Currently, only simple operations like addition, subtraction, multiplication, and division are supported.

5.2.6. Qualities

There are also different qualities of items. They range from common to legendary and have a corresponding pickup, as shown in Figure 5.4, where white stands for common and orange for legendary. A pickup is an object that appears in the real world as a placeholder for the different items and can be collected by clicking on it to obtain the item. This is how an item dropped by an enemy or a chest is added to the player's inventory.

In addition, items can also be dropped and removed from the inventory by dragging them from the inventory interface into the world. When the players want to collect the item again, all they have to do is click on the pickup in the world, and it will be added back to the inventory.

Figure 5.4.: Different pickup qualities.

5.2.7. Drops

When an enemy dies or a chest is opened, the players can receive items. These are called drops, which means that a pickup is spawned in the world, which the players can then collect and receive that particular item. To indicate exactly what items are dropped, each enemy and chest has a drop table that describes this.

To specify what is dropped where and when, a script called *Randomdropper* was developed, in which the developer can configure various parameters. These include the scatter distance which is the distance around the opponent where the pickup is spawned and the respective drop table. It is also possible to set if and which drop table should be used when a certain condition is met. This option can be used when enemies have a default drop table, but when a particular quest is active, they should have a different drop table that contains a particular quest item. Therefore, developers do not need to create and place new enemies that drop this item, but can use the enemies already present in the world. Once the quest is completed, the drop table is automatically reset to the default drop table so that the quest items are no longer dropped.

Drop tables are implemented using scriptable objects that contain a list of items, the relative chance, the minimum and the maximum number of drops for each item, a global percentage for the drop chance, and the minimum and maximum drops for the total items in the drop table.

The inclusion of drop tables also adds a bit to the players' mathematical understanding, as players can, if they wish, collect data by killing enemies in an area and then evaluate it to derive the drop table itself. From this, they can then deduce how likely it is to get a particular item.

5.3. Stats and Traits

Another important part of an RPG are stats. In this game, the following stats are included: *Health, Damage, Mana, ManaRegenerationRate, HealthRegeneration, Defense, CooldownReduction, ManaCostReduction, BuyDiscountPercentage, XPReward, XPtoLevelUp* and *TotalTraitPoints*. The player and also the enemies have base stats that are based on their level. For instance, a level 1 enemy has 50 health and a level 2 enemy has 70. The player's stats can be increased in various ways, such as by leveling up, by traits, or by equipping and upgrading items. The players can view their stats by pressing the [*S*] key.

In addition, traits can be used to improve stats without having to equip an item. For example, the *Charisma* trait increases the *BuyDiscountPercentage* stat by 2, while the *Stamina* trait increases the *Health* stat by 2 percent per trait point. The trait window which is displayed in Figure 5.5 is opened by pressing the [*T*] key, and then trait points can be assigned by clicking on the [+] next to the desired trait and confirming. Once a trait point is confirmed, it cannot be undone, so the players must carefully assign their trait points.

Figure 5.5.: Trait window with one point already assigned and 3 points to be confirmed.

The stats are stored in a scriptable object called *Progression* and can be set per character class like *Player* or for different enemy types like *Archer* or *Soldier*. Once a character class is selected, the corresponding stats for each level of that character can be configured. These stats are then used as the base stats for each character class. As the players level up, the new values for each stat will be taken from that progression object.
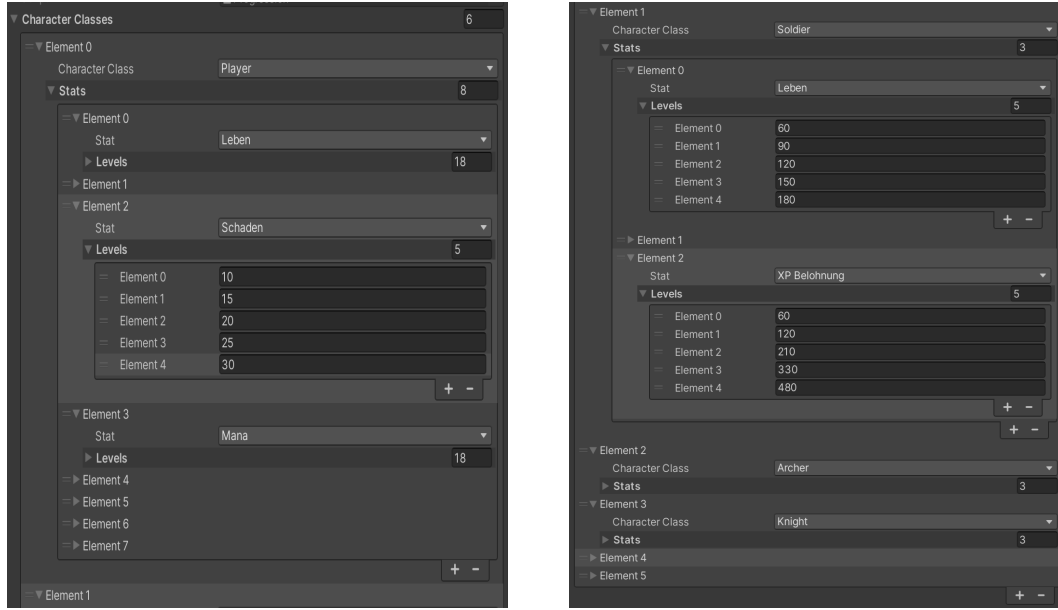
(a) Player class   (b) Soldier class

Figure 5.6.: Stat configurations for different character classes and levels.

In this way, the developer can easily set the different stats per level for the characters while always keeping an eye on the overall progression, as shown in Figure 5.6. These stats can easily be displayed in a spreadsheet to get a better overview of the different characters and their stats and, most importantly, to balance the game.

$$Stat = (BaseStat + AdditiveMod + BonusMod) * (1 + \frac{PercentageMod}{100}) \qquad (5.1)$$

Also, items can have additive, percentage, or bonus modifiers for stats. Additive modifiers and bonus modifiers modify a character's stats by adding them to the base stats, and percentage modifiers modify them by multiplying them to the base stats after adding the bonus and additive modifiers to the base stat, as shown in equation 5.1.

5.4. Dialogues

As mentioned in chapter 4, a compelling story is an essential part of the game design. For this reason, dialogues, which are mainly used to convey the story through normal dialogues and quests, are equally important. To help developers create branching dialogues easily, a custom editor has been developed that provides the ability to create conditional dialogues and quests with multiple choices. How exactly these dialogues and the corresponding editor work is described below.

5.4.1. Gameplay

When players hover over an NPC and the mouse pointer turns into a speech bubble icon, it is possible to have a dialog with that NPC. The dialog can be started by clicking on the respective NPC. If the players are not in range, they will automatically walk toward the NPC until they are in range. Then the dialog window opens, and the dialog is started. The dialog always starts with the NPC part, and when the players click the [*Weiter*] button, the next part of the conversation is displayed, either another NPC part or the player's part. The player part of the conversation has either one or more answer choices, depending on the developer's decision. As described in chapter 4, this adds to the immersion of the players. Furthermore, a dialog can be closed at any time by clicking the cross in the upper right corner. Figure 5.7 shows the NPC segment of the dialog, and Figure 5.8 shows an example of the player's response with multiple answer choices.
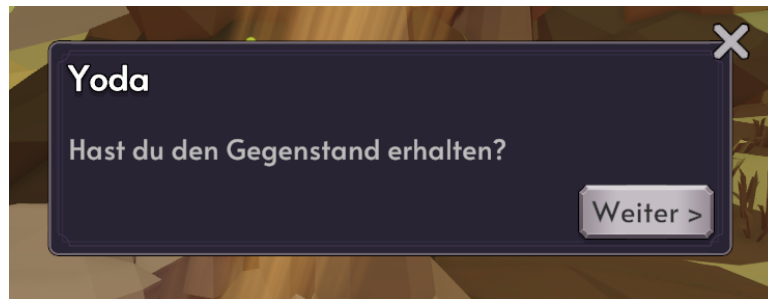

Figure 5.7.: NPC part of the Dialogue.

Dialogs can trigger NPC actions or other actions in scripts. These actions can be, for example, giving quests or items, different answers in the dialog, or putting the NPC in a different state, e.g. in the tutorial by switching to the next part of the tutorial and the next dialog. In addition, it has been implemented that NPCs can also give random
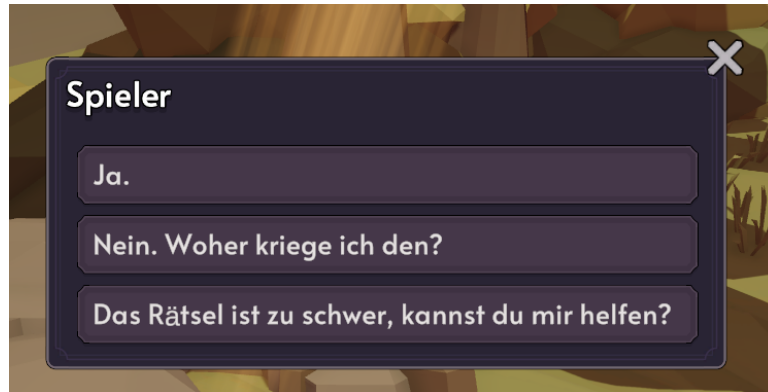
Figure 5.8.: Player part of the dialog with multiple answer options.

answers, chosen from a pool of possible answers, to create a more natural dynamic feeling in the conversation. Also, each NPC has a different name that can be selected in the editor and is displayed at the top of the dialog window to indicate who is speaking.

Conditions and multiple player answers can be used to create multiple-choice questions, since each of the players' answers can be a possible answer, and the correct answer can trigger an action that results in a reward. These dialogs with actions can also be used to give a hint next to a chest, and the hint could cost something. So the NPC giving the hint might ask the players if they want to pay for it and if the players click [*Yes*], the money is removed from their inventory and the NPC gives the hint.

5.4.2. Custom Editor

To speed up the creation of dialogs for the game, a special editor tool has been developed. A new dialog can be created by right-clicking on the appropriate folder and then selecting [*Dialogue System*]->[*Create New Dialogue*]. This will create a new scriptable object for that dialog. Each dialog consists of several nodes, as shown in Figure 5.9. These nodes are connected by Bézier curves to show their order and their relationships to each other. When a dialog is created, it initially has only one root node, and by clicking the [+] button, a new node can be added as a child node. These nodes are also scriptable objects that are children of the scriptable dialog object.

There are several possible configurations for each node. First, the size of the text field can be adjusted to the length of the answer. This is useful to keep the editor organized and always display all the text readably if it is a long text, and if it is a short text, the field can be made smaller to not take up too much space. Next, it can be selected whether the node is a player part or an NPC part of the conversation. It is also
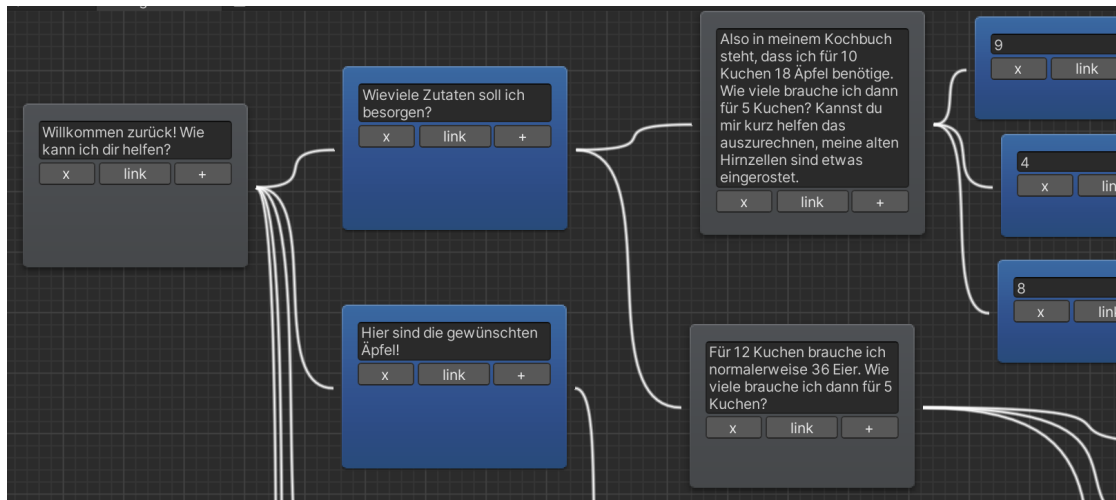
Figure 5.9.: Dialogue Editor with an example of a branching Dialogue.

possible to add an *Enter* or *Exit* action that is triggered when the dialog node is entered or exited, which is done by clicking the [*Next*] button or closing the dialog.

Additionally, conditions can be set, e.g. that the players must have a certain amount of an item in their inventory to unlock a certain answer option. When the condition is met, the corresponding dialog segment is activated. This is especially useful for quests where the players need to return diamonds, for example, and the NPC will not thank the players and trigger the *removeQuestItemsFromInventory*, *giveReward*, or *completeQuest* actions until the players have all the diamonds in their inventory. The combination of conditions and triggers in dialogs is a very powerful tool to drive the story and gameplay.

If a developer wants to change the structure of the dialog, there are the following possibilities: A node can be added by clicking the [+] button, it can be linked to another node, by clicking on the [*link*] button in the middle of the node, and then on the other node which then will be made a child node of the first; a link can be removed by clicking on the [*link*] button of a node and then on the other node between which the link should be removed; nodes can be deleted by clicking on the [*x*] button at the bottom left of the node. This provides an opportunity for the developer to customize the dialog at any time without much effort. To keep the dialog window organized and to get a better overview of the individual nodes, they can be moved and arranged by dragging them.

5.5. Quests

Another important part of the game are quests, as they guide the players through the story and the world by giving them options of what to do next. To start a quest, the players usually have to talk to an NPC and confirm that they accept a task, and then the quest is added to the quest list.

When the players click on the book at the bottom right of the screen, the quest window opens, displaying active and completed quests as shown in Figure 5.10. There also the name of the quest and the current status can be found. When the players hover over a quest with the mouse, the respective goals are displayed with description and current status, as well as the rewards the players will receive after completing the quest.

To finish a quest, all objectives of this quest must be completed. Whether an objective is completed is indicated by the checkbox next to the respective objective. If it is checked, it is completed, otherwise, it is not. At the bottom of the tooltip, the rewards that the quest gives are displayed, usually, these are experience, money, and items. Once the quest is completed, the reward items are added to the inventory, and money and experience are also added, but directly to the players' current balance.

Figure 5.10.: Quest list and Tooltip of an example Quest.

These quests are implemented using scriptable objects that contain a list of objectives and a list of rewards. The objectives have a description and a reference, which is

needed to make them easier to use in dialog triggers, as well as possible conditions to automatically complete them when a condition is met, such as when an item is collected. To give the quest to the players, dialog triggers are used that call the quest giver's *GiveQuest* method. They are also used in the same way for completing objectives and quests.

5.6. NPCs

As mentioned in the section 5.5, NPCs are important for the players' interaction with the game world, through quests and dialogs. An NPC can either be a static NPC that is just animated and placed in the world, or an NPC with a dialog or quest for the players. Static NPCs are therefore important to make the world feel more lively, while the other NPCs are important for the story, gameplay, and immersion since the players can interact with them.

NPCs are implemented using an *NPC Controller* that contains a list of *NPCActions*. Each of these *NPCActions* has a description, a corresponding position in the game world, a time in the action, a speed to that action, a dialog, and a list of animation states that can be configured. The NPC always starts in the first action and moves at the set speed to the position of the next action after the specified time has elapsed or when a dialog trigger switches to the next action. For example, if the players have accepted a quest from an NPC, the NPC will move to the next quest point and offer another dialog for the players to complete the quest. This implementation was done to give the developer a lot of control over the NPC. Also, a single NPC can perform multiple actions and dialogues, which makes it feel more natural and alive.

5.7. Chests

Another important function are the chests. Chests, as the name suggests, are objects placed in the world that contain items and work as follows. When the players hold the mouse cursor over a chest, the mouse cursor turns into a yellow square. When the players click on a chest, they automatically move into range of the chest, if they are not already in that range from where they can open it. Once the players are within range, the chest window displayed in Figure 5.11 opens. The window consists of a mathematical question, an answer field where the players can enter their answer, and a confirmation button. If the players enter an incorrect answer, they receives visual feedback in the form of a screen shake, after which they can try again. If the answer is correct, the chest opens and a pickup for an item is spawned.

There are three different types of chests: easy chests, which are wooden and can be opened by solving easy math problems or even trick questions; medium chests, which are golden and can be opened by solving medium math problems; and difficult chests, which are purple and have a golden frame and can be opened by solving difficult math problems, as shown in Figure 4.2. Next to some chests is an NPC, usually a fairy, who gives the players hints if a puzzle is too difficult. Currently, these hints are free, but in the future, each hint will cost a small amount of money. This is to prevent players from looking at the clues before trying to solve the problem themselves.
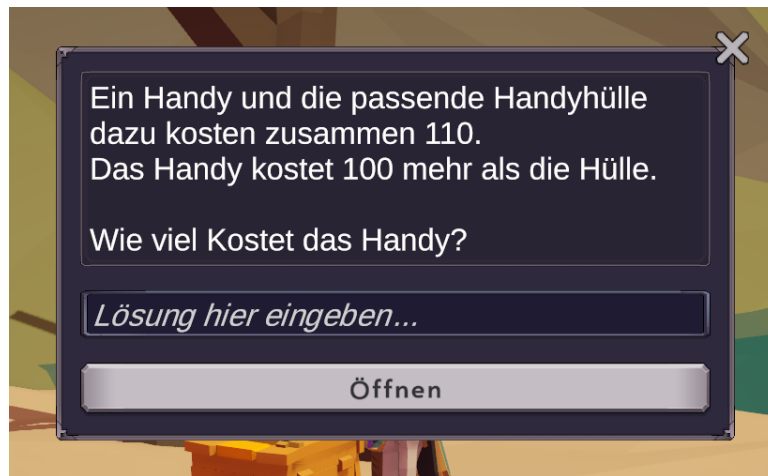

Figure 5.11.: Chest UI with the corresponding mathematical problem.

The chests are implemented using scriptable objects, where the developer can configure various options. One of them is the respective math problem, which is also implemented via a scriptable object consisting of the difficulty, a question, a solution, and a list of hints. The chest object additionally has a chest prefab depending on the difficulty, a chest protector being the fairy with the clues, a voice output for opening the chest, a level, and a drop library containing the loot that is spawned when the chest is opened.

5.8. Shops

Shops are also a central part of the math system mentioned in chapter 4, as they subtly teach math by motivating the players to buy and sell items at different prices and with or without discounts. A shop is indicated in the game by an NPC called a *shopkeeper*. When the players move the mouse pointer over a *shopkeeper*, the cursor turns into a brown chest. When the *shopkeeper* is then clicked, the players automatically move into

its range if they are not already there. Then the shop window shown in Figure 5.12 opens. It contains various items available for purchase at the current player level, the quantity available for each, the price, and the number that will be added to the shopping list. The players can also switch between buying and selling by pressing the [*Wechsel zu Kaufen*], [*Wechsel zu Verkaufen*] buttons.

Also, the players can filter the items by clicking the corresponding buttons, e.g. [*Rüstung*], [*Tränke*], etc. To buy something, the players can click the [+] or [-] button to add or remove an item from their shopping list. If they have enough money to buy the corresponding items, they can click the [*Kaufen*] button and the items will be added to the players' inventory. It should be noted that the transaction is completed only when there is enough space in the inventory and that the stackable items are stacked and not placed in separate places. If the players do not have enough money, the total amount will be displayed in red and the [*Kaufen*] button will be disabled.

Selling items works similarly, with the difference that only the items that can be sold in the store are displayed if the players hajve them in their inventory. To close the shop, the players can click the cross in the upper right corner.

Figure 5.12.: Shop UI.

Before a *shopkeeper* is placed in the world, some configurations must be made. First, a name for the shop must be chosen. Next, the stock is set by adding items to the stock list and configuring them. Therefore, the initial stock of an item and the level at which the item is sold in the shop can be set. This is used to replenish the shop when a player reaches a new level. If 2 healing potions are set for level 1 and 4 for level 2, there will be 6 healing potions in the shop when the player reaches level 2.

Also, the default discount for an item and the sale percentage at which the item can be sold back to the shop can be set. This discount on the item can be increased at a higher level using the previously mentioned configuration in combination with this setting, so that, for example, the healing potion that costs 50 at level 1 is reduced by 10 percent at level 2, and then a potion costs only 45, which also applies to the potions from level 1.

The different selling percentages and default discounts for an item can be used to sell that item in different shops at different prices. Thus, the players are encouraged to do calculations and buy the items in a shop where they are cheap and sell them in a store where they are expensive, as mentioned in section 4.5.3.

Furthermore, a default selling percentage can be set for the shop, which is the percentage of money that the players will receive less for each item that they sell in that shop. The only difference from the previously mentioned item selling percentage is that this percentage can be set for the entire shop, which means that the same percentage should apply to every item, and the default percentage for each item can be left blank to speed up the creation of the shop. Finally, the maximum discount that players can get in this shop if they maximize the *Charisma* trait, can be set.

5.9. Enemies

An enemy is a character similar to the NPC, but with the difference that players can fight against it. In this game, there are different classes of enemies such as unarmed, soldiers, and archers, depending on the fighting style. This class also determines the basic stats of the enemy. There are also different enemy types such as skeletons, goblins, and guards, which currently only determine the appearance of the enemies, but not their stats. An example of enemies with different types in combination with individual classes is shown in Figure 5.13.

These enemies have various configuration options, so it is easy for the developer to create a large set of different enemies in a short time, which are now briefly described. Each enemy has a drop table that can be set regardless of class or type. There are also the following settings: the chase distance, which describes how far the enemy follows the players; the suspicion time, which is the time the enemy waits at the last point

Figure 5.13.: Different enemy types (goblins, skeletons, guards) and classes (unarmed, soldier, archer).

where it saw the player before they were out of range, after which the enemy returns to its starting position; a patrol path with different dwell times at the waypoints, which are visually represented in the editor to help the developer with placement; the patrol speed; the aggro cooldown; and the shout distance, which describes the radius at which the enemy alerts other enemies when it is attacked.

In addition, aggro groups can also be defined, which contain all enemies that should attack when an enemy nearby is attacked. This can be used, for example, if a player angers an NPC during a dialogue and then the whole village should become aggressive and attack the player. The various configuration options allow the developer to give the enemies dynamic behavior, making the game feel more natural than if the enemies were just standing around doing nothing.

5.10. Combat

The previously mentioned math content and items are needed to make the players strong for combat, which is essential for the entertaining part of the game.

As soon as the players hover the mouse cursor over a potential enemy, the cursor turns into a sword if they can fight it. To attack an enemy, the players only need to click on it with the left mouse button, whereupon the players automatically move into range if they are not already. After that, the players automatically attack until the enemy is dead, and move to the next enemy, which is randomly selected from the attacking enemies. The automatic attack was implemented to make combat a bit easier, as the

controls and camera are difficult to control at first, and the colliders of the enemies are quite small, so the players may click out of place, which can be frustrating. However, the players can also switch between enemies and run away by themselves and do not have to use automatic attacks, as they only serve as an aid

When an opponent or the player is hit, the damage value is displayed above the head of the respective character. After the player's first attack, the enemy's life bar is also displayed. This was implemented so that the world still looks immersive and players cannot see the enemies' life bars from afar and find them easily. When an enemy dies, the loot is spawned according to the respective drop table and the enemy will remain dead.

If the players die, they will respawn at a set respawn point in the level with 70 percent health, and the enemies they fought will also regenerate up to 70 percent health and will move back to their starting position over time. The players also do not lose loot when they die, as not to punish them for it. Also, different sounds are played for the different character classes when they get hit or die, along with corresponding animations

5.11. Controls

There are several controls for movement, user interface, and combat. First, the players can move by clicking on the ground, up to a certain distance that can be set by the developer, and only if the place they want to move to is accessible. For example, if they click on an island in the sea and there is no way to get there, they will not be able to move there. This is indicated by the cursor, if the place is reachable the cursor becomes a white cross, if it is not reachable it becomes a red cross. *Raycasts* and a *Navmesh* were used to implement the movement.

The camera is a 3rd person *cinemachine free look camera* that follows the players automatically. If the players want to zoom in or out, they can do so by scrolling the mouse wheel. To rotate the camera around the player, they must hold down the right mouse button and then move the mouse.

When the players move the mouse over NPCs, chests, or stores, the cursor changes to a speech bubble, a yellow square, or a chest. When the players then left-click on it to interact with it, the players move into range, if not already in range, and the corresponding UI opens. If an enemy is attackable, the cursor displays a sword when the players move the mouse over it.

To use an ability or a consumable item, the players must press the key shown on the action bar above the respective ability. From left to right, these would be the keys [Q], [W], [E], [R], [1], [2] as shown in Figure 5.2. Using an ability may require another

interaction, such as clicking on the ground where the ability is to be cast after the button is pressed.

There are also several user interfaces that can be opened by pressing the corresponding key and closed by clicking the cross at the top right. To open the pause window, [*P*] must be pressed; to open the quest menu, the players must click on the book at the bottom right of the screen; to open the inventory, [*I*] must be pressed; for the traits window, [*T*]; and for the stats window, [*S*].

Figure 5.14.: Main Menu.

Furthermore, there is also a main menu, which is shown in Figure 5.14. This is where the players can continue a game, create a new game by giving it a name and then clicking [*Create*], or open a saved game by clicking [*Load*] and selecting the appropriate file. The players can also play the tutorial by clicking [*Tutorial*], or quit the game by clicking [*Exit*]. In the settings menu, the sound and quality settings can be configured.

5.12. HUD

The *HUD* is used to display various information to the players. It is static on the screen so that the information remains visible during the game, as shown in Figure 5.15. In this game, the HUD consists of the purse, which displays the player's current money in the lower left, the quest menu in the lower right, the action bar in the lower center, and the player status in the upper left. The player's status bar shows the player's icon, current and maximum *Health*, current and maximum *Mana*, and current level and the experience needed to level up.

Figure 5.15.: In-game HUD

5.13. Saving and Scene Management

The game can be paused at any time by pressing the [*P*] key. Then the game is frozen, i.e. the time is stopped, and the pause menu, which is shown in Figure 5.16 is opened. There, the game can be saved by clicking on [*Speichern*] or [*Speichern & Schließen*]. This will save the entire game state, including dropped items, shops, chests, current health, mana, positions, money, inventory and equipment, dead enemies/players, experience, stats, traits, etc. When the game is closed, the players return to the main menu.
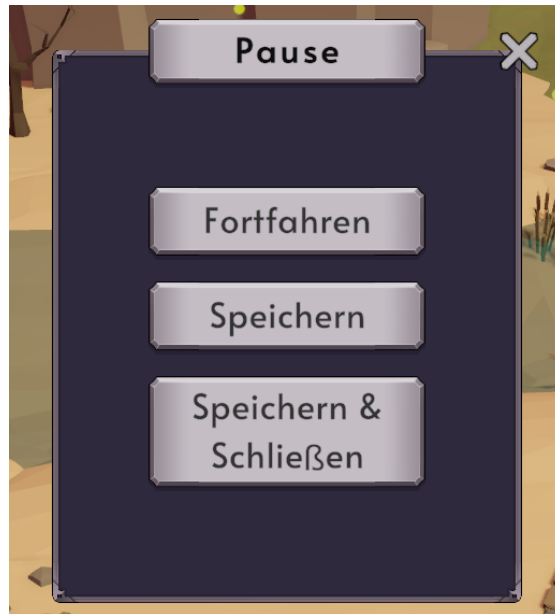
Figure 5.16.: Pause Menu.

The game is also saved when a new level or scene is loaded. For this, persistent objects which persist between scenes are used as an alternative to the singleton pattern. Portals are used for the transition between levels, through which the players can pass. As a transition, a white screen is displayed to provide enough time for the new scene to load, and then that scene is displayed. The players have set spawn points and are then spawned at that point and the corresponding level is loaded.

The saving system is implemented by using unique IDs for each object to be saved, collecting all these objects, and saving them using *JSON*.

5.14. Content

Currently, there are two tutorial levels and one prototype level with content, for a total of about one to one and a half hours of gameplay. Since the game has several game mechanics, a tutorial was developed to teach them to the players step by step. The prototype level on the other hand should serve as a proof of concept and contains an example quest line, the different features, and corresponding math content.

5.14.1. Tutorial

The tutorial explains the various mechanics and features of the game. It is linear, so the players learn the individual parts little by little. Some checkpoints verify that the players have understood the explained mechanics, and only then the tutorial continues. This has been implemented using an NPC that explains each feature to the players in a dialog, and once the dialog is finished, moves on to the next feature by going to a new point and changing the dialog. It is also implemented that for example when explaining chests, the players must first open a chest and bring the item inside to the NPC before they can proceed. The top-down view of the first tutorial level is shown in Figure 5.17 and the top-down view of the second tutorial level is shown in Figure 5.18.
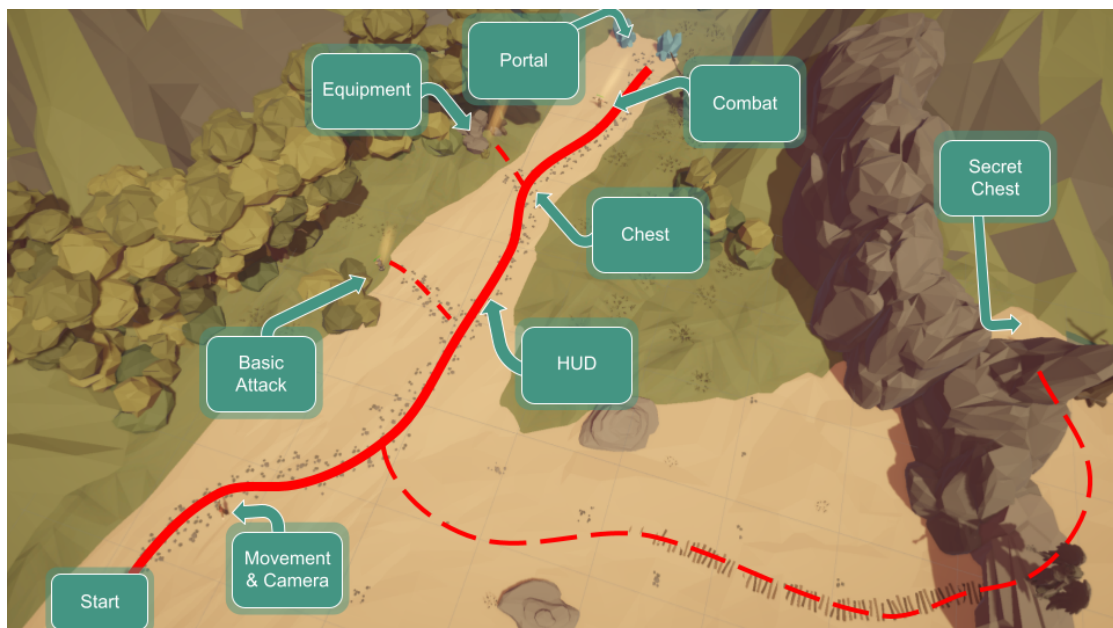

Figure 5.17.: First part of the tutorial with corresponding checkpoints.

The tutorial begins with the players talking to the NPC. First, the movement and camera controls are explained, then the basic combat is demonstrated by letting the players hit a dummy target. Next, the HUD is explained, which includes indicators for *Health, Mana, Experience* and *Money*. After that, a chest must be opened and an item collected and equipped to fight an enemy that blocks the way to the next tutorial level.

To reach the second level, the item from the chest and the loot from the enemy must be collected, which is ensured by a dialog condition that checks if the players have both items in their inventory and only then activates the portal. Then the portal is explained, through which the players can reach the next level, and the players must pass through it.
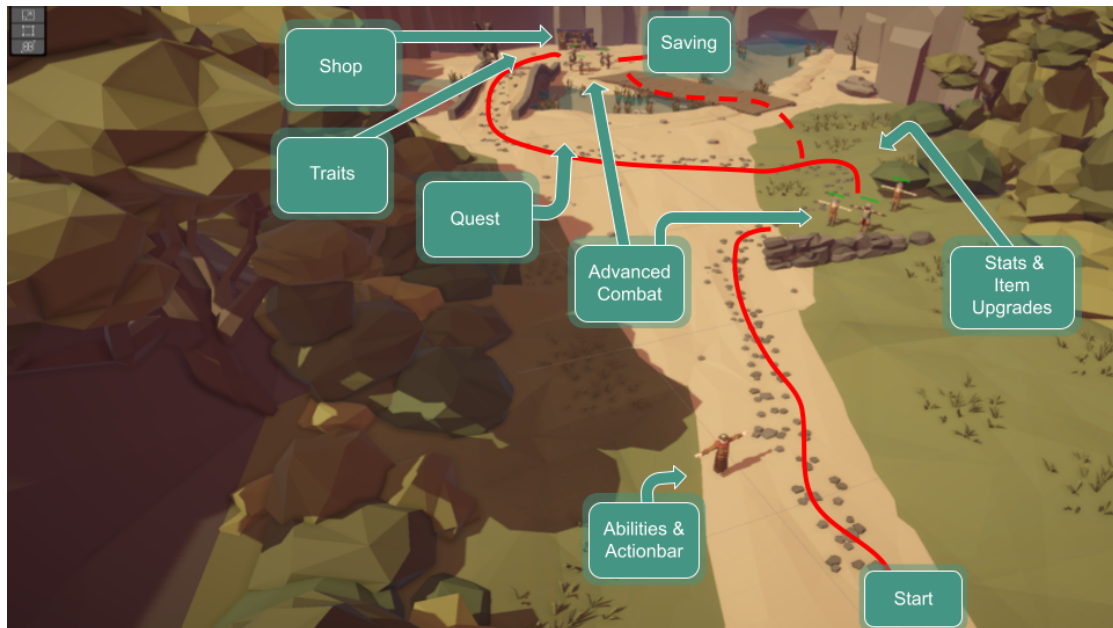

Figure 5.18.: Second part of the tutorial with corresponding checkpoints.

In the second part of the tutorial, first, the abilities and the action bar are explained, followed by a short combat sequence. This serves to reinforce the previously learned combat mechanics and give the players a chance to test the newly learned ability. An item is dropped from one of these enemies, which is then used to explain the players' stats. After that, a chest must be opened that contains a number that is used in combination with the previously obtained item to explain the item window and how the item is enhanced by bonus stats. Next, quests are introduced by explaining to the players what a quest is and what the quest window looks like. They are also given the task of collecting diamonds from nearby enemies, which in turn serves to deepen the combat mechanics and quests. After the players collect the diamonds, the quest is completed, and they receive a reward. This levels the players up, and therefore the traits are explained next, as the players gain trait points when leveling up. After that, shops are explained, and lastly, the players learn how to pause and save the game, which returns them to the main menu, where they can start the first level.

5.14.2. Level

The first level contains 13 hidden chests and one main quest line, where the players have to help a farmer chase dwarves away from his farm. The quest starts in a small village, where the farmer tells the players about his problem and asks them to follow him to his farm and help. On the way there, the players must first defeat some enemies in the forest and nearby ruins that want to prevent them from following the farmer. Once at the farm, the players must talk to the dwarves, who will explain their situation to them and ask them for apple pie so that they leave the farm without violence.

Figure 5.19.: Prototype level with chests, quest points, enemies and shops.

Therefore, the players set out to find an old granny who bakes the best apple pie in the area. This granny then gives them the task of calculating how many apples and eggs she needs to bake the cake for five dwarves because the recipe she has is meant for a different number of people. Once the players have given the correct answer, she sends them off to collect the apples from skeletons in a graveyard that they have stolen from nomads nearby. The eggs, on the other hand, the players must retrieve from the enemy soldiers in the mountain base where they have hidden them. Once the players have collected the apples and eggs and given them to granny, she hands them the cakes for the dwarves. The dwarves leave the farm peacefully after receiving the cake from the players, and the farmer thanks the players and rewards them.

But not only the quests are important, but also the chests that are hidden throughout the level that offer variety to the player and make his life easier by giving him items that make combat easier. Furthermore, there are shops in two places in the level where the players can buy items to get stronger with the money they get from quests, chests, and enemies. The top-down view with the most important parts of the level is shown in Figure 5.19.

6. Evaluation

To assess if and how well the game reached its goals, a user study with a focus on the player experience and the included math content was conducted. The used procedure of the study including the participants, the corresponding questionnaires, and the results will be described in detail in this chapter.

6.1. Participants

The target audience for the game were students in grades 6 to 8, and therefore study participants aged 10 to 14 were selected. Due to the choice of this age group, only 6 participants were found. 3 of the participants were female, and the other 3 were male, with 2 of the participants reporting previous experience with video games. Before participation, the parents of the participants were asked to sign an informed consent form to confirm that their child was allowed to participate in the study. The declaration, which is found in Appendix B, includes that the data of the participants will be treated anonymously and that the participants can stop at any time without suffering any disadvantage. Furthermore, also experts in game development and education were asked to play the game and give feedback.

6.2. Procedure

To provide a friendly and familiar environment, the study participants were allowed to choose the place where the study was conducted. Five of the participants chose to have the study done together at one of the participant's homes, and one chose to do it alone. As displayed in Figure 6.1 firstly, the participants were given a brief introduction to the study process, their questions were answered, and they were asked if they still wanted to participate. They were then requested to complete the first part of the questionnaire, which is shown in detail in Appendix A. Next, the workstation was prepared for testing the game. This included a laptop with a mouse, a headset, a pen, paper for any notes and the questionnaire. After the participants had settled in at the workstation, they were asked to play the game. They started with the two tutorial levels, and after they understood the basic mechanics of the game, they tested the prototype level. Overall,

the game process took between one and one and a half hours, depending on how the participants engaged with the content. Some took longer because they were exploring everything, trying to open all the chests and fight all the enemies, and some took less time because they were directly following the main quest. Throughout the process, participants were supervised, notes were taken on potential problems, and questions were answered. At the end of the game, the participants were asked to complete the remaining questionnaire and some more questions and comments from the participants were answered. In total, the process took between two and two and a half hours, depending on the participants, as shown in Figure 6.1.
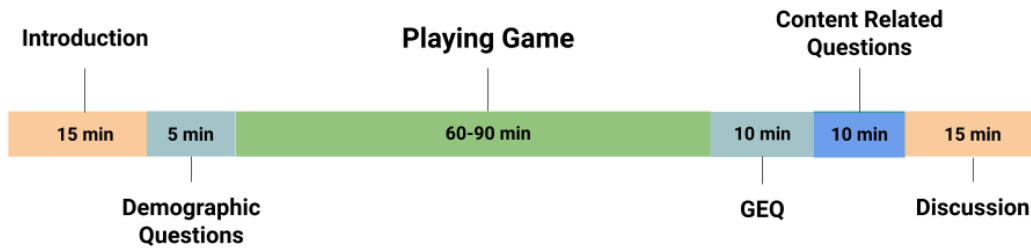

Figure 6.1.: Timeline of the conducted user study.

6.3. Questionnaire

The questionnaire used to evaluate the game consists of four parts, which are shown in detail in Appendix A. The first part included demographic questions such as age, gender, previous experience with video games, how much they like to engage with mathematics and games, and a mathematical question. The math question, which is also present in the game, was used to compare whether it makes a difference in which context the question is asked.

As a second part, the core module of the Game Experience Questionnaire (GEQ) was used. It consists of 33 questions and was developed by Poels (Poels et al. 2007) to evaluate the game experience. The module consists of seven components: *Competence, Immersion, Flow, Tension, Negative and Positive Affect*, and *Challenge*. For each of these components, 4-6 items (questions) are needed for a robust measure. For example, to evaluate the *Flow* component, the average score of questions 5, 13, 25, 28, and 31 from the core module was used.

To evaluate the content of the game, especially the mathematical content, 15 additional questions were developed. They focus on how the participants perceived the inclusion of the mathematical content, in which context they would play the game (at home, at school, etc.), how they liked the different aspects of the game and if they think the game could improve mathematical abilities or increase their motivation to engage with math. The last part of the questionnaire consists of open questions regarding what the participants liked or disliked and potential wishes and suggestions for improvement. The results of the evaluation of this questionnaire are described in the next section.

6.4. Results

First, the data of the GEQ was evaluated, as it represents the overall game experience. For this purpose, the answers to the individual questions were converted into scores between 0 and 4, with 0 representing *"not at all"* and 4 *"extremely"*. For each component, the average of the corresponding scores was calculated. The resulting scores of the respective components of the module are shown in Figure 6.2. It can be seen that the *Positive Affect* has a very high average score of 3.6, which is far above the average of the possible scores. The components *Negative Affect* and *Tension and Annoyance* on the other hand have a score of 0.3 which is far below the average. The scores for the *Competence, Immersion* and *Flow* components are also above the average score, whilst the score for the *Challenge* component is below.

The results regarding gender were extracted from the demographic questions and were used to subdivide the participants to see if there were differences in their perceptions of the game experience. As a result, the score for the *Flow* component for male participants was 2.9, far higher than the score of 1.6 for female participants. This is consistent with Poels results (Poels et al. 2007), where female participants also had lower scores on the *Flow* component. Female participants, on the other hand, had a higher score of 0.8 on the *Tension and Annoyance* component than males, which had a clear 0. Participants were also divided according to prior experience with video games, which turned out to make only a minimal difference.
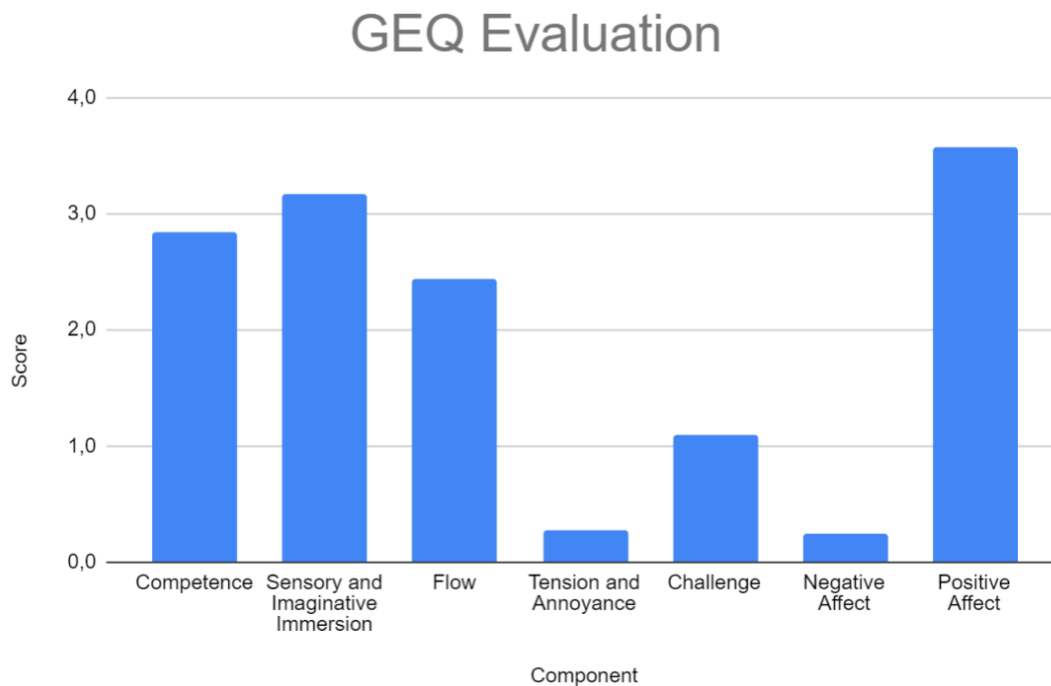
GEQ Evaluation

Figure 6.2.: Average score of GEQ components on a scale of 0 to 4, where 0 stands for "not at all" and 4 for "extremely".

In the third part of the questionnaire the possible scores ranged from 1 to 5 with 1 being *"do not agree at all"* and 5 being *"fully agree"*. The most important questions were the questions on how the participants liked the math content. The question asked was "I liked the inclusion of math in combination with *Element*", with the element being the respective math content element. It resulted in an average score of at least 4 out of 5 for each of the four ways in which math was included in the game as displayed in Figure 6.3. Furthermore, it shows that of the different ways math was included, *Chests* and *Item Upgrades* were liked most.

Also, the questions of whether the participants think that the game increases their motivation to engage with math and whether they can improve their math knowledge through the game achieved scores of 3.8 out of 5 which is displayed in Figure 6.4a. The highest scores were given to the game's world and style, with 4.7 and 4.8 out of 5, respectively, as shown in Figure 6.4b.
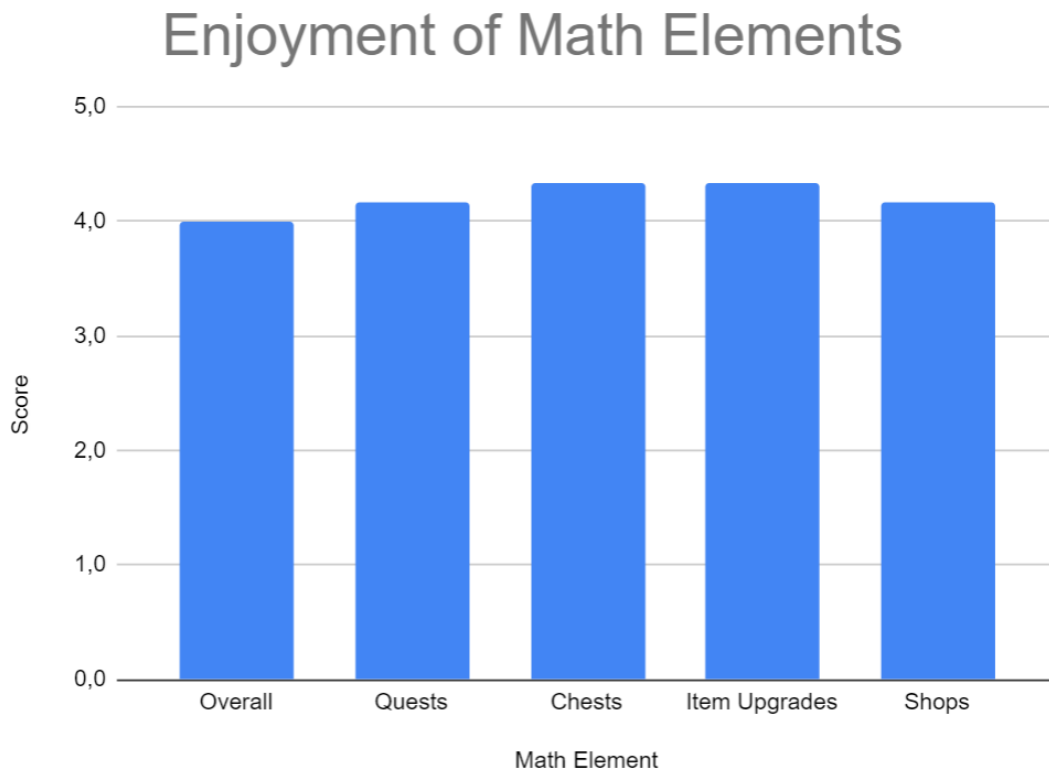
Enjoyment of Math Elements

Figure 6.3.: Average score of math elements,with scores ranging from 1 to 5, where 1 is "strongly disagree" and 5 is "strongly agree".

In the last part, the participants were asked what they liked most about the game, which answers were fighting against enemies and the graphics. What they disliked most was the camera and the movement, that there were no further levels and that they needed to run a long way back when they died. The participants also stated that they would play the game mostly in their free time and maybe use it as study help. In terms of mathematical content, most participants would not change anything, except two participants, one of whom wanted more mathematical content and the other who wanted simpler riddles. Other wishes they mentioned were a multiplayer mode, more levels, skins, and the possibility to play with the controller. The results will be analyzed and discussed in chapter 7 and future work to build up on those suggestions will be introduced in chapter 8.
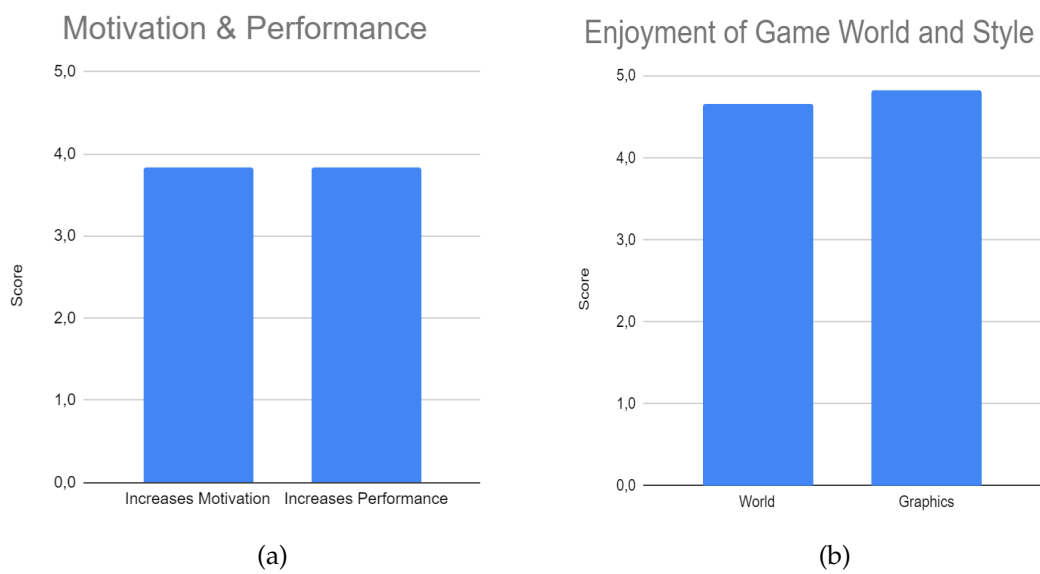
(a)   (b)

Figure 6.4.: Average score of the different elements, with scores ranging from 1 to 5, where 1 is "strongly disagree" and 5 is "strongly agree".

7. Discussion

It should be noted that the results of the study should be interpreted more as a tendency due to the small number of participants. The results of the evaluation show that the game affected the participants positively and not negatively. This is shown by the *Positive Affect* component scoring 3.6 out of 4, while the *Negative Affect* component has a score of 0.3. Participants also did not feel tense or annoyed, as indicated by a score of 0.3 for the *Tension and Annoyance* component. In addition, participants felt immersed in the game and were in the flow, which is supported by the corresponding components' scores of 3.2 and 2.4, which are also above the average of 2. The score of 2.8 for the *Competence* component furthermore indicates that the participants felt they had achieved something, and were euphoric and proud, which could support their motivation to play the game and engage with the mathematical content. These results can be considered a success, as they show that the game was liked by the participants and that the goal of immersion and game flow, as explained above, was achieved.

It was also found that the game is more tiring for females, as indicated by the higher scores compared to male participants in the *Tension and Annoyance* component. This probably also leads to the fact that the female participants were significantly less in the flow than the male participants. It should be kept in mind that little significance can be attributed to these results, as the two groups consisted of only 3 participants each, which is not enough to be statistically significant.

The evaluation also revealed that the challenge level was not that high for the participants, which means that the game needs to be better balanced, as the score of the *Challenge* component was only 1.1 out of 4. This could be achieved either by adjusting the difficulty of the mathematical puzzles or the opponents. Perhaps this could help players feel more in the flow, as this is the state in which the player's skill level matches the difficulty of the task, as described in section 2.2.

In addition, the evaluation showed that the participants liked the way mathematical content was integrated into the game, as the different elements had at least a score of 4 out of 5 as shown in Figure 6.3. Furthermore, the evaluation revealed that participants felt that the game would increase their motivation to engage with mathematics. Also, the participants stated that they would play the game in their free time and not only for study purposes, which also indicates that the game makes fun and is played voluntarily,

although it is a serious game. These results indicate that the main goal of the game, which includes that it is fun, the math content is well integrated and that it motivates players to engage with math topics, was achieved.

While supervising the participants during play, it was noticed that they had different play styles. Some tried to find all the chests and solve the riddles, others tried to fight all the time, and others followed the main quest and opened only the obvious chests and fought the enemies they must. This shows that the game offers multiple ways for different types of players to play and progress, as it was intended in the game design.

The game was also offered at the*Pizza Playtest* for testing by other game developers, but most of them were reluctant to play it because it was declared a serious game. Those who did play it were pleasantly surprised that it was fun despite the math content, and that the math content was included voluntarily. Since the *Pizza Playtest* was a community event, several people were standing next to the players and the players were always happy to find a chest because it was fun to solve the puzzle together and see who was smart enough to solve it. The biggest problem was that most people had not played the tutorial and did not know what to do, or did not know the key bindings and could not open the inventory and upgrade the items.

It is to mention that the game aims to improve the mathematical skills of the players over a longer period of time and not from one second to the next, and therefore it was not possible to test this improvement concretely. This would require a study over a longer time, as explained in chapter 8. However, participants stated that the game would increase their math skills as described in chapter 6. The evaluation also revealed that some participants had problems with the camera and controls and would like to see additional content such as a multiplayer mode and skins. These potential improvements and other ideas to extend the project in the future will be discussed in more detail in the next chapter.

8. Future Work

Since the scope of this project was limited by the time available, not everything that would have been possible could be incorporated into the game. Therefore, the goal was to create a prototype that would provide answers to the research question and could be considered a solid foundation for future development. This was achieved, as discussed in chapter 7, but there is still room for improvement, which will be described in this chapter, in addition to other features that can enhance the game.

8.1. Content

As mentioned above, additional content was requested, including more chests, additional enemies, and more levels. The possible solutions to the problems encountered during the study and possible extensions to further improve the gameplay are presented below.

Controls: The most criticized part of the game are the camera and movement controls, which are a bit difficult to master. Since this takes up a large part of the gameplay, it really should be reworked. The desired movement scheme was to move with the [*W*][*A*][*S*][*D*] keys and to control the camera with the mouse. Right now, clicking is used not only for movement but also for combat and interactions. This rework would require a lot of time and therefore could not be implemented during the thesis, however, it would be a beneficial improvement for the future. Also, the shortcut keys could be replaced with more intuitive ones, such as [*Exit*] instead of [*P*] to open the menu.

Checkpoints: When observing participants during the game, it was noticed that when they died, they would respawn at the beginning of the level and have to run all the way back to the spot where they died. This can be very annoying as it takes quite a lot of time and may be frustrating for players who are not so good and die frequently. To overcome this issue, checkpoints could be added throughout the game that serve as respawn points. Such a checkpoint could be an NPC asking a question, and if the question is answered correctly, the point is unlocked and activated, and if the players die, it serves as a new respawn point.

Limited Attempts: To prevent players from simply trying all possible answers to a problem on a chest, the number of attempts could be limited. For example, players could be given only 3 chances to enter the correct solution, and if they do not succeed, the chest is locked for a certain time, e.g. one hour. After this time, players will have 3 more chances to enter the correct solution, otherwise, they will have to wait again. This is to encourage players to think about a solution first before entering it, rather than just guessing. However, it also does not overly penalize players since the chest is not locked forever, and they can still try to get the loot after a certain amount of time. It could also be implemented that the players can buy attempts with the in-game currency if they want to try again.

Item Upgrade Slots: Another idea would be to add more slots to the item upgrade window and unlock the slots as the players level up. For example, at level 1 only one slot is available to enter a number, and at level 2 two more slots are unlocked to enter an additional sign and number. This should motivate the players to recalculate the current bonus values of their items by adding additional math items to increase their stats as they level up. Also, this would provide the players with an additional feeling of progression in the game.

Explanatory Scenes: Another idea to incorporate mathematical content would be animated scenes that are structured like explanatory videos and teach the players mathematical concepts. However, this would be a very time-consuming process that should be well-planned in advance. In addition, quests could be included that require the players to interact with the environment. For example, an NPC could ask the players to enclose an area as large as possible for their horses with a certain number of fences, and the players would then have to place the fences in that location. Afterward, it would be evaluated whether the players had succeeded, and they would receive an appropriate reward. If it is not clear to the players how to achieve an optimal solution, an NPC could explain it to them if asked. This would be an important part of teaching math at a level where the players actually learn to understand the use cases and will be able to decide which concepts to use to achieve the best result.

Achievements: To further motivate the players and give them additional feedback, achievements could be built into the game. For example, the players could receive an achievement for opening all the chests in a level or for solving a puzzle with only a few attempts. Likewise, a player who completes all side quests in a level could receive achievements to motivate the player to continue side quests and open chests to engage with mathematical content.

UI and FX: Another part that could be reworked would be the user interface, which could be replaced with a more appealing one. Also, additional special effects, sounds, NPCs, and animations could be added to make the game more lively and appealing. Moreover, more details could be added to the levels, such as grass, birds, and so on, to create a more immersive world.

Crafting System: Also, a crafting system could be added to the game, where players will have to collect ores, wood, and other crafting materials that can then be used to level up items or to craft helpful items like potions. Crafting an item requires the materials and a resource such as fairy dust. To craft the item, an equation must be solved that consumes a resource when the confirmation button is clicked. If the answer is correct, the item is crafted, if it is incorrect, players have the option to repeat the crafting process until they run out of the resource, in this case, fairy dust. This would ensure that players do not try to test all possible answers to the equation, but think about it before they submit an answer.

8.2. Customization

To better immerse players in the game and make them more attached to their character, character customization could be added. This feature could be implemented by allowing players to choose their names at the beginning of the game, which would then be displayed in dialogs and cut scenes. In addition, the character itself could also be customized by allowing players to choose a hairstyle and other characteristics to create a character to their liking. Another idea that would allow players to customize their character would be to add 3D versions of the items they have equipped and display them on the character in-game. For example, if the character has a legendary helmet equipped that looks fantastic, the helmet would be displayed on the in-game model of the character. Players could also be given the option to change the keyboard shortcuts so that they can play the game according to their preferences and not have to learn all the new keyboard shortcuts used in the game, even though this game has tried to make them as similar as possible to what is common in this genre.

8.3. Multiplayer

The option to play together with other players could also be added. This could be done either by including different leaderboards or a multiplayer mode. For example, the leaderboards could be based on chests, i.e. for each chest opened, it could be displayed how the players did in terms of time and attempts needed to open the chest compared

to other players. Another leaderboard at the end of each level could compare how many chests players found, which could motivate exploration and the opening chests, how many times players died, how quickly they killed enemies, or how quickly they finished the level. This could also be done simply by adding a statistic for each level without a leaderboard, allowing each player to follow their preferred play style without being measured too much. The multiplayer aspect could be improved by adding an arena where players can compete against each other either as a group or 1v1, showing off their current equipment. This would also increase motivation to engage in the math content, such as opening more chests, getting better items, and getting stronger, since everyone wants to become the best player. A multiplayer mode could also be added, where players can play levels together, so that one is searching for chests, for example, and the other is taking care of the battles and item optimization. A trade function between players could as well be introduced so that these players can exchange items.

8.4. Other Devices

Another suggestion from some participants was the possibility to play the game with controllers. This feature would be relatively easy to add since Unity's new input system was used for input controls, so it would be straightforward to add controllers as a new input method. The problem with this would be that movement would have to be done with buttons instead of clicks, which might not be as convenient. This would open up the game to a new player base, as not everyone plays games on the PC, but also uses other platforms like Playstation, Switch, or Xbox. The game could also be offered for touch devices, but it's important to keep in mind that the game is currently not optimized for mobile devices in terms of performance, and the input would also have to be adjusted accordingly.

8.5. Instructor Input

Another idea that could be used to improve the mathematical content in the game would be an interface for instructors. There, a teacher or parent could select the mathematical content from given sets on various topics such as geometry or equations, or create sets of mathematical problems themselves. These selected problems would then be used for the puzzles in the chests and possibly for the crafting system, should it be introduced, to tailor the content to individual players and their current learning level. For example, if the topic in school is currently geometry, parents or teachers may set this as the active topic, and accordingly, problems on this topic would then be used in the levels. In this way, students would have the opportunity to review and

reinforce the content they are currently learning, which would help them understand it better. The given sets of topics could also be supplemented and modified to better adapt the content to the particular abilities of the students. Another point that could be specified by the teachers would be the difficulty level of the tasks or the game, as they can better assess their students and their abilities. For example, a student who is not so good at math could get more easy and medium chests with corresponding problems in the level, while a student who is good at math could get more difficult chests and tasks. If a player is not strong at playing video games and has difficulty with the combat, the enemies could be adjusted by teachers to make the game more enjoyable and motivating for the player.

8.6. Data Collection

Another way to improve learning outcomes could be to collect in-game data and then analyze it to provide statistics and feedback to instructors or even the players themselves. For example, data could be collected on how long and how many attempts it took players to solve certain mathematical tasks within chests. This data could be visualized with statistics or graphs so that teachers can identify which tasks students had the most difficulty with or what problems certain students were having. Teachers could use this feedback to individualize the content for specific students so that the content can be adapted to their weaknesses. This can ensure that students can continue at their own pace and help to create a better-individualized learning path for them. Parents could also use this data to arrange tutoring for their children if they have major comprehension problems or difficulties with certain subjects. This could be shown with statistics on the players' average performance on each task, and then show a comparison between each student's performance and that of the average student, giving insight into the student's learning level.

In addition, data could also be collected from gameplay, such as mouse movements, the start, and end of a gaming session, or other variables such as enemies killed, deaths, and quests completed. This data can then be used to provide general statistics about the game, such as how many players played the game, how long they played, when players stopped playing, or how much content they completed in one session. This helps to determine how players interact with the game, what content they are most engaged with, and where they stop, which can then be improved and used to enhance the overall game experience. The data can also be used to gather information about how engaged students are with different types of math content and whether optional content is played at all.

8.7. Difficulty Adaptation

To keep players in the flow state, the difficulty of the tasks must match the players' ability, as described in section 2.2. For example, if players try to solve a task and find that they are unable to do so and are not given any hints or instructions, they may feel frustrated or disappointed. On the other hand, players might feel bored if they progress in the game and the tasks they have to solve are too easy. To overcome this problem and provide players with challenges that match their abilities, in-game data could be collected and then used to personalize the game for each player. The difficulty of math problems and opponents could then be adapted to individual players, for example by offering hints or easier chests for players who took many tries to open a chest.

There are already several methods for dynamically adjusting content that could be used in this project. For example, Spronck uses dynamic scripts to adapt the skills of enemies based on the players' skill level to keep the players in the game flow (Spronck et al. 2006). Another adaptation engine selects tasks based on a player model defined by skill relevance, entertainment value, learning styles covered, difficulty, and so on. The algorithm then selects the optimal task by calculating the cost of task sequences (Bellotti et al. 2009).

8.8. Long Term User Study

Another important aspect to obtain more significant results about the effectiveness of the methods used in this game for teaching mathematics would be a long-term study. The evaluation of this study would provide information about the learning effect and possible improvements. In addition, it could be investigated whether the optional content is played at all and whether the voluntary nature of the content increases the learning effects. To do this, participants could be divided into two subgroups, half of which are required to engage with the mathematical content and the other half of which can engage with it voluntarily. The learning outcomes and game experiences of both groups can then be evaluated to answer the question of which group has a better game experience or achieves greater learning success. In addition, the motivation of the respective groups to play the game voluntarily in their free time could also be evaluated.

9. Conclusion

In this thesis, a serious game for teaching mathematics in secondary education was proposed. The goal was to make the game entertaining, engaging, and immersive. In addition, the mathematical content should be integrated in such a way that it can be played voluntarily, which should help motivate players to engage with mathematical topics and improve learning outcomes in the long term. The proposed research question was divided into four sub-questions, which were addressed throughout the thesis and are briefly summarized in this chapter.

In the beginning, important terms and concepts were first introduced, and related works were analyzed to establish a solid knowledge base and to identify design principles that could help to make the game more interesting and motivating for the players. The game concept was then developed by defining the requirements and comparing different design options to determine which ones would contribute the most towards achieving the main goal of the game. The choices made at this stage were based on the previously researched design principles, namely to engage and involve the players in the game through a hero and an exciting story, to immerse them in the game, keep them in the flow of the game, and to provide intrinsic and extrinsic motivation to engage with the serious content of the game.

The mathematical content was also integrated in an immersive way to make the game enjoyable and to motivate players to engage with the mathematical content. This was achieved by integrating the mathematical content in such a way that it can be played voluntarily, but rewards players by making them stronger. The integration was realized through chests, quests, shops, and item upgrades to provide different options for different types of players.

Once the game concept was completed, a prototype of the game called *Kingdom of Math* (Marsoner 2022) was implemented, following the design decisions made in the game concept phase and established programming patterns. To find out if the game achieved its goals, a user study was conducted to evaluate the game experience and the inclusion of mathematical content. The results of the study showed that the game had positive effects, the players were immersed, liked the way the mathematical content was included, felt motivated to engage with mathematical topics, and indicated that the game would improve their mathematical skills, which contributed to the conclusion that the goal was achieved.

However, due to the small number of participants, these results can only be considered as a tendency and a long-term study would be needed to obtain statistically relevant results. This and the problems discovered during the study, mainly related to the control scheme of the game, were noted, and possible improvements were discussed. In addition, possible options for expanding the project in the future were presented to further enhance the learning experience, including additional content, instructor input, personalization, and adaptation.

Overall, this work has shown that the approach of teaching mathematics on a voluntary and playful basis has a positive impact on students, although there is still room for improvement.

List of Figures

Bibliography

Adobe Systems (2008). *Mixamo*. URL: shorturl.at/hlvPV (visited on 12/09/2022).

Afza Shafie, W. F. W. A. (2011). *Math Quest*. Game [Web, iOS, Android]. Available under: shorturl.at/dmF13.

Artmedia (2004). *KleineSchule - Matherätsel*. URL: shorturl.at/qOUY8 (visited on 09/15/2022).

Autonome Provinz Bozen (2021). *Rahmenrichtlinien für die Grund- und Mittelschule in Südtirol*. URL: shorturl.at/fKMU4 (visited on 10/08/2022).

Backlund, P. and M. Hendrix (2013). "Educational games-are they worth the effort? A literature survey of the effectiveness of serious games." In: *2013 5th international conference on games and virtual worlds for serious applications (VS-GAMES)*. IEEE, pp. 1–8.

Bellotti, F., R. Berta, A. De Gloria, and L. Primavera (2009). "Adaptive experience engine for serious games." In: *IEEE Transactions on Computational Intelligence and AI in Games* 1.4, pp. 264–280.

Blizzard Entertainment (2022). *Diablo Immortal*. Game [Andriod, iOS]. Available under: shorturl.at/isEQT.

Bopp, M. (2007). "Storytelling as a motivational tool in digital learning games." In: *Didactics of microlearning. Concepts, discourses and examples*, pp. 250–266.

Bormann, M., K. Heyligers, M. Kerres, and J. Niesenhaus (2008). "Spielend lernen! Spielend lernen? Eine empirische Annäherung an die Möglichkeit einer Synthese von Spielen und Lernen." In: *Workshop Proceedings der Tagungen Mensch & Computer 2008, DeLFI 2008 und Cognitive Design 2008*. Logos Verlag.

BOXOPHOBIC (2019). *FREE Skybox Extended Shader*. Version v. 1.9.0, 2022. URL: shorturl.at/kHMY5 (visited on 12/09/2022).

Cabalo, J. M. S. S. and R. G. Panopio (2017). "Evaluation of 'Prodigy', an online educational game-based platform on mathematics." In: *Learning technologies in education: Issues and trends*, p. 130.

Chen, J. (2007). "Flow in games (and everything else)." In: *Communications of the ACM* 50.4, pp. 31–34.

Chorianopoulos, K., M. N. Giannakos, and N. Chrisochoides (2014). "Design principles for serious games in mathematics." In: *Proceedings of the 18th Panhellenic Conference on Informatics*, pp. 1–5.

Connolly, T. M., E. A. Boyle, E. MacArthur, T. Hainey, and J. M. Boyle (2012). "A systematic literature review of empirical evidence on computer games and serious games." In: *Computers & education* 59.2, pp. 661–686.

Csikszentmihalyi, M. (1990). *Flow: The psychology of optimal experience.* Vol. 1990. Harper & Row New York.

Deterding, S., D. Dixon, R. Khaled, and L. Nacke (2011). "From game design elements to gamefulness: defining" gamification"." In: *Proceedings of the 15th international academic MindTrek conference: Envisioning future media environments*, pp. 9–15.

Dörner, R., S. Göbel, W. Effelsberg, and J. Wiemeyer (2016). *Serious games.* Springer.

Duolingo, I. (2011). *Duolingo.* URL: shorturl.at/ntBJY (visited on 12/02/2022).

Egenfeldt-Nielsen, S. (2011). *Beyond edutainment: Exploring the educational potential of computer games.* Lulu.com.

Engels, S. A. (2021). "Design Factors for Educational Video Games." PhD thesis. University of Toronto (Canada).

GameDev.tv (2014). *GameDev.tv.* URL: shorturl.at/lmFPQ (visited on 12/09/2022).

Gee, J. P. (2009). "Deep learning properties of good digital games: How far can they go?" In: *Serious games.* Routledge, pp. 89–104.

Graesser, A. C. and V. Ottati (2014). "Why stories? Some evidence, questions, and challenges." In: *Knowledge and memory: The real story* 8, pp. 121–132.

Jackson, S. A. and H. W. Marsh (1996). "Development and validation of a scale to measure optimal experience: The Flow State Scale." In: *Journal of sport and exercise psychology* 18.1, pp. 17–35.

Jason Skoubye (2019). *Mage Math.* Game [PC]. Available under: shorturl.at/efst7.

Kelleher, C., R. Pausch, and S. Kiesler (2007). "Storytelling alice motivates middle school girls to learn computer programming." In: *Proceedings of the SIGCHI conference on Human factors in computing systems*, pp. 1455–1464.

Krita Foundation, KDE (2005). *Krita.* Tool [PC]. Version v. 5.1.3, 2022. Available under: shorturl.at/xDT46.

Layer Lab (2019). *GUI PRO Kit - Fantasy RPG.* URL: shorturl.at/kEJQ6 (visited on 12/09/2022).

Lyons, C. (2020). "Identifying Opportunities And Challenges Of Using Prodigy Math In A Sixth Grade Math Classroom." Retrieved from Sophia, the St. Catherine University repository website: https://sophia.stkate.edu/maed/373.

Malone, T. W. (1981). "Toward a theory of intrinsically motivating instruction." In: *Cognitive science* 5.4, pp. 333–369.

Marsoner, L. (2022). *Kingdom of Math.* Game [PC]. Available under: shorturl.at/mrzR1.

Michael, D. R. and S. L. Chen (2005). *Serious games: Games that educate, train, and inform.* Muska & Lipman/Premier-Trade.

Mind Design Marketing and Communication Pvt. Ltd. (2021). *Game of Physics*. Game [Android, iOS]. Available under: `shorturl.at/cW257`.

Nacke, L. (2009). "Affective ludology: Scientific measurement of user experience in interactive entertainment." PhD thesis. Blekinge Institute of Technology.

Nakamura, J. and M. Csikszentmihalyi (2002). "The concept of flow." In: *Handbook of positive psychology*, pp. 89–105.

ovos (2014). *Ludwig*. Game [PC]. Available under: `shorturl.at/iwCMR`.

Plecher, D. A. and J. Borowski (2021). "Work-In-Progress-Mathstation - A Grade School Math Supplement Serious Game." In: *2021 7th International Conference of the Immersive Learning Research Network (iLRN)*, pp. 1–3. DOI: `10.23919/iLRN52045.2021.9459416`.

Poels, K., Y. de Kort, and W. IJsselsteijn (2007). *D3.3 : Game Experience Questionnaire: development of a self-report measure to assess the psychological impact of digital games*. English. Technische Universiteit Eindhoven.

Prodigy Education Inc. (2011). *Prodigy Math*. Game [PC,Andriod,IOS]. Available under: `shorturl.at/AMQW5`.

Rieber, L. P. (1996). "Seriously considering play: Designing interactive learning environments based on the blending of microworlds, simulations, and games." In: *Educational technology research and development* 44.2, pp. 43–58.

Ruske and Pühretmaier (1999). *Physikus*. Game [PC]. Available under: `shorturl.at/fgqUY`.

Seery, M. D., J. Blascovich, M. Weisbuch, and S. B. Vick (2004). "The relationship between self-esteem level, self-esteem stability, and cardiovascular reactions to performance feedback." In: *Journal of personality and social psychology* 87.1, p. 133.

Sinclair, J. (2011). "Feedback control for exergames." PhD thesis. Edith Cowan University.

Spronck, P., M. Ponsen, I. Sprinkhuizen-Kuyper, and E. Postma (2006). "Adaptive game AI with dynamic scripting." In: *Machine Learning* 63.3, pp. 217–248.

Staatsinstitut für Schulqualität und Bildungsforschung (2022). *LehrplanPLUS*. URL: `shorturl.at/mvGP2` (visited on 10/09/2022).

Sweetser, P. and P. Wyeth (2005). "GameFlow: a model for evaluating player enjoyment in games." In: *Computers in Entertainment (CIE)* 3.3, pp. 3–3.

Synty Studios (2014). *Synty Studios*. URL: `shorturl.at/DGRS2`.

TiMer Games (2021). *Aron's Adventure*. Game [PC]. Available under: `shorturl.at/loqxK`.

– (2022). *Aron's Adventure Website*. URL: `shorturl.at/cflq4` (visited on 12/11/2022).

Wagner, M. G. and T. Wernbacher (2013). "Iterative didactic design of serious games." In: *FDG*, pp. 346–351.

Wernbacher, T., A. Pfeiffer, M. Wagner, and J. Hofstätter (2012). "Learning by playing: Can serious games be fun?" In: *European conference on games based learning*. Academic Conferences International Limited, p. 533.

Wong, W. L., C. Shen, L. Nocera, E. Carriazo, F. Tang, S. Bugga, H. Narayanan, H. Wang, and U. Ritterfeld (2007). "Serious video game effectiveness." In: *Proceedings of the international conference on Advances in computer Track changes is on SCHOOL OF COMPUTATION, INFORMATION AND TECHNOLOGY - INFORMATICS TECHNICAL UNIVERSITY OF MUNICH Bachelor's Thesis in Informatics: Games Engineering Developing a Serious Game to teach Mathematics Laura Marsoner SCHOOL OF COMPUTATION, INFORMATION AND TECHNOLOGY - INFORMATICS TECHNICAL UNIVERSITY OF MUNICH Bachelor's Thesis in Informatics: Games Engineering Developing a Serious Game to teach Mathematics Entwicklung eines Serious Game um Mathematik zu lehren Author: Laura Marsoner Supervisor: Prof. Gudrun Klinker, Ph.D. Advisor: Dr. David A. Plecher Submission Date: 15.12.2022 entertainment technology*, pp. 49–55.

A. Questionnaire

Demografische Daten

Zu welcher der nachfolgenden Alterskategorien gehören Sie?
- ☐ 8 oder jünger
- ☐ 9-10
- ☐ 11-12
- ☐ 13-15
- ☐ 15-25
- ☐ 25 oder älter

Bitte geben Sie Ihren Beruf an:

[   ]

Bitte geben Sie Ihr Geschlecht an:
- ☐ Männlich
- ☐ Weiblich
- ☐ Anders (Bitte angeben)_____

Haben Sie schon Erfahrung mit Videospielen?
- ☐ Ja
- ☐ Nein

Falls Ja, mit welchen?

[   ]

Auf einer Skala von 1 bis 10, wie gerne beschäftigen Sie sich mit Videospielen?
1 gar nicht gerne - 10 äußerst gerne

[   ]

Auf einer Skala von 1 bis 10, wie gerne beschäftigen Sie sich mit Mathematik?
1 gar nicht gerne - 10 äußerst gerne

[   ]

Mathe Frage

Für 10 Kuchen braucht man 18 Äpfel, wieviele Äpfel braucht man für 5 Kuchen?

[   ]

Für 12 Kuchen braucht man 36 Eier, wieviele Eier braucht man für 5 Kuchen?

[   ]

1

Game Design Fragebogen

Bitte geben Sie anhand der Skala für jede der folgenden Aussagen an, wie Sie sich während des Spielens gefühlt haben.

	gar nicht	ein wenig	mittel mäßig	ziem lich	außer ordent lich
1. Ich fühlte mich zufrieden					
2. Ich fühlte mich geschickt					
3. Ich war an der Geschichte des Spiels interessiert					
4. Ich fand es lustig					
5. Ich war voll und ganz mit dem Spiel beschäftigt					
6. Ich fühlte mich glücklich					
7. Das Spiel machte mir schlechte Laune					
8. Ich habe über andere Dinge nachgedacht					
9. Ich fand es ermüdend					
10. Ich fühlte mich kompetent					
11. Ich dachte es sei schwierig					
12. Das Spiel war ästhetisch ansprechend					
13. Ich habe alles um mich herum vergessen					
14. Ich fühlte mich gut					
15. Ich war gut darin					
16. Ich fühlte mich gelangweilt					
17. Ich fühlte mich erfolgreich					
18. Ich fühlte mich phantasievoll					
19. Ich hatte das Gefühl, dass ich Dinge erforschen könnte					
20. Das Spiel hat mir Spaß gemacht					

2

---

	gar nicht	ein wenig	mittel mäßig	ziem lich	außer ordent lich
21. Ich habe die Ziele des Spiels schnell erreicht					
22. Ich fühlte mich verärgert					
23. Ich fühlte mich unter Druck gesetzt					
24. Ich fühlte mich gereizt					
25. Ich habe die Zeit aus den Augen verloren					
26. Ich fühlte mich herausgefordert					
27. Ich fand es beeindruckend					
28. Ich war sehr in das Spiel vertieft					
29. Ich fühlte mich frustriert					
30. Das Spiel bot eine reichhaltige Erfahrung					
31. Ich habe die Verbindung zur Außenwelt verloren					
32. Ich fühlte Zeitdruck					
33. Ich musste mich sehr anstrengen, um das Spiel zu schaffen					

3

	stimme überhaupt nicht zu	stimme nicht zu	stimme weder zu noch lehne ich ab	stimme zu	stimme voll und ganz zu
Die Einbindung von Mathe in das Spiel insgesamt hat mir gefallen					
Die Einbindung von Mathe in Kombination mit Quests hat mir gefallen					
Die Einbindung von Mathe in Kombination mit Truhen hat mir gefallen					
Die Einbindung von Mathe in Kombination mit Gegenstand Upgrades hat mir gefallen					
Die Einbindung von Mathe in Kombination mit Händlern hat mir gefallen					
Ich würde das Spiel wieder spielen					
Ich würde das Spiel in meiner Freizeit spielen					
Ich würde das Spiel als Lernunterstützung spielen					
Ich würde das Spiel in der Schule spielen					
Die Welt in der das Spiel spielt hat mir gefallen					
Das Spiel erhöht meine Motivation mich mit Mathe zu beschäftigen					
Ich kann durch das Spielen des Spiels meine Mathekenntnisse verbessern					
Die Grafik/der Stil vom Spiel hat mir gefallen					
Ich würde das Spiel an meine Freunde weiterempfehlen					
Ich würde die Rätsel mit Freunden zusammen lösen					

4

Was hat dir am Spiel am besten gefallen?

```



```

Was hat dir am Spiel gar nicht gefallen?

```



```

Wie würdest du das Spiel verwenden? (als Lernhilfe, in der Freizeit,...)

```



```

Was würdest du an der Art, wie Mathe in das Spiel eingebunden ist, verändern/verbessern?

```



```

Wenn du etwas in das Spiel einfügen könntest, was wäre das?

```



```

Wie könnte man das Spiel besser machen?

```



```

Sonstige Ideen und Vorschläge:

```



```

5

B. Declaration of Consent

Einwilligungserklärung zur Teilnahme an der Studie zum Lernspiel
„Kingdom of Math"

Liebe Eltern,

Im Folgenden werden Sie als Eltern oder gesetzlicher Vertreter sowie Ihr Kind über das Ziel und den Ablauf der Studie informiert. Bitte lesen Sie sich die folgenden Informationen und Erklärungen sorgfältig durch und stellen Sie Fragen, sollten Sie oder ihr Kind welche haben. Wenn Ihr Kind teilnehmen möchte und Sie mit der Teilnahme Ihres Kindes einverstanden sind, würden wir Sie bitten, dass Sie und Ihr Kind die Einwilligungserklärung unterschreiben und diese am Durchführungstag der Studie mitbringen.

Ziel der Studie

Die Studie wird im Rahmen der Bachelorarbeit „Developing a Serious Game to teach Mathematics" durchgeführt. Das Ziel dieser Studie ist es, herauszufinden inwiefern sich das Serious Game „Kingdom of Math" zum beibringen von mathematischen Inhalten eignet. Es ist vor allem interessant wie Kinder die eingebauten Inhalte wahrnehmen, ob das Spiel Spaß macht/interessant ist, ob die mathematischen Inhalte beim Verständnis von Grundprinzipien helfen und ob sie die allgemeinen mathematischen Fähigkeiten der Kinder langfristig verbessern könnten.

Beschreibung der Studie

Falls Sie sich entschließen, an der Studie teilzunehmen, werde ich Sie einmal einladen/an einem vereinbarten Termin besuchen und die Studie durchführen.

Der Ablauf der Studie sieht wie folgt aus und sollte maximal 2 Stunden in Anspruch nehmen:

Die Teilnehmer werden gebeten einen Fragebogen mit verschiedenen Fragen zu mathematischen Themen auszufüllen. Daraufhin werden die Teilnehmer gebeten ein Spiel spielen. Abschließend werden die Teilnehmer nochmals einen Fragebogen zum Spiel ausfüllen und einen mit mathematischen Fragestellungen.

Die Teilnahme an der Studie ist freiwillig. Sie und Ihr Kind haben zu jeder Zeit (auch während der Studie) die Möglichkeit die Einwilligungserklärung zu widerrufen und die Teilnahme an der Studie abzubrechen. Eine Verweigerung der Einwilligung oder ein anschließender Widerruf hat keine Folgen. Hierdurch entstehen Ihnen oder Ihrem Kind in keinster Weise Nachteile. Die Teilnahme an der Studie ist freiwillig. Sie und Ihr Kind haben zu jeder Zeit (auch während der Studie) die Möglichkeit die Einwilligungserklärung zu widerrufen und die Teilnahme an der Studie abzubrechen (Art 7 Abs. 3 DSGVO). Eine Verweigerung der Einwilligung oder ein anschließender Widerruf hat keine Folgen. Hierdurch entstehen Ihnen oder Ihrem Kind in keinster Weise Nachteile.

Risiko und mögliche Unannehmlichkeiten

Die Prozedur beinhaltet lediglich ein geringes Risiko: Das Spielen des Spiels könnte Ihr Kind ungewohnt sein und dadurch leicht irritieren. Sie können jederzeit die Teilnahme entweder vorübergehend oder dauerhaft unterbrechen.

Falls Ihr Kind müde wird oder das Interesse verliert, können Sie die Teilnahme entweder vorübergehend oder dauerhaft abbrechen.

Datenschutzrechtlicher Informationsteil

Alle Daten, die während der Studie gesammelt werden, werden vertraulich behandelt und ausschließlich zu wissenschaftlichen Zwecken innerhalb der Bachelorarbeit genutzt. Die Schüler und Schülerinnen sind während und nach Ablauf der Studie jederzeit anonym, das heißt wir erfassen weder den Namen Ihres Kindes noch sonstige personenidentifizierenden persönlichen Daten.

Die Studie ist in Übereinstimmung mit der europäischen Datenschutz-Grundverordnung (DSGVO), welche individuelle Daten von jedwedem Missbrauch schützt. Sie und Ihr Kind haben uns gegenüber das Recht, Auskunft darüber zu erhalten, welche Daten wir zu Ihrer Person verarbeiten (Art. 15 DSGVO). Im Rahmen der Studie werden folgende Daten erhoben und ausgewertet: Neben den Antworten aus den genannten Fragebögen zum Spiel werden mathematische Kenntnisse abgefragt. Zudem werden folgende personenbezogene Daten erfasst: Alter, Geschlecht, Klasse, Vorkenntnisse im Genre des Spiels. Die Daten werden nur in anonymisierter Form analysiert. Dies erlaubt zu keinem Zeitpunkt Rückschlüsse zum individuellen Kind.

Freiwilligkeit der Teilnahme und Recht auf Löschung

Die Teilnahme an dieser Studie ist freiwillig. Wenn Sie sich zu einer Teilnahme entschließen, steht es Ihnen jederzeit frei, Ihr Einverständnis zurück zu ziehen und Ihre Teilnahme zu beenden.

Sie haben jederzeit das Recht auf eine Auskunft über die zu Ihrer Person gespeicherten Daten zu erhalten sowie das Recht auf Löschung dieser Daten. Eine Löschung der Daten kann ab dem Zeitpunkt der Anonymisierung nicht mehr verlangt werden.

Auskunfts- und Beschwerderecht

Falls Sie jetzt Fragen zum Forschungsprojekt haben, äußern Sie diese bitte direkt. Wenn Sie später inhaltliche Fragen zur Forschung oder zu damit verbundenen Themen (z. B. dem Ablauf der Studie oder den Ergebnissen) haben, kontaktieren Sie bitte laura.marsoner@hotmail.com.

Für den Fall, dass Sie und Ihr Kind mit dem Ablauf der Studie, der Teilnahme Ihres Kindes sowie der Verwendung der Daten zu den angegebenen Forschungszwecken einverstanden sind, würden wir Sie beide bitten, die untenstehenden Einwilligungserklärungen zu unterschreiben. Hinweis für SchülerInnen: Das Einverständnis Deiner Eltern berechtigt zur Teilnahme, aber es verpflichtet nicht dazu.

Einverständniserklärung *(Eltern, gesetzlicher Vertreter)*

Ich erkläre hiermit, dass ich im ausreichenden Maße über das Ziel und den Ablauf der Studie zum Lernspiel „Kingdom of Math" informiert wurde und die Informationen zu Datennutzung und Datenschutz verstanden habe.

Des Weiteren bin ich darüber in Kenntnis gesetzt worden, dass meine und die Teilnahme meines Kindes freiwillig sind und ich diese ohne Angabe von Gründen jederzeit beenden kann, ohne dass mir oder meinem Kind dadurch Nachteile entstehen. Meine personenbezogenen Daten beziehungsweise die personenbezogenen Daten meines Kindes werden in diesem Falle umgehend gelöscht. Auch kann ich nach der Studie jederzeit die Löschung der Daten beantragen. Vor meiner Einwilligung hatte ich die Möglichkeit, Fragen zu stellen. Die gestellten Fragen wurden zu meiner Zufriedenheit beantwortet.

Hiermit erkläre ich, dass ich die Inhalte des Informationsschreibens und der Einwilligungserklärung gelesen habe und dass ich Gelegenheit hatte, Fragen zur Studie zu stellen. Ich erkläre mich damit einverstanden, dass mein Kind

_____   _____

(Vorname/Nachname der Bezugsperson)   (Vorname/Nachname des Kindes)

an der Studie teilnehmen darf. Ich bin berechtigt im Namen beider Erziehungsberechtigten diese Erklärung abzugeben.

Ich stimme zu, dass:

☐ die erhobenen Daten von mir und meinem Kind wie oben beschrieben verarbeitet werden;

_____   _____

Ort, Datum   Unterschrift Erziehungsberechtigte(r)

Diese Seite ist für Ihre Unterlagen.

Einverständniserklärung *(Eltern, gesetzlicher Vertreter)*

Ich erkläre hiermit, dass ich im ausreichenden Maße über das Ziel und den Ablauf der Studie zum Lernspiel „Kingdom of Math" informiert wurde und die Informationen zu Datennutzung und Datenschutz verstanden habe.

Des Weiteren bin ich darüber in Kenntnis gesetzt worden, dass meine und die Teilnahme meines Kindes freiwillig sind und ich diese ohne Angabe von Gründen jederzeit beenden kann, ohne dass mir oder meinem Kind dadurch Nachteile entstehen. Meine personenbezogenen Daten beziehungsweise die personenbezogenen Daten meines Kindes werden in diesem Falle umgehend gelöscht. Auch kann ich nach der Studie jederzeit die Löschung der Daten beantragen. Vor meiner Einwilligung hatte ich die Möglichkeit, Fragen zu stellen. Die gestellten Fragen wurden zu meiner Zufriedenheit beantwortet.

Hiermit erkläre ich, dass ich die Inhalte des Informationsschreibens und der Einwilligungserklärung gelesen habe und dass ich Gelegenheit hatte, Fragen zur Studie zu stellen. Ich erkläre mich damit einverstanden, dass mein Kind

_____   _____

(Vorname/Nachname der Bezugsperson)   (Vorname/Nachname des Kindes)

an der Studie teilnehmen darf. Ich bin berechtigt im Namen beider Erziehungsberechtigten diese Erklärung abzugeben.

Ich stimme zu, dass:

☐ die erhobenen Daten von mir und meinem Kind wie oben beschrieben verarbeitet werden;

_____   _____

Ort, Datum   Unterschrift Erziehungsberechtigte(r)

Bitte geben Sie diese Seite ab.