Doctoral Dissertation

Immersive and Engaging Forms of Virtual Learning

New and improved approaches towards engaging and immersive digital learning

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Dissertation

Immersive und motivierende Formen von virtuellem Lernen

Neue und verbesserte Methoden für motivierendes und immersives digitales Lernen

Dipl.-Ing. Johanna Pirker, BSc

Dissertation zur Verleihung des akademischen Grades
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Graz, August 2017

Statutory Declaration

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Ich erkläre an Eides statt, dass ich die vorliegende Arbeit selbstständig verfasst, andere als die angegebenen Quellen/Hilfsmittel nicht benutzt, und die den benutzten Quellen wörtlich und inhaltlich entnommenen Stellen als solche kenntlich gemacht habe.

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[1]Beschluss der Curricula-Kommission für Bachelor-, Master- und Diplomstudien vom 10.11.2008; Genehmigung des Senates am 1.12.2008

Abstract

The learning environments, the teaching methods, and the needs of learners have changed over the past decades. Millions of learners today are using digital tools to learn and acquire new skills. Additionally, the new generation requires a more flexible and mobile way of learning. Unfortunately, many existing learning environments fail to meet these requirements and also lack strategies to motivate users to keep learning. As a consequence, dropout rates are often high and the learning experiences are seen as "boring" and not interesting.

This dissertation investigates and discusses strategies and technologies to create motivational learning environments. We are interested in identifying tools to motivate learning in different environments, such as blended or fully-digital learning. How can we use strategies inspired by highly motivational tools such as video games to engage learners? How can we utilize emerging technologies such as virtual reality to make STEM education more interesting? To answer these questions, we introduce a conceptual model to create motivational learning environments based on immersion and engagement. This thesis demonstrates how systems based on strategies and tools supporting engagement and immersion can be used to motivate and support the new generation of learners. These scenarios point to a future where digital engaging, immersive, and collaborative learning experiences are a central element of in-class, and also of remote learning.

We investigate and develop these ideas through a series of different experiments on prototypes, implemented as part of this thesis, which use design strategies influenced by elements inspired by video game design to engage learners and innovative virtual reality technologies to create immersion.

First, we describe the blended learning environment and teaching model *MAL (Motivational Active Learning)* that builds on engagement methods and uses strategies based on game design theory to engage learners. With an analysis and evaluation of this scenario in a computer science course, we show the potential of designing engagement strategies for different player types and demonstrate collaboration as a tool supporting engagement in in-class learning settings. We show that people are engaged by different elements in learning environments.

To evaluate immersion and engagement in a virtual learning environment, we introduce the educational virtual physics laboratory *Maroon*. *Maroon* is designed and built as an extensible learning environment and lets users interact and learn with different hands-on learning experiences such as physics experiments and simulations. This lab was used as a basis to evaluate further different design strategies to create more immersive and engaging experiences. Immersion has been shown to be a valuable tool to create focused learning experiences. We demonstrate the potential of room-scale virtual reality scenarios to create immersive and interactive hands-on learning experiences and compare it with mobile virtual reality scenario, supporting flexible and guided learning experiences. Finally, we discuss the potential of collaborative virtual reality scenarios for future learning scenarios.

Kurzfassung

Über die letzten Jahrzehnte haben sich Lernumgebungen, Lehrmethoden und die Bedürfnisse der Lernenden verändert. Heutzutage benutzen Millionen von Lernenden digitale Werkzeuge, um neue Inhalte oder Fähigkeiten zu erlernen und zu erwerben. Darüber hinaus benötigt die neue Generation eine flexiblere und mobilere Art des Lernens. Jedoch werden viele der vorhandenen Lernumgebungen diesen Anforderungen nicht gerecht. Außerdem fehlt es vielen dieser Umgebungen an Strategien, Benutzer dazu motivieren zu lernen und dieses Lernen auch fortzusetzen. Infolgedessen ist die Anzahl derjenigen, die eine universitäre, schulische, außerschulische, betriebliche etc. Ausbildung beziehungsweise Weiterbildung abbrechen, sehr hoch und Lerninhalte werden als "langweilig" und uninteressant gesehen.

Diese Dissertation analysiert und diskutiert Strategien und Technologien zur Schaffung von motivierende Lernumgebungen. Es sollen Werkzeuge und Strategien identifiziert und aufgezeigt werden, welche Lernende in verschiedenen Lernumgebungen, wie beispielsweise in Blended Learning oder voll-digitalen Umgebungen, motivieren. Es soll dokumentiert werden, wie Strategien von stark motivierenden Tools, wie beispielsweise Videospielen, zur Motivation von Lernenden verwendet werden können. Ferner wird auch dokumentiert, wie neu aufkommende Technologien wie Virtual Reality (VR) genutzt werden können, damit zum Beispiel der Physik- oder Informatikunterricht interessanter gestaltet

werden kann. Zur Beantwortung dieser Fragen wird ein konzeptuelles Modell vorgestellt, um motivierende Lernumgebungen, basierend auf den Elementen “Immersion” und “Engagement”, zu schaffen. Diese Dissertation untersucht, wie Systeme, welche auf Strategien, die diese Elemente unterstützen, beruhen, angewandt werden können, um Lernende zu motivieren und die Bedürfnisse der neuen Generation zu stillen. Diese Szenarien deuten auf eine Zukunft hin, in der digitale, motivierende, immersive und kollaborative Lernerfahrungen ein zentrales Element sowohl im Klassenzimmer als auch im Fernunterricht sind.

Diese Ideen werden durch eine Reihe von verschiedenen Experimenten an Prototypen, welche als Teil dieser Arbeit implementiert wurden, erforscht und entwickelt. Diese Prototypen beinhalten Motivationsstrategien von Videospielen und unterstützen innovative VR Technologien, um das Gefühl von Immersion zu erzeugen.

Zuerst wird die Blended Learning Lernumgebung *MAL (Motivational Active Learning)* beschrieben. Diese baut auf Engagement-Strategien auf und verwendet Methoden des Spieledesigns, um Lernende zu motivieren. Mit einer Untersuchung und Evaluierung dieses Szenarios in einem Informatik-Kurs werden das Potential, Engagementstrategien für verschiedene Typen von Spielern zu entwerfen und der Einfluss von Kollaboration auf die Motivation von Lernenden aufgezeigt. Es wird demonstriert, dass unterschiedliche Menschen von verschiedenen Elementen in Lernumgebungen unterschiedlich motiviert werden.

Um das Gefühl von Immersion und Engagement in virtuellen Umgebungen zu evaluieren, wird das virtuelle Physiklabor *Maroon* vorgestellt. *Maroon* wurde also erweiterbare Lernumgebung designt und ermöglicht Benutzern die Interaktion mit verschiedenen praktischen Lernerfahrungen, wie beispielsweise Physikexperimenten oder Simulationen. Dieses Labor wurde als Grundlage für die Evaluierung von verschiedenen Designstrategien verwendet, um Erfahrungen zu erstellen, die ein höheres Level an Immersion und Engagement schaffen.

Immersion wurde als wertvolles Werkzeug für die Erstellung von fokussierten Lernerfahrungen demonstriert. Das Potential von raumfüllenden VR Szenarien, um immersive und interaktive Hands-on Lernerfahrungen zu schaffen, wird aufgezeigt und mit mobilen VR Szenarien, welche flexible und geführte Lernerfahrungen unterstützen, verglichen. Abschließend wird das Potential von kollaborativen VR Szenarien für zukünftige Lernszenarien diskutiert.

Acknowledgments

> ”I may not have gone where I intended to go, but I think I have ended up where I needed to be.”
>
> Douglas Adams, 1988

Along the way, so many people have inspired and supported me during the research and writing process, and have added thoughts and ideas to this work. In the following, I would like to express my gratitude to at least some of the numerous people who inspired and shaped my work and probably me throughout the last years.

First of all, I would like to thank my advisors Christian Gütl and John Winston Belcher. I am extremely grateful for their guidance and excellent feedback throughout the idea finding, research, and now especially the writing process.

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John, thank you for all your inspiration and constant engagement which made Maroon into the powerful and promising project it is now. Discussions with you were always extremely inspiring and motivating. Also, your affection towards video games was one of the most powerful inspirations for this thesis and I still often think about your words that you don't like video games such as Super Mario, because the physics are not realistic. Instead, you like games such as Skyrim, because they did the physics right.

I would also like to express my appreciation to everyone at IICM. I had so many fruitful and inspiring discussions with so many members of the institute.

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Along the way, I had support from so many students who were involved in several research projects described in this thesis and they contributed many fantastic own ideas to the different projects. I would especially like to acknowledge all students who were involved in the development of Maroon. The physics Team with Michael Holly(!), Simon Oblasser, Christopher Schinnerl, Christian Kartnig, Michael Schiller, and David Szammer. The VR Team with Isabel Lesjak(!), Mathias Parger, and Stefan Sgouridis. The networking team with

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Of course, I would like to express my gratitude to my *beloved* parents and my dear friends, who always supported me through the process of writing this thesis (especially the last nights!). I don't know how much time has passed; all I know that sometimes it felt like forever. Especially when spending nights and summer days writing this thesis and working on publications, this constant support and *quality time* was extremely important in this time of my life.

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Abbreviations

CS Computer Science
HMD Head Mounted Display
IE Interactive Engagement
MAL Motivational Active Learning
MOOC Massive Open Online Courses
PCG Procedural Content Generation
PI Peer Instruction
PRS Personal Response System
STEM Science, Technology, Engineering, and Mathematics
TEAL Technology-Enabled Active Learning
VR Virtual Reality

1. Introduction

> "There is a single light of science, and to brighten it anywhere is to brighten it everywhere."
>
> Isaac Asimov

1.1. Motivation

The lack of graduates in the Science, Technology, Engineering, and Mathematics (STEM) fields is a crucial issue. In a report to the U.S. president in 2012, the President's Council of Advisors on Science and Technology reported a need to increase the number of students who receive undergraduate STEM degrees by about 34% annually to reach the goal of 1 million more professionals in these fields in the US (Olson & Riordan, 2012) over the next decade. In addition, reports by the European Commission illustrate the demand for STEM professionals. Around 7 million job openings in STEM fields are forecast until 2025 (Caprile, Palmén, Sanz, & Dente, 2015). The demand was expected to grow by around 8% by 2025 (cedefop.europa.eu, 2014). One issue is the lack of STEM graduates and also students have the perception of STEM fields as *boring, hard, and complicated* topics. A shift to more interactive and engaging pedagogical models is also required to change the students' perception and raise their engagement. Strategies should aim to promote a more positive image of STEM, raise awareness, and improve school-based education, increase students' interest, and to address the gender imbalance (Caprile et al., 2015). To face this challenge, in the last decades, several implementations of STEM education efforts have been designed and recorded to make learning more interesting and the concepts easier to understand (Sanders, 2008). To engage students and make the content easier to understand, instructors need to focus on teaching how to solve problems and not only recite solutions. Hence, many modern pedagogical approaches are based on constructivism and use ***interactive engagement*** (Hake, 1998; Sanders, 2008; Pirker & Gütl, 2015a). Interactive engagement and active learning strategies methods often involve learning experiences and activities such as interactive in-class experiences, constant interactions with peers and instructors, and hands-on experiments and tasks (Dori & Belcher, 2005).

A crucial factor for increasing the numbers of STEM graduates on a large scale is the involvement of digital and remote learning environments in various stages of education. STEM education should be available for a larger learner group and should also be designed more attractively to engage underrepresented groups. While many in-class and blended approaches are already successful in teaching STEM fields in an engaging and convincing way, often remote and digital learning environments such as MOOCs struggle with a lack of learner engagement and high dropout rates and many digital learning environments are structured around trade-offs between flexibility and learner engagement. Learners are often required to self-regulate the learning process in online environments, which often leads to limited motivation and a feeling of isolation (Gütl, 2010). As a result, the drop-out rates of digital remote learning environments such as Massive Open Online Courses (MOOC) are comparatively high (Onah, Sinclair, & Boyatt, 2014).

Additionally, the new generation learns in a different way, thus, requires different methods and processes for them to be engaged in various learning environments. This generation wants to have flexible, dynamic, engaging, and also mobile learning environments. Also, the needs of different learner types are often not provided for in a sufficient way. Different learner types can be built on their learning style (i.e. whether they prefer hands-on experiences over peer discussions) or preferred interactions with the learning content (i.e. auditory learners vs. visual learners). More than 70 models of learning styles are known (Coffield, Moseley, Hall, & Ecclestone, 2004). To summarize, digital learning environments offer flexibility but often either fail to engage or to retain learners' engagement. ***Active involvement*** and ***interactive engagement*** are key elements of such environments and also pedagogical strategies to keep students *focused, concentrated*, and *engaged*. Thus, it is crucial to identify and integrate elements of pedagogical approaches which are designed to engage learners with the content and keep them motivated and focused. Additionally, it is important to engage not only one learner type but in the best case all learner types.

With a closer look at pedagogical elements of interactive engagement, we can identify similarities to engagement elements used in video games and gamification strategies: collaborative play, feedback systems, and explorative strategies are typical design elements also used to engage players in video games (Gee, 2007; Mitchell & Savill-Smith, 2004; Bartle, 1996). Interestingly, video games are likely one of the most engaging and immersive experiences for keeping users fascinated and immersed for hours. Players can spend many hours in a row in a state of full concentration and fully immerse themselves in the environment, completing one task after another (Jennett et al., 2008). This is a state of concentration and engagement we are often missing not only in in-class instruction but also in self-regulated learning environments. Thus, understanding video games, game design theory, and emerging technologies supporting immersion (such as Virtual Reality (VR) devices) can be crucial in also understanding the motivation of people. As a result, we should take a closer look at features that engage and drive players to spend so much time, effort, and money in video games and emerging entertainment, and learn from these features to also create tasks and environments in a learning context that are more attractive. Constant **engagement** and full **immersion** seem to be the primary drivers in video game design and will also be the core goal of this thesis to create more stimulating learning environments.

To summarize, we can identify the following two main limitations of today's learning environments and concepts. The first main limitation of traditional learning environments is the lack of sufficient support for the new behaviors of different learners. This is in particularly true because the new Generation Z prefers more flexible, mobile, and engaging learning environments (Bell & Smetana, 2008; Williams, 2015). The second main limitation refers to the lack of motivational and engagement tools needed to make self-directed learning scenarios, and also in-class learning environments, more attractive.

1.2. Objectives

People learn in different ways. Learners have different styles and behaviors when learning. Moreover, different generations use different tools, learn in different ways and own preferences. In particular, very new generations, such as Generation Z, require new tools and strategies. As identified in the previous section, the lack of sufficient support of the different and new behaviors of these learners, as well as the lack of motivational tools in self-directed learning scenarios and in-class learning environments, have been identified as the main limitations. In this thesis, we try solving these limitations in the following ways:

Identification and Analysis of Virtual Learning Environments to Engage and Actively Involve the New Generation of Learners The current generation(s) of learners has different demands and is engaged by other strategies and other digital tools. A primary objective of this thesis is to analyze their needs and demands and investigate learning environments supporting these. Emerging environments and tools such as virtual reality devices and mobile virtual reality headsets are particularly interesting environments to support new forms of learning.

Bridge Learning and Gaming Theory through Engagement Strategies As gaming is a highly engaging and immersive activity, and video game designers have discovered and investigated different strategies to motivate users, gaming theory is also valuable for digital and blended learning environments. This thesis tries to examine strategies and elements used in game design which can also be tools to motivate learners. In this thesis similarities between learners and gamers will be identified and discussed, so as to strengthen engagement theories for learning environments with playful strategies.

Investigating Immersive and Engaging Environments and Technologies for Learning Immersion is described as the second most important driver for achieving enjoyment (Douglas & Hargadon, 2001). To achieve full immersion, in this thesis innovative emerging technologies will be the focus of the research on effects of immersion in interactive, engaging learning environments. While immersion can usually be a result of a good design of virtual environments, in this thesis, the focus will be on the development of immersion analysis of immersive virtual reality environments supported by emerging head-mounted displays.

The core of this dissertation is a set of elements supporting immersion and engagement inspired from game design, and using the emerging technologies described as a pattern for developing interactive learning environments for STEM education. This goal is accomplished by developing a series of prototypes with a focus on investigating engagement and strategies elements, each of which advances engaging learning in digital environments. This thesis proposes that combining learning theories with the motivation factors of video games and emerging entertainment technologies allows the creation of engaging and efficient learning experiences. These experiences will engage various types of learners and players in in-class learning, blended learning, and fully digital learning scenarios. Based on game design techniques and design methods from engaging and immersive entertainment technologies, various e-learning and blended learning prototypes are developed and evaluated mainly in the fields of physics and computer science. The overall aim of this dissertation is to bridge the gap between learning and game design theory in order to support learners in learning in a more **engaging** and **immersive** way.

1.3. Contributions

We make contributions to theory, methods, and systems in the field of human-computer interaction and e-learning with this dissertation. The main contributions can be summarized as follows:

- **State-of-the-art review**. First, research of related work and background in the context of the new generation of learners is introduced to investigate their needs and demands. Second, player types and learner types are analyzed, and different styles of engagement and learning are described. Furthermore, game design theory, which is relevant for developing engaging learning environments, is discussed. The focus is hereby on engaging and immersive virtual environments.
- **Conceptual model describing the relationship between engagement and immersion to create motivational environments**. In a literature review, immersion and engagement are identified as key drivers

and motivators. In this thesis, a conceptual model is constructed discussing these elements in a conceptual context. This model can be used to create motivational environments and also builds the basis for the learning environments introduced in this thesis.

- **MAL (Motivational Active Learning)**. This thesis contributes the pedagogical strategy *Motivational Active Learning (MAL)*. MAL is built on engagement strategies analyzed and structured as a pedagogical model within this thesis. This teaching approach was shortlisted in the category for best hybrid learning award[1]. With this pedagogical model for blended and virtual learning environments, a new and promising tool to engage learning in different settings is introduced and evaluated in a computer science setting.
- **Maroon**. *Maroon* is an award-winning[2] simulation software of physical phenomena that uses the generic gaming engine Unity[3] to implement various educational physics experiments and allows for rendering them to various engagement platforms, such as collaborative virtual worlds, virtual realities (with head-mounted displays), or stand-alone applications with integrated elements based on engagement strategies inspired by game design. Users can work with various simulations of different physical phenomena. *Maroon* opens a design space to create different prototypes to implement and test various engagement variants. The system design of Maroon is based on *Procedural Content Generation (PCG)* to support dynamic and intelligent creation. With Maroon, a virtual physics laboratory implementing different realistic physics simulations and visualizations is presented. Maroon was inspired by MIT's TEALsim simulations and takes them to a more flexible and dynamic environment. Maroon is designed as an interactive and intelligent system represented as a virtual physics environment. We will build prototypes of engagement

[1] Wharton Reimagine Education Awards 2015
[2] GOLC Online Laboratory Awards for the *Best Visualized Experiment*
[3] https://unity3d.com

and immersion strategies in these environments to demonstrate that such environments allow us to re-envision engaging learning and e-learning strategies.

- **Maroon VR and Maroon Mobile VR**. With Maroon, two highly immersive forms of Maroon are developed supporting modern virtual reality technologies such as room-scale virtual reality setups, and more cost-effective and flexible mobile virtual reality setups are implemented. The two different setups allow different forms of interactions with the virtual environment, and thus also require different design strategies to create immersive and interactive engagement systems.
- **Comparative evaluations of different immersive forms of Maroon**. The different implementations of environments supporting different forms of engagement and immersion in Maroon allow for a detailed evaluation of immersion, engagement, usability, advantages, and disadvantages of different virtual environments.

As immersion and engagement have already been shown to be essential tools of learning, the focus of this thesis is not to evaluate learning progress and behavior in the different environments but to identify and investigate immersion and engagement in various environments.

1.4. Methodology and Thesis Structure

To meet the objectives of this thesis, four main phases have been applied. Figure 1.1 summarized these phases and links them to the different chapters. In the first phase, a theoretical literature and background survey was conducted with a focus on finding bridges between learning and playing. In particular, immersion and engagement have been identified as the primary drivers of motivation in learning and play. This builds the basis for the second phase, the design of a conceptual model to create motivational environments. This model is used in the third phase as the basis for the development of different prototypes to investigate the influence of various strategies and technologies to enhance immersion and engagement in different learning settings. The developed prototypes are then evaluated and compared with qualitative and quantitative studies in the fourth phase.

In more detail, the thesis is structured as follows:

To begin, **Chapter 2** presents relevant background literature closing the bridge between pedagogy and game design. First, the new generation of learners is investigated and their needs and demands analyzed. Challenges of online and self-regulated learning environments are discussed. Based on that, engagement, and immersion are discussed as main elements of involvement and motivation. Additionally, a bridge between game design theory and learning theory is built, and different types of learners and players are introduced. The chapter closes by introducing a conceptual model for interactive involvement. This model builds the core of this thesis. **Chapter 3** provides an introduction to various challenges in STEM education and related e-education, and places this work in the context of related research with a focus on environments based on games, gamification, or virtual reality systems.

In **Chapter 4** a pedagogical model *MAL (Motivational Active Learning)* incorporating game design elements is introduced, which shows the potential of the described efforts in a blended learning environment. It is evaluated on an example of Computer Science education.

Chapter 5 introduces the virtual environment (designed as a virtual laboratory) *Maroon*. This chapter describes the main conceptual design and architecture of Maroon and introduces forms of Maroon supporting engagement and immersion. With Maroon Mobile VR and Maroon Room-scale VR, virtual reality environments as immersive tools for educational scenarios are introduced. The chapter discusses the advanced learning tools implemented in a VR with a focus on investigating the effect of VR on engagement and learning. Maroon

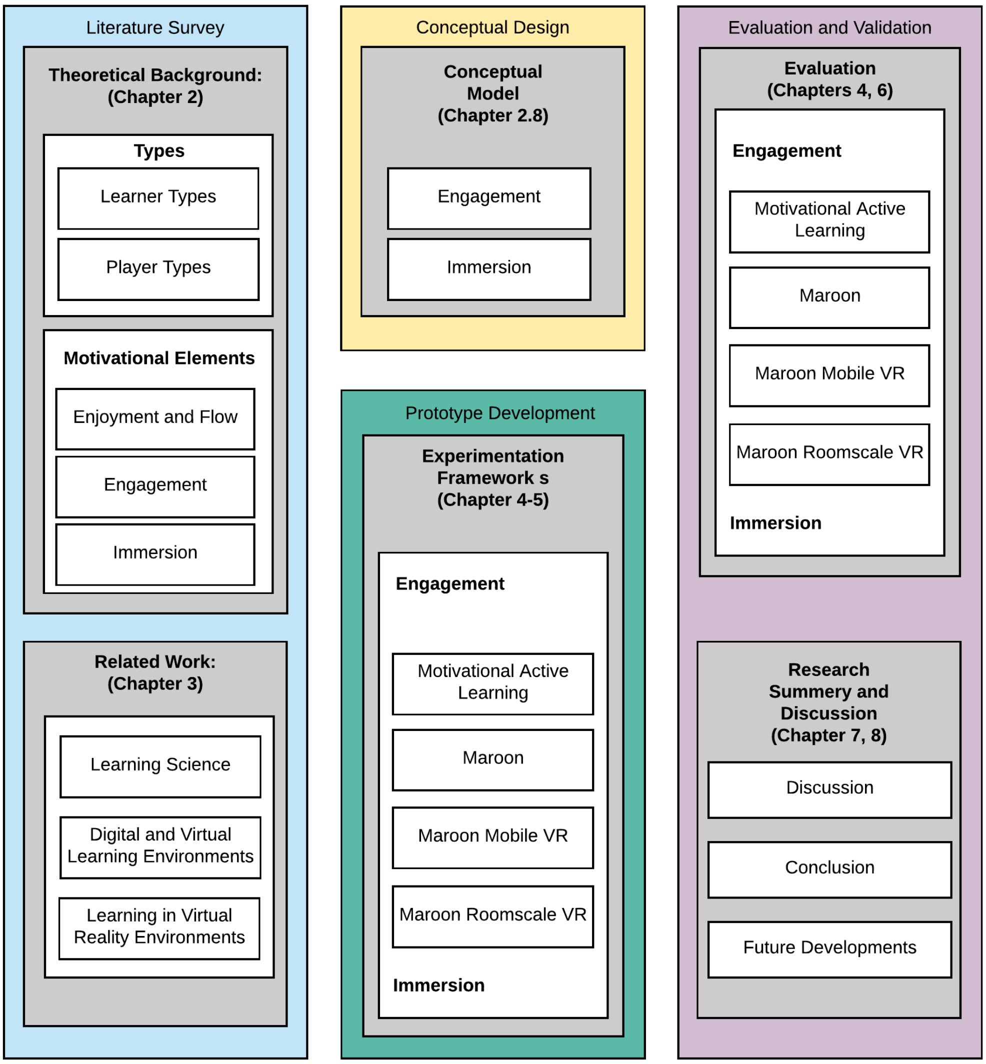

Figure 1.1.: Structure and methodology of the thesis

and the different versions of Maroon supporting immersion and engagement are evaluated and compared in **Chapter 6**.

Chapter 7 reflects on the various engagement aspects and provides a strategy for choosing between different types of motivators inspired by game and entertainment design theory. We also discuss opportunities, limits, and challenges of such approaches. Finally, to conclude, **Chapter 8** reflects on the contributions of this thesis of the use of game design theory in education and forms a vision for the future in this field.

1.5. Publications

All major contributions in this thesis have already been published and were accepted for publication by peer-reviewed conference proceedings or journals. At the beginning of each chapter, the publications on which the chapter is based are enumerated.

1.5.1. Publications about this Thesis

The following list introduces publications, which were published as part of conference proceedings, book chapters, or journal articles and represent the core of this thesis.

- Pirker, J., Lesjak, I., & Gütl, C. (2017a). An educational physics laboratory in mobile versus room scale virtual reality–a comparative study (extended). *International Journal of Online Engineering (iJOE)*, *13*(08), 106–120
- Pirker, J., Lesjak, I., & Gütl, C. (2017b, July). Maroon vr: a room-scale physics laboratory experience. In *2017 ieee 17th international conference on advanced learning technologies (icalt)* (pp. 482–484)

- Pirker, J., Lesjak, I., Parger, M., & Gütl, C. (2017). An educational physics laboratory in mobile versus room scale virtual reality – a comparative study. In *Remote engineering and virtual instrumentation (rev), 2017 14th international conference on* (in press). IEEE
- Pirker, J., Gütl, C., & Löffler, J. (2017). Ptd: player type design to foster engaging and playful learning experiences. In *Interactive collaborative learning (icl), 2017 international conference on* (in press). IEEE
- Pirker, J., Holly, M., Hipp, P., Koenig, C., Jeitler, D., & Gütl, C. (2017). Improving physics education through different immersive and engaging laboratory setups. In *Interactive mobile communication technologies and learning (imcl), 2017 international conference on* (under review). Springer
- Settgast, V., Pirker, J., Lontschar, S., Maggale, S., & Gütl, C. (2016). Evaluating experiences in different virtual reality setups. In *International conference on entertainment computing* (pp. 115–125). Springer
- Pirker, J., Riffnaller-Schiefer, M., Tomes, L. M., & Gütl, C. (2016). Motivational active learning in blended and virtual learning scenarios: engaging students in digital learning. *Handbook of Research on Engaging Digital Natives in Higher Education Settings*, 416
- Pirker, J. & Gütl, C. (2015a). Educational gamified science simulations. In *Gamification in education and business* (pp. 253–275). Springer International Publishing
- Pirker, J., Riffnaller-Schiefer, M., & Gütl, C. (2014). Motivational active learning: engaging university students in computer science education. In *Proceedings of the 2014 conference on innovation & technology in computer science education* (pp. 297–302). ACM
- Pirker, J., Gütl, C., & Kappe, F. (2014). Collaborative programming exercises in virtual worlds (abstract only). In *Proceedings of the 45th acm technical symposium on computer science education* (pp. 719–719). SIGCSE '14. Atlanta, Georgia, USA: ACM. doi:10.1145/2538862.2544286

1.5.2. Publications beyond the Scope of this Thesis

Besides work as listed in the previous section, the author of this thesis contributed to additional work in the fields of virtual learning environments, gamification, educational games, game analysis, game development research, AI, data analysis, social graph analysis, HCI, and information retrieval. An overview of these publications is given to also demonstrate the research potential of games research in the field of computer science and reflects the interest of the author in these areas.

- Pirker, J., Pojer, M., Holzinger, A., & Gütl, C. (2017). Gesture-based interactions in video games with the leap motion controller. In *International conference on human-computer interaction* (pp. 620–633). Springer
- Hutzler, A., Wagner, R., Pirker, J., & Gütl, C. (2017). Mythhunter: gamification in an educational location-based scavenger hunt. In *International conference on immersive learning* (pp. 155–169). Springer
- Pirker, J., Khosmood, F., & Gütl, C. (2017). Social network analysis of the global game jam network. In *Proceedings of the second international conference on game jams, hackathons, and game creation events* (pp. 10–14). ACM
- Pürcher, P., Höfler, M., Pirker, J., Tomes, L., Ischebeck, A., & Gütl, C. (2016). Individual versus collaborative learning in a virtual world. In *Information and communication technology, electronics and microelectronics (mipro), 2016 39th international convention on* (pp. 824–828). IEEE
- Rattinger, A., Wallner, G., Drachen, A., Pirker, J., & Sifa, R. (2016). Integrating and inspecting combined behavioral profiling and social network models in destiny. In *International conference on entertainment computing* (pp. 77–89). Springer
- Pirker, J., Griesmayr, S., Drachen, A., & Sifa, R. (2016). How playstyles evolve: progression analysis and profiling in just cause 2. In *International*

conference on entertainment computing (pp. 90–101). Springer

- Cheong, C., Filippou, J., Cheong, F., Pirker, J., & Gütl, C. (2016). Using persuasive system design principles to evaluate two next generation digital learning environments. In *International conference on interactive collaborative learning* (pp. 255–268). Springer
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2. Motivating Generation Z

> "Children are young because they play, and not vice versa [...] men grow old because they stop playing, and not conversely"
>
> G. Stanley Hall, 1904

The new generations of learners acquire knowledge and skills in a different way to previous ones. Their learning habits tend to be more engaged and self-directed, and they have flexible learning styles. As a result, they require flexible and engaging environments for success. However, how to actively involve students in learning tasks and learning environments still poses a significant challenge. The lack of *student engagement*, defined as *behavioral intensity and emotional quality of active involvement* (Reeve, Jang, Carrell, Jeon, & Barch, 2004), is still one of the primary reasons for the dropout and failure rates in STEM. Active learning approaches and environments have been shown to be valuable tools for increasing student performance (Freeman et al., 2014).

Key elements of **active involvement** are on the one hand environments helping students keep *focused and concentrated* and on the other hand, strategies to keep them *engaged*.

Learning strategies and environments supporting interactive engagement and immersion have been shown to be a valuable tool to support learning and keep students actively involved. While there is a consensus that engagement and immersion are crucial elements of interaction design and important factors to support instructional tools and educational strategies, there is still a lack of methodologies or frameworks to support the design, analysis, and assessment of engaging and immersive educational tools (Hake, 1998; Dede, 2009).

Immersion and engagement are also well known as strong elements for the design and creation of interesting playful games and experiences. Video games and various forms of interactive entertainment are becoming increasingly important in our society. The video game industry has already outperformed Hollywood and music sales (Chatfield, 2009) in the last few years and has also reached the classroom. The power of video games for learning has already been discovered by education and research. However, while the use of video games and gamification strategies became increasingly attractive as tools in education and many researchers have shown their positive impact on educational effectiveness and student motivation (Papastergiou, 2009), the nature of educational environments with a focus on engaging learners based on their learning and playing habits is still an open issue and will be the main research topic of this thesis.

Hence, the core of this thesis is the investigation of emerging digital environments and strategies inspired by game design and emerging virtual reality technologies to **engage** and **immerse** students into the learning content. We aim to reduce the gap between video game development and the design of learning environments and strategies.

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2.1. The New Generation of Learners

In this section, we discuss the needs and habits of the new generation of learners. The section is mainly based on Pirker, Riffnaller-Schiefer, Tomes, and Gütl (2016).

Over the past decades, the way of teaching STEM (Science, Technology, Engineering, and Mathematics) fields has changed from traditional lecture setups to more interactive and engaging models. In Chapter 3 we will investigate those models in more detail. While many modern pedagogical models for teaching STEM fields use innovative teaching methods based on interactive engagement strategies and involving digital learning aids, the digital tools used have barely changed. However, the generation of learners has changed and has a different understanding and expectations of digital tools. Our modern world has changed dramatically over the last century and is vastly influenced by various media and technologies, such as electronic games, computers, mobile devices, social media, and the participatory web. Consequently, learning has also significantly changed from passive and repetitive learning to active learning with new tools. In the following paragraphs, Generation Y and Generation Z and their needs are investigated.

2.1.1. Generation Y

After the generations of the *"Baby Boomers"* born between 1945 and 1965 (the so-called Space Explorer generation), and the "Generation X" born between 1965 and 1985 and influenced by the growth of mass media, the *"Generation Y"* or "Gen Y" born after 1985 has grown up with computers and mobile phones ("Millennials - Wikipedia," n.d.). Gen Y is influenced by a world which is connected, accessible, interactive, and open. Gen Y can be characterized as *"individualistic, independent, confident, ambitious, team-oriented, direct, empowered, and driven achievers who depend on technology as their support system"*. Gen Y learning must be *"captivating as they share and learn with their peers. The teachers have subsumed the role of a facilitator rather than an authority figure as it was with the other generations"* (Chang & Gütl, 2010). Consequently, such a new generation calls for new learning and teaching styles supported by innovative and participatory technologies.

2.1.2. Generation Z

Generation Z, or the Post-Millennials ("Generation Z - Wikipedia," n.d.) is known as the *"Web generation"*. Youths born in or after 1990 already grew up with the graphical Web and are skilled with tools such as Google, social media platforms, and instant messengers, and are comfortable with technologies. Every day they take their mobile phones and the mobile web with them everywhere and 66% list gaming or mobile gaming as their main hobby (Week, 2014). In summary, their lives became more mobile, self-directed, technology focused, and entertainment-centered.

This generation craves web-based and research-based tasks as part of the curriculum (Geck, 2007). Self-regulated and independent learning has become more important to them. Social interactions and group work in learning environments have taken a back seat, and they are increasingly moving towards digital environments. Thus, self-regulated learning but also social and collaborative learning strategies need to be revised to engage and motivate this new generation of students (Igel & Urquhart, 2012).

To summarize, the following list gives an overview of characteristics, preferences, and expectations of the new *Generation Z*:

- **Affiliation with digitization and technology:** This generation has grown up with the Web, with social media, and mobile technologies such as smartphones (Williams, 2015).
- **Mobility and flexibility:** Growing up with smartphones and the mobile Web, they are used to having constant access to information, entertainment, and digital tools (Williams, 2015)
- **Entrepreneurial spirit**: Inspired by the high-tech environments and innovative and successful tech start-ups, Generation Z is described as more entrepreneurial and desire more independent working environments (Beall, 2016). They are inspired and influenced by start-ups representing

themselves online (Williams, 2015). 42% expect to work for themselves in their future career (Northeastern, 2014b).

- **Self-directed and self-motivated:** This generation is highly self-directed and knows about the importance of higher education to achieve their career goals (Northeastern, 2014b).
- **Less focused**: They have issues focusing on tasks for a long time(Beall, 2016) and lose interest very fast (Williams, 2015).
- **Multi-tasking**: They are used to multi-tasking, and they work with several tools and technologies at the same time (Beall, 2016).
- **Higher expectations**: this generation was already born into a world full of innovative technologies and many alternative tools, software pieces, and entertainment strategies. Thus, if a tool does not fully satisfy their needs, they simply move on to the next tool (Beall, 2016)
- **Concerned about education fees**: Two-thirds of them are concerned about being able to afford college (Hawkins, 2013). 46% believe that colleges should *"significantly change how they offer education, because the current way just doesn't work anymore"* (Northeastern, 2014a). They also express interest in cheaper online learning alternatives (Beall, 2016).
- **Values social and interpersonal interactions**: Even so, this generation still prefers direct interaction over online-only interaction (Northeastern, 2014b)

These needs summarize the desire for a new and innovative but affordable learning environment, which supports interactive engagement, active involvement, as well as emerging technologies. Based on these characteristics and needs of Generation Z, the following observation summarizes the requirements of Generation Z towards an educational environment:

Observation
Observation 1. Generation Z requires an online and digital learning environment, which supports ***social interaction*** and allows ***self-regulated learning*** in a ***mobile and flexible*** way. To help them to focus on the task and keep them engaged, the design of this motivational environment should be ***engaging*** and ***actively involving*** and it should support ***innovative and interesting technologies***.

In the following sections, the main elements essential for educational environments for this generation are discussed in more detail. As self-regulated learning is a crucial part of modern learning environments and still a major challenge, the next section focuses on identifying elements necessary to engage learners in self-regulated learning environments.

2.2. Self-regulated Learning

Pintrich (2000) describes self-regulated learning as *"the application of general models of regulation and self-regulation of cognition, motivation/affect, behavior, and context to issues of learning"*.

The key components are summarized by Schraw, Crippen, and Hartley (2006) as cognition, meta-cognition, and motivation. *Cognition* includes types of learning skills such as problem-solving or critical thinking; skills necessary to encode, memorize, and recall information. *Meta-cognition* includes skills, which allows learners to understand and monitor their cognitive process. *Motivation* includes beliefs and attitudes that affect the use and development of cognitive and meta-cognitive skills. Motivation refers to learners' confidence in their competence and consists of self-efficacy and epistemological beliefs. These components can be supported and enhanced by engagement elements such as collaborative communication, feedback systems, and knowledge representation techniques to keep learners in self-regulated environments engaged.

Taking a closer look at the elements used to engage learners, we can identify similarities to engagement elements used in video games. Collaborative play, feedback systems, and explorative strategies are typical design elements also used to engage players in video games. Interestingly, video games are probably one of the most engaging and immersive experiences and keep users fascinated and immersed for hours. Players can spend hours in a row in a state of *full concentration* and *immersed* in the environment, and complete one task after another (Jennett et al., 2008); a state of concentration and engagement we are often missing in self-regulated learning environments. Thus, understanding video games and game design theory can be a crucial element also to understand the motivation of people. As a result, we should take a closer look at features that engage and drive players to spend so much time, effort, and money on video games and learn from these features to also create tasks in a learning context more interesting.

In the following sections, we discuss the motivators and interaction forms based on engagement and immersion as motivators found in learning, play, game design theory, and gamification strategies. Since many different definitions of concepts such as motivation, enjoyment, engagement, and immersion can be found in the literature, the focus of this section is also to discuss and define the concepts as a basis for this thesis.

2.3. Motivation in Learning and Play

In this section, we discuss motivation in learning and play. The section is mainly based on Pirker and Gütl (2015a).

Motivation is a key element of effective learning (De Freitas, 2006; Garris, Ahlers, & Driskell, 2002). Engagement and technology-support have been identified as important elements for pedagogical strategies supporting the needs of Generation Z. In this section, we first discuss motivation through pedagogical and psychological lenses compared with elements from game design. This is followed by an introduction of game-based engagement elements and strategies in educational settings.

According to Graham and Weiner (1996) *"motivation is the study of why people think and behave as they do. In the context of academic achievement, motivational concerns would be addressed if we were to ask, for example, why some students complete tasks despite the enormous difficulty, while others give up at the slightest provocation, or why some students set such unrealistically high goals for themselves that failure is bound to occur."*

In the literature, two different forms of motivation are defined: intrinsic motivation and extrinsic motivation.

2.3.1. Intrinsic Motivation

Intrinsic motivation is driven by the satisfying, fun, and interesting nature of activities (Vallerand et al., 1992; Deci & Ryan, 2010). Intrinsic motivation is an important concept for instructional designers and teachers, because it results in *"high-quality learning and creativity, it is especially important to detail the factors and forces that engender versus undermine it"* (Ryan & Deci, 2000). In the context of learning, three types of intrinsic motivation are identified: (I1) Intrinsic motivation to know, (I2) intrinsic motivation toward accomplishments, and (I3) intrinsic motivation to experience stimulating sensations such as sensory pleasure or excitement (e.g., through excitement from active class discussion).

2.3.2. Extrinsic Motivation

In contrast to intrinsic motivation, extrinsic motivation represents behavior which does not stem from personal interest. It is possible to differentiate between three types of extrinsic motivation: (E1) External regulation (e.g., child learns because the parents force them to), (E2.) Introjection (the individual has already internalized the reasons for the action), and (E3.) Identification (the actions are perceived as chosen by the individual).

Besides intrinsic motivation and extrinsic motivation, amotivation is used to describe the state where individuals are neither intrinsically nor extrinsically motivated and do not experience any external or internal motivators (Vallerand et al., 1992).

2.3.3. Quantification of Motivation

Vallerand et al. (1992) introduce the Advanced Motivation Scale (AMS) as a scale for measuring motivation in educational settings. It is based on the Echelle de Motivation en Education (EME) (Vallerand, Blais, Brière, & Pelletier, 1989) and helps to measure the three types of intrinsic motivation, the three types of extrinsic motivation, and amotivation.

2.4. Enjoyment and Flow

In this section, we discuss the highly motivating and engaging states enjoyment and flow. The section is mainly based on Pirker and Gütl (2015a).

The Oxford dictionary describes enjoyment as a *"state or process of taking pleasure in something"* (Oxford-Dictionaries, n.d.). M. Csikszentmihalyi and

Csikszentmihalyi (1992) identified eight major components that cause enjoyment: (1) Tasks we have a chance of completing, (2) ability to concentrate on what we are doing, (3) tasks with clear goals, (4) tasks with immediate feedback, (5) deep and effortless concentration, (6) sense of control over actions, (7) loss of self-consciousness, (8) sense of the duration of time is altered. Csikszentmihalyi describes flow as a *"state of deep absorption in an activity that is intrinsically enjoyable, as when artists or athletes are focused on their play or performance"* (Shernoff, Csikszentmihalyi, Shneider, & Shernoff, 2003; M. Csikszentmihalyi, 2014). These experiences can be described as the state of flow. Csikiszentmihalyi (1975) introduced the term flow as an optimal experience characterized by full attention and maximum performance on an activity. Flow can be found in different activities such as experiencing a book, sports activities, art, music, a programming session, or an involved calculation in physics. Plays, games, and computer games are obvious activities which are likely to promote such flow states. Many of the eight components that cause enjoyment can be found in games. Flow is a targeted feeling in many domains (games, learning, training) for creating engaging experiences. It is created by balancing the skill level and the challenge and describing clear goals (M. Csikszentmihalyi & Csikszentmihalyi, 1992; Brockmyer et al., 2009). Designing interfaces and experiences which support flow, games and game-based teaching methods can be a powerful way to achieve higher student motivation in different learning environments, such as in classrooms, in online environments, or in blended systems.

2.5. Engagement

Engagement is a key driver of successful games and an important concept for successful pedagogical models. In Schaufeli, Salanova, González-Romá, and Bakker (2002) the authors describe engagement as *"a positive, fulfilling, and work-related state of mind that is characterized by vigor, dedication, and absorp-*

tion", which is not a momentary state, but rather a persistent affective-cognitive state. They refer to *vigor* as high levels of energy and mental resilience, dedication as a sense of significance and enthusiasm, and absorption as concentration and engrossment. Following, we look at engagement first from a game design perspective, then through an educational lens.

2.5.1. Engagement in Games

Games are known as experiences, which sustain user engagement. Przybylski, Rigby, and Ryan (2010) describe the different needs of players:

- (1) competence need: challenges grow with the player's experience
- (2) autonomy need: many games provide a set of interesting choices and strategies towards a goal
- (3) relatedness need: social interactions as an important element in multiplayer games
- (4) mastery of controls: ability to perform intended in-game actions and interactions without effort after a learning period (learning curve)

Experiences, which are designed to fulfill these needs, are expected to contribute to intrinsic motivation, immersion, and player well-being.

Schoenau-Fog (2011) explains engagement in games as a process where players are engaged by pursuing *objectives* through performing *activities* in order to be rewarded for an *accomplishment* to feel *affect*. Objectives include intrinsically (self-defined goals) and extrinsically (goals set by the game) motivated goals. Activities describe what players need to do in order to achieve objectives and include elements such as solving, sensing, interfacing, exploring, creating, destructing, experiencing a story, experiencing characters, or socializing. Accomplishments are related to the result of activities and could be for instance achievements, progression, or completion. Affect concerns the players' experience during activities or when accomplishing something and is either positive (e.g., enjoyment, fulfillment, success, curiosity) or negative (frustration, feeling bored, time-wasting) or relates to absorption, a feeling related to flow, immersion, and presence.

Bartle (1996) describes four main activities to engage gamers in multi-user environments based on the players' interactions with other avatars or the environment: achieving, exploring, socializing, or competing. These engagement types also refer to different player types and will be discussed in a later section.

2.5.2. Engagement in Education

Engaging learners in learning activities and with the learning environment is a crucial but challenging task. Reeve et al. (2004) summarize engagement in the context of learning as *"behavioral intensity and emotional quality of a person's active involvement during a task"* and involves learners' *"enthusiastic participation in a task"* involving *"expressions of motivation, such as intrinsically motivated behavior, self-determined extrinsic motivation, work orientation, and mastery motivation"*. Dickey (2005) describes the potential of engagement models found in video games to design instructions and summarizes the following main concepts of engaged learning: *"focused goals, challenging tasks, clear standards, protection from adverse consequences for initial failures, affirmation of performance, affiliation with others, novelty and variety, and choice."*

2.5.3. Quantification of Engagement

Reeve et al. (2004) describe ways to measure engagement in an educational setting by observing the learners' active involvement including effort and emotions towards the tasks.

Engagement and flow are crucial states to reach when designing educational environments. Based on the observation as stated above to create interesting experiences (e.g., games) to reach engagement and flow, we draw the following conclusions for designing motivational environments.

Observation
Observation 2. Motivational environments supporting engagement or even flow experiences tend to share the following features: *clear goals*, *challenges requiring competence*, *a level of freedom*, *social aspects*, and *clear feedback*. They can be described through a process where users are engaged by pursuing ***objectives*** through performing ***activities*** in order to be rewarded an ***accomplishment*** to feel ***affect***.

Prensky states that video games require active engagement from players (Prensky, 2003; Dickey, 2005). However, with emerging technologies such as virtual reality devices, not all games now require active engagement in the gaming context for entertainment. VR takes users to a state of immersion without the necessity of full engagement. Immersion is also an interesting concept for supporting concentration and active involvement in learning settings. The next section will introduce and discuss immersion in gaming and educational contexts.

2.6. Immersion

Immersion is known as one of the main drivers and motivators of users in games and virtual reality experiences. However, how to define, measure, and quantify immersion still poses a challenge. Also, in interactive media we can experience different forms and degrees of immersion (Dede, 2009). Definitions of this concept found in literature are vague and overlaps between definitions of engagement, presence, and immersion are often identified (Brown & Cairns, 2004; Nacke & Lindley, 2008). This section tries to investigate and discuss different definitions of immersion found in the literature and agree on a definition as a basis for this thesis.

2.6.1. Defining Presence

Presence, also known as telepresence, is described as sense of *"being in"* the environments (Reeves, 1991) and can be typically supported by the use of hardware such as head-mounted displays, headphones, and motion-sensing gloves (Steuer, 1992). While there is a common understanding of presence and telepresence in literature, definitions of immersion often differ.

2.6.2. Defining Immersion

Bowman and McMahan (2007) describe immersion as an element with the goal to let users / players *"experience a computer-generated world as if it were real - producing a sense of presence, or "being there," in the user's mind"*.

Dede (2009) describes immersion as *"subjective impression that one is participating in a comprehensive, realistic experience"*. Actional, symbolic, and sensory factors can be used as design elements to create an environment in which users believe that they are "inside" this setting. Such immersive digital interfaces have been shown to be valuable tools to promote learning and engagement, as well as for the transfer from an in-class room setting to a setting in a real-world scenario.

While McMahan (2003) describes immersion, engagement, and presence as the main concepts to design and analyze three-dimensional games, Brown and Cairns (2004) identify three stages of game immersion: *engagement, engrossment, and total immersion.* In this context, engagement is described as first involvement with the game. After the stage of engagement players would become more engaged with the game, namely "engrossed". At this stage already a high level of emotional investment in the game can be observed and players are less aware of their surroundings. This emotional investment keeps players playing, which leads to the third stage. Total immersion is also described as *"presence"*. Players would describe their experience as being cut-off from reality and full involvement in the game. Slater (2003) refers to immersion in the context of virtual reality as a term describing *"what the technology delivers from an objective point of view.* He uses presence instead as a description of human reaction to immersion. Brown and Cairns (2004) also identify parallels between immersion and Czsentmihalyi's concept of flow, since flow requires full attention and an environment free of distraction (M. Csikszentmihalyi & Csikszentmihalyi, 1992).

McMahan (2003) describes three main conditions to create immersive experiences in three-dimensional environments or in VR: *(1) the user's expectations of the game or environment must match the environment's conventions fairly closely; (2) the user's actions must have a non-trivial impact on the environment; and (3) the conventions of the world must be consistent."*

Freina and Ott (2015) differ between *non-immersive VR* (*"computer-based environments that can simulate places in the real or imagined worlds"*) and *immersive VR* (adding the *"perception of being physically present in the non-physical world"*). Based on their differentiation, immersive VR is evolving with emerging technologies and devices such as recent head-mounted displays and tracked controllers. Immersive VR experiences create immersion through well-designed auditory, visual, and eventually even haptic experiences (Bowman & McMahan, 2007). Slater lists several elements about how to quantify immersion including *visual, auditory, haptic, resolution, stereo, behavioral fidelity of what is being simulated, display lags and system latency, coverage of tracking, and also elements such as temperature, air flow.* (Slater, 2003). For this thesis we refer to this type of immersion as spatial immersion or also presence.

2.6.3. Immersion in Education

In education, studies have shown the potential of immersion in digital learning environments in various ways including the support of multiple perspectives, situated learning, and transfer (Dede, 2009). Studies also showed that learners benefit from immersion through virtual reality scenarios and show significant increased knowledge gain when compared with partially immersed (computer screen) environments (Coulter, Saland, Caudell, Goldsmith, & Alverson, 2007).

2.6.4. Immersion in Gaming

E. Adams (2004) defines three main categories of immersion:

- *Tactical Immersion:* Tactical immersion is created through "moment-by-moment" acts, such as found in fast-paced action games. It is created through challenges, which can be solved within a few seconds and which take players to a meditation-like state (e.g., when playing Tetris). Design elements to support the creation of tactical immersion include flawless user interface with rapid, intuitive, and reliable responses. Rapid changes of the environment, the interface, and the type of challenge disrupt this state of immersion.
- *Strategic Immersion:* Through strategic immersion players are involved in a game by seeking a path to victory. It is a state of full concentration to optimize the solution (e.g., as when playing chess). Player actions include observing, calculating, deducing. To design such experiences, it is important to provide mental challenges. Illogical challenges and gameplay disrupt this state of immersion.
- *Narrative Immersion:* Narrative immersion is created through interesting storylines and characters, as is well known in movies or books. To design

experiences creating narrative immersion good storytelling is the focus of the design. Badly designed dialogs, characters, or unrealistic plots destroy this state.

Different players and users prefer different sorts of immersion.

2.6.5. Quantification of Immersion

In order to analyze the concept of immersion within motivational environments, a tool to measure and quantify immersion is required. In Jennett et al. (2008) the authors created questionnaires and measures to obtain an immersion score representing the level of immersion while playing a video game. They found that immersion can be measured in a subjective way through questionnaires as well as in an objective way through measures such as task completion time or eye movements.

Observation

Observation 3. Different forms and ways of immersion can be observed. On the one hand forms of immersion can be created through story and activity design such as ***tactical immersion*** (e.g., through challenges), through ***strategic immersion*** (e.g., solution optimization), or ***narrative immersion*** (e.g., interesting stories or characters). On the other hand immersion can be created through environment and technology design (e.g., virtual reality experiences), which relates to ***spatial immersion*** or presence. Motivational environments can be created by adding different forms of immersion.

In the previous sections we observed different forms of engagement and immersion in gaming and learning. In both, game design theory and pedagogically different learner and player types can be observed. The following section seeks to investigate relevant types further as a basis for this thesis.

2.7. Player and Learner Types

As we observed in the previous sections, many forms of engagement and immersion have been discovered and discussed in both learning and also playing applications. In the following learner and player types are analyzed to find similarities and potential bridges.

2.7.1. Learner Types

In pedagogical theory, dozens of models describing learner types exist. In Coffield et al. (2004), the authors identified 71 models of learning styles. Popular categorizations are (for example) Neil Fleming's VARK model (Leite, Svinicki, & Shi, 2010), which divides the learning content based on the learners' interaction with it into the four types: visual learners, auditory learners, reading-writing learners, and kinesthetic learners. Another example is David Kolb's model (Kolb, 2014) based on learners' experiences and abstract conceptualization. Kolb identified four types of learners based on their learning styles: *the Accommodator*, who prefers strong hands-on practical experiences; *the Converger*, who is strong in practically applying existing theories; *the Diverger*, who is strong in imaginative abilities and discussions; and *the Assimilator*, who has a strong focus on inductive reasoning and creation of theories.

2.7.2. Player Types

Similar to the theory on various learner types in pedagogy design, video game designers have discovered different types of gamers, who are motivated by various forms of interactions. One key element of game design theory is Bartle's player types; the British game researcher (Bartle, 1996) observed players in multi-player online dungeons (MUDs) and investigated the preferred

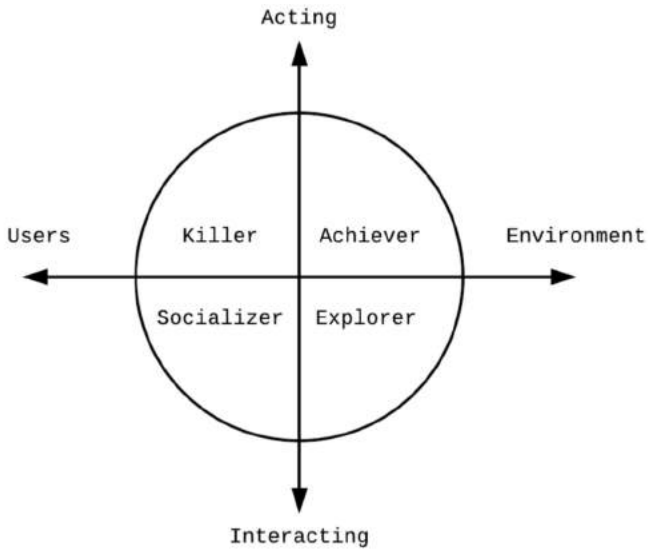


Figure 2.1.: Bartle's player types as they act or interact with avatars and the environments (Bartle, 1996)

interactions of players with other players or with the environment. Based on these observations, Bartle summarized four main player types:

- *"Achievers (A)"*, who are engaged by achievements within the game context
- *"Explorers (E)"*, who enjoy the exploration of the game
- *"Socializers (S)"*, who are engaged by socializing with others
- *"Killers (K)"*, who are engaged by imposition upon others

Figure 2.1 illustrates the four player types with respect to their relationship to other avatars and the environment. Again, similarities between players and learners in self-regulated environments can be identified. In this thesis, these similarities will be identified and discussed so as to strengthen engagement theories for learning environments with playful strategies.

Hamari and Tuunanen (2014) investigate different player types found in the literature. They identified seven main dimension based on their synthesis: (1)

intensity, (2) achievement, (3) exploration, (4) sociability, (5) domination, (6) immersion, and (7) in-game demographics.

In Fjællingsdal and Klöckner (2017), the authors describe a conceptual framework model of game enjoyment and environmental learning and also describe the importance of the different player types to motivate and create a stage of engagement with a game, which they describe as "gameplay stage". They point out that a lack of consideration of different player types in educational games, can lead to a lack of attention and the inability of entering a flow state or becoming immersed.

Observation
Observation 4. In both, learning and playing different types can be identified and motivational environments should be designed to fit the different types to maximize objectives such as immersion, engagement, and learning outcome. ***Achievements***, ***exploration***, and ***social interactions*** can be summarized as important tasks (activities) in playing experiences for the further development of this thesis.

2.8. Conceptual Model for Creating Motivational Environments

The observations as identified in the previous section lay the basis for the conceptual model for creating *motivational environments* such as developed in this thesis. Figure 2.2 summarizes the main elements of the model used to create motivational environments, which promote immersion and engagement as main elements to support learners in learning settings.

Engagement and immersion are the two main elements of our model. The main component for engagement require (1) clear goals and objectives (given by the

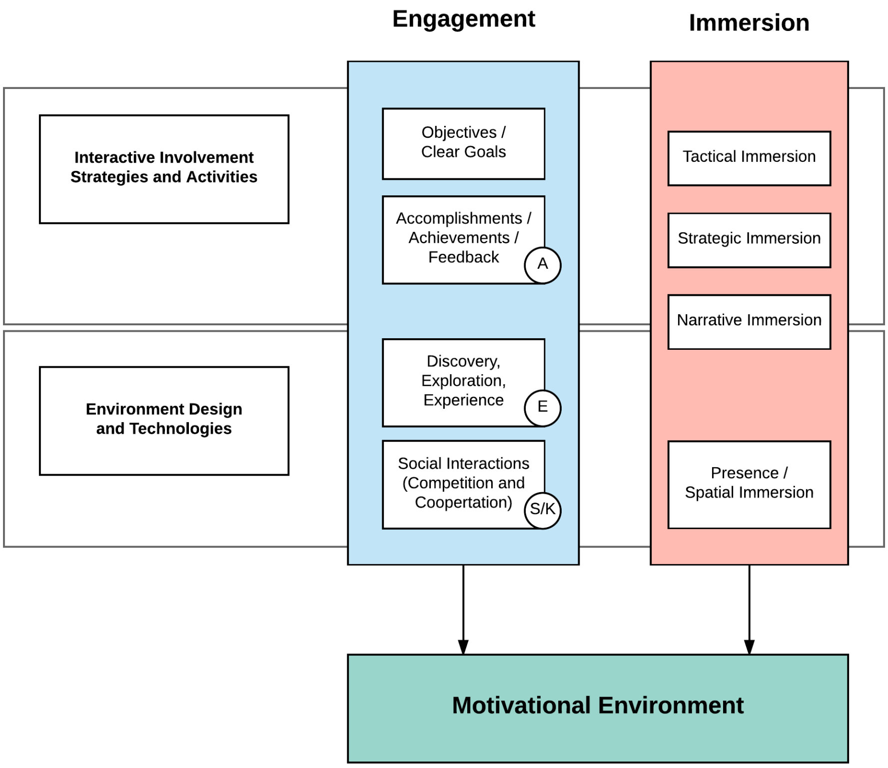


Figure 2.2.: Conceptual model for creating *motivational environments* through immersion and ingagement. A, E, and S/K also refer to the elements mapped to the four player types.

application or self-defined), (2) feedback and accomplishments (in the form of of progress, rewards, achievements), (3) explorative experiences such as discovery, experiencing stories, characters, or the environment, solving, or sensing), and (4) social interactions (cooperative or more competitive forms).

Engagement

As we have discussed earlier, in game design theory different kinds of engagement styles for different player types are used. In (Pirker, Gütl, & Löffler, 2017), we have proposed ***Player Type Design (PTD)*** to simplify design processes to attract and engage the four player types as introduced by Bartle (1996). When designing activities in a non-gaming context, such as in learning settings, designers should think of specific tasks and engagement elements in the form of verbs. More specifically, designers can think of tasks in line with the following action verbs:

A: Achieving, Gaining, and Producing. To please the player type achiever, it is essential to design elements that suggest to the user/learner that something has been achieved. Typical game elements here include elements suggesting performance (points, progress bars, levels, etc.) or special visible rewards (badges, achievements). Achievers need clear goals and objectives to be completed, and also feedback on their current progress towards this goal. **E: Exploring, Researching, and Testing.** The main goal for explorers is a depth exploratory experience featuring lots of freedom through discovery, experimentation, finding secrets, and surprise elements. Furthermore, it is important to reward this behavior in a visible way. The real reward here is the possibility provided for interacting in an explorative way with the environment. **S: Socializing, Collaborating, and Joining.** Interactions with other users, collaborations, discussions, and building relationships and friendships are the most important reward factors for socializers. Sharing information, completing tasks together, or working together towards a goal are activities that will attract and engage them. **K: Competing, Challenging, and Bragging.** The gamer type killer seeks ways to compete with others. Typical elements supporting this group of users are special rewards, leadership information, or rankings. However, the activities are not only limited to obvious competitions. Killers can also be engaged by activities that might be helpful, such as sharing information or gifts, just to make others aware of their higher status or simply bragging (demonstration of superiority over fellows). The personal reputation and the recognition of skills and levels are important to this gamer type.

Figure 2.2 illustrated the four types in context with the role in enhancing engagement.

Immersion

Four main forms of immersion have been identified: (1) spatial immersion, also known as presence. This form of immersion is mainly reached through environment design (including sound design) and technical aids such as virtual reality devices and interaction aids (controllers, gloves, eye-tracking). Other forms of immersion as described by E. Adams (2004) include tactical immersion (created through fast-paced challenges), strategic immersion (optimizing solutions through observing and calculating), and narrative immersion (created through interesting stories).

Interactive involvement strategies and activities as well as *environment design and technologies* play important roles in creating engagement and immersion. Immersion is often more influenced by the environment or used technologies (such as VR technologies). Engagement is usually more influenced by involvement strategies and activities. However, aspects driving engagement and immersion also influence each other and often there is no strict separation between those two elements and design strategies. In particular, different forms of activities are unique in that they build a bridge between the two elements.

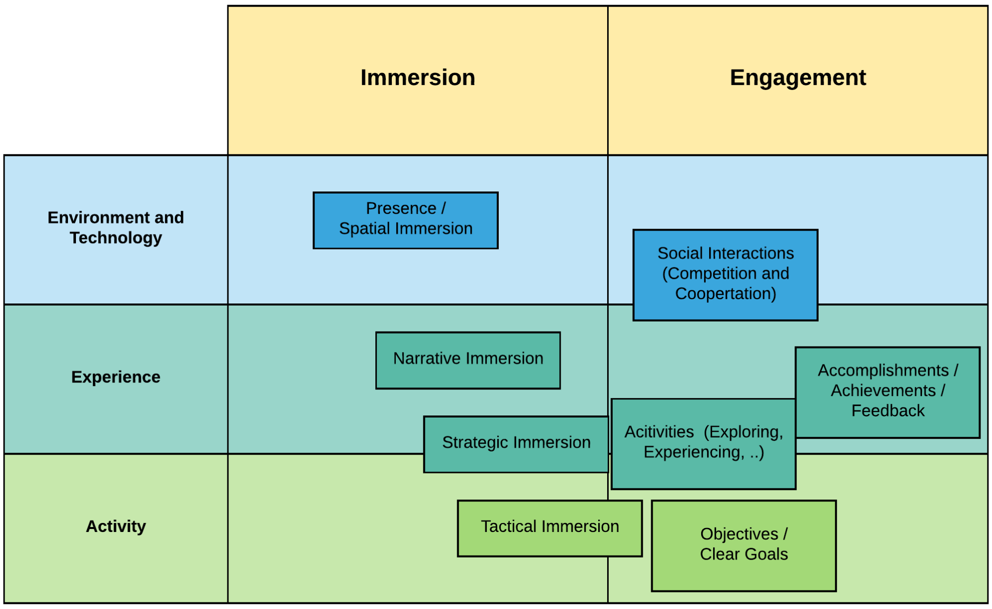


Figure 2.3.: Immersion and engagement created through design of environments and technology, experiences, and activities

The design and implementation focus is on three main elements to support the different forms of immersion and engagement: the *environment and technology*, the *experience*, and the *activities*. Figure 2.3 illustrates how the different forms of engagement and immersion as introduced in our conceptual model can be placed in the context of these elements.

This conceptual model only outlines the design of motivational environments as described in this thesis, and is not designed as a complete and exhaustive model.

2.9. Summary and Discussion

The new generations have different expectations of learning. The involvement of technologies in a flexible and motivational way is key. Immersion and engagement are key elements to create motivational environments to make learning more interesting and rewarding for this generation.

As it has been shown in this chapter, the definition of key elements forming this thesis, such as immersion, engagement, flow, or presence have often been discussed, but definitions are vague and overlap. For the purpose of this thesis, we have presented a conceptual model describing immersion and engagement as the main parts of creating interesting learning experiences. Bartle's player types (Bartle, 1996) build the basis to create different engaging experiences and activities: (1) accomplishment, feedback, and achievements; (2) discovery, exploration, and design-driven experiences (e.g., by characters, environment, or story), and (3) social interactions such as collaboration but also competition. To support immersion as the main element, we have presented tactical, strategic, and narrative immersion as elements, which can be created mainly by designing corresponding activities. Spatial immersion (also presence) is mainly supported through environment design and supporting technologies (such as head-mounted display or immersive sound systems). Taking into account design elements to create immersive and engaging experiences as also often used in video game design, is an important step towards creating experiences and environments to make learning more attractive for new generations.

This conceptual model builds the basis for the motivational environments introduced in the next chapters. Before introducing those environments, however, we will discuss related work found in literature to get a better understanding of learning environments and their relation to video games and virtual realities.

3. Related Work

> "*Education* refers to the process, not the object. Although, come to think of it, some of my teachers could easily have been replaced by a cheeseburger."
>
> Terry Pratchett, 1996

Interactive systems helping students understand complex science concepts in an immersive and engaging way build on work from e-learning, user interface design, machine learning, procedural content generation, intelligent tutoring systems, gamification, virtual reality design, and game design theory. However, the design and development of educational tools are very interdisciplinary research processes. It is strongly influenced by pedagogy, cognitive science, and the subject of the educational application.

Thus, the theoretical background of this thesis summarizes relevant work that supports the *pedagogical* and *technical* value of the systems introduced in this thesis. It is built upon the following main areas: First, **STEM education** (with a focus on physics and computer science) to make pedagogically meaningful enhancements to digital learning environments. Second, the two main drivers to create motivational environments as described in our conceptual model: ***engagement*** and ***immersion***. Research on engagement theory will summarize relevant work found in **(1) gamification strategies and game design theory** to identify elements to engage learners in a playful way; **(2) social environments**, such as multi-user learning environments, to better support cooperative and competitive learning elements; and **(3) explorative strategies** to support new forms of digital learning. On the one hand, the discussion of immersion will focus on introducing relevant psychological work, and on the other hand also on relevant emerging technologies, such as recent head-mounted displays supporting **virtual reality** experiences. This chapter reviews existing literature and work in these domains with a focus on science education.

The following sections are based on and supported by work previously published in

- Pirker, J. & Gütl, C. (2015a). Educational gamified science simulations. In *Gamification in education and business* (pp. 253–275). Springer International Publishing,
- Pirker, J., Riffnaller-Schiefer, M., Tomes, L. M., & Gütl, C. (2016). Motivational active learning in blended and virtual learning scenarios: engaging students in digital learning. *Handbook of Research on Engaging Digital Natives in Higher Education Settings*, 416,
- Pirker, J., Lesjak, I., & Gütl, C. (2017b, July). Maroon vr: a room-scale physics laboratory experience. In *2017 ieee 17th international conference on advanced learning technologies (icalt)* (pp. 482–484),
- Pirker, J., Lesjak, I., & Gütl, C. (2017a). An educational physics laboratory in mobile versus room scale virtual reality–a comparative study (extended). *International Journal of Online Engineering (iJOE)*, *13*(08), 106–120,
- Pirker, J., Riffnaller-Schiefer, M., & Gütl, C. (2014). Motivational active learning: engaging university students in computer science education. In *Proceedings of the 2014 conference on innovation & technology in*

computer science education (pp. 297–302). ACM, and

- Pirker, J., Holly, M., Hipp, P., Koenig, C., Jeitler, D., & Gütl, C. (2017). Improving physics education through different immersive and engaging laboratory setups. In *Interactive mobile communication technologies and learning (imcl), 2017 international conference on* (under review). Springer.

3.1. STEM Education

In this section, we discuss STEM education. The section is mainly based on Pirker and Gütl (2015a), Pirker, Riffnaller-Schiefer, and Gütl (2014).

Teaching conceptual content such as found in STEM (Science, Technology, Engineering, and Mathematics) fields represents a challenge for many educators. Modern pedagogical approaches are based on constructivism and interactive engagement (Sanders, 2008; Hake, 1998). It is necessary to not only re-cite formulas but to teach how to solve problems and apply these formulas. Key issues include the level of abstraction and the invisibility of phenomena such as electromagnetism in physics, or complex algorithms in computer science (e.g., sorting algorithm). In this context, the visualization of a concept can improve the students' understanding.

Many authors have discussed different learning approaches to make education more attractive and help students to *"learn more, learn it earlier and more easily, and* [...] *learn it with a pleasure and commitment"* (DiSessa, 2001). In the last decades, many innovative interactive teaching styles have emerged to support STEM fields. Quantitative research promotes the effectiveness of different active learning models using strategies such as collaborative learning methods or computers as an auxiliary device for learning (Prince, 2004).

3.1.1. Active Learning and Interactive Engagement

Active learning refers to a pedagogical model, which integrates different interactive assignments and activities such as group discussions, in-class group assignments, and direct interactions with instructors. Particularly in STEM fields, such approaches are an important way to teach abstract concepts. The approach focuses on improving problem-solving abilities instead of simply reciting theoretical concepts (Hake, 1998). Active learning and interactive engagement formats have been adopted by many educational institutions to optimize the students' learning experience, foster their problem-solving abilities, and enhance their conceptual understanding.

Interactive Engagement (IE) challenges students in face-to-face lectures to solve problems together. A study with 6000 students shows that IE strategies are superior to support the students' problem-solving abilities and their conceptual understanding (Hake, 1998). In the following sections, different formats grounded in IE strategies and active learning are presented.

Peer Instruction Peer Instruction (PI) is a teaching model for physics education introduced by Mazur at Harvard. To design a large-scale course to be more interactive and personal, students use personal Personal Response System (PRS) to answer short multiple-choice questions in the lecture. Afterwards, they discuss the questions with their peers and can revise their answer (Mazur, 1999). Many authors also report successful integrations of PI in Computer Science courses. Porter and Simon used a format grounded in PI to teach media computation (learning computation through digital media manipulation), and pair programming (solving programming exercises in pairs). They report reduced dropout rates, increased student pass rates, and an absolute improvement of more than 30% in programmatic retention among students in a Computer Science (CS) 1 course (Porter & Simon, 2013).

Scale-Up Scale-Up (Student-Centered Activities for Large Enrollment for Undergraduate Programs) is an interactive learning approach which integrates typical small class elements into large enrollment passive physics courses. Scale-Up combines lecture (discussion), polling questions, laboratory experiments, discussion, and problem-solving to create an interactive learning environment. Students work in homogeneous groups of three. Every student has a special role. Each group sits on a rounded table together with two other groups (nine students on each table) (Gaffney, Richards, Kustusch, Ding, & Beichner, 2008). The special classroom features whiteboards on the walls, portable whiteboards, a computer or laptop for each group, and a class presentation system. Research has shown that this interactive learning environment has positive effects on the students' learning process. As a result, Scale-Up improves problem-solving skills and conceptual understanding. They also noted a positive effect on the grades in follow-up classes (Beichner & Saul, 2003).

Studio-Physics Studio-Physics is another example of an active learning approach. Kohl and Kuo transformed the traditional physics course at the Colorado School of Mines into a Studio-Physics course. Modern information technologies were used together with conventional techniques for experiments, hands-on activities, and problem-solving tasks. Some of the activities were done in homogeneous groups so that students could learn from each other. Activities include in-class activities such as conceptual questions as well as home assignments. An essential element of Studio-Physics is the scaffolding system, which iteratively improves the students' problem-solving skills. A study has shown that the students' grades have improved. However, they also noted that there is no automatic improvement without also adapting the curriculum to the new learning approach (Kohl & Vincent Kuo, 2012).

3.1.2. Technology-Enabled Active Learning

One important noteworthy pedagogical model which will form the basis for further work in this thesis is *Technology-Enabled Active Learning (TEAL)*. TEAL was designed to optimize physics education at the Massachusetts Institute of Technology. It uses the concept of small lecture/content pieces interrupted by constant interactions such as conceptual questions, desktop experiments, interactive physics simulations, and group discussions. In particular, TEALs combination of collaborative and interactive activities with in-class technology setups (simulation software, experiment setups, personal response systems) is used to enhance students' problem-solving abilities and their conceptual and visual understanding (Dori & Belcher, 2005).

3.2. Digital and Virtual Learning Environments

In this section, we discuss digital and virtual learning environments. The section is mainly based on Pirker and Gütl (2015a), Pirker, Lesjak, and Gütl (2017a). While many in-class setups are engaging and support the learners' needs, many setups are often very expensive and not flexible. Current pedagogical strategies tend towards self-directed online learning scenarios. More and more learners want to learn in their own space, in a time- and location-independent way. Online and virtual are becoming increasingly important in supporting remote education and the learning styles and preferences of the new generation. In the following sections, we investigate digital and virtual forms of education.

Digital and online learning are essential topics in educational research. But what are the differences between the individual digital and online learning environments? What does the implementation of these look like? And what are the main effects on a student's learning process and how do these environments support learning science? Are the existing solutions designed in a proper way to fulfill the needs of the new generation of learners? These questions will be discussed in the following sections.

3.2.1. E-Learning, Online Learning, and Blended Learning

Digital and online tools give learners access to information independent of location and time. In addition to that, E-learning experiences embed pedagogical principles into digital and online environments (Govindasamy, 2001).

E-Learning is defined as electronic communication (asynchronous and synchronous) to create and confirm knowledge. Govindasamy (2001) describes E-Learning as *"another way of teaching and learning"*, which includes elements such as "*instruction delivered via all electronic media including the Internet, intranets, extranets, satellite broadcasts, audio/video tape, interactive TV, and CD-ROM.*" Furthermore, E-Learning is the foundation for online learning and blended learning.

Online Learning combines independence with asynchronous communication technologies and interaction. Therefore, users of online learning are space and time independent (Garrison & Vaughan, 2008). Online learning is strongly related to Learning Management Systems (LMS). LMSs are software tools for the administration and management of courses and course content. Features of learning management tools include course registration, presentation of learning content, and assessment of student performance (Carliner, 2004). Rahman, Ghazali, and Ismail (2010) have found that some students avoid using certain features of LMS, such as submission tools, communication tools, and self-evaluation possibilities. They prefer these activities in the form of face-to-face interactions or manual tasks. Another study by Bonk, Olson, Wisher, and Orvis (2002) has evaluated the effects of different kind of distance-learning technologies on the students' learning experience. The results have shown that there are some problems with using Learning Management Systems because these tools are often not flexible enough for the students' and instructors' requirements.

In summary, LMSs in online learning setups are software tools with many different features. However, many features are often not used by the instructors or the students. Also, despite a large number of features, the systems are often not flexible enough for the users' needs. Many important activities of active learning models (peer discussions, hands-on experiments, or interactive assignments) used to engage users and to support the enhancement of their conceptual understanding are hard to integrate and implement in such environments. Thus, many e-learning setups are combined with regular in-class meetings. Such hybrid learning settings are called blended learning. In the next section, aspects and prospects of blended learning are discussed.

Blended Learning E-learning is not only the foundation for online learning setups but also for blended learning (Garrison, 2011). Blended learning is a combination of face-to-face, in-class interactions between students and instructor, and digital and online learning scenarios. The pedagogical goal is to foster students' engagement and to use the advantages of internet-based learning (Garrison & Vaughan, 2008).

Chen and Jones (2007) compared blended learning to a traditional course at a university in the US. For this comparison, they split the students of the class into two groups. One group of students was enrolled in the traditional course with face-to-face interaction between instructor and students twice a week. Lectures and discussions were setup as in-class activities for this course. The second group of students was enrolled in a course with a blended learning setting. These students had a two-hour online meeting each week and four face-to-face meetings at the university. Both groups had the same instructor and the same grading system. The study has shown that some results of the evaluation were the same for both groups. The students' learning outcomes and the students' perception of the course were the same. However, some results clearly differed between the two groups. Students in the traditional course setting liked the clarity of the course instruction more. On the other hand, analytical skills of students were fostered better in the course with the blended learning setup. The authors suggest that the blended learning approach may improve the learning experience and broaden the understanding of concepts in the field. One reason for this might be that by learning on the computer, students make use of more additional resources on the Internet. Therefore, traditional learning approaches and blended learning can both be improved by using elements of each other. For example, students of the traditional course should use resources on the web to a greater extent (Chen & Jones, 2007).

Another study at the University of Granada evaluated a blended learning course on general accounting with 1,431 students. The objective of the study was to assess the effects of students' perceptions of the blended learning activities on their learning outcomes. The course was split into a face-to-face part with in-class activities and into activities in an e-learning environment. Students had the possibility of using websites for finishing the in-class activities. The e-learning environment consisted of single tasks and collaborative tasks (e.g., activities in forums and wikis). Students were supposed to use the content of the face-to-face lectures for finishing these e-learning activities. The results of this study show that by using a blended learning format for the course, they were able to reduce the dropout rate. Moreover, the combination of traditional face-to-face learning and e-learning activities had a positive effect on the final marks of the students (Lopez-Perez, Perez-Lopez, & Rodriguez-Ariza, 2011).

We conclude that blended learning combines advantages of face-to-face learning and online learning to improve a student's learning process. But to achieve these benefits of blended learning on the learning process, it is important to motivate the students to learn in such environments (Visser, Plomp, Amirault, & Kuiper, 2002). Additionally, blended learning environments limit mobile and flexible learning settings and might not support all requirements to engage Generation Z. Also, STEM education requires more accurate tools and techniques to engage learners and to teach conceptual fields such as physics or computer science. The following section investigates science education in digital and online environments.

3.2.2. Virtual Science Education

In particular, fields which require students to understand different phenomena, the use of hands-on laboratory experiments enables interactive learning and engagement with the learning content in classroom settings. These hands-on experiences can be supported and to some extent replaced by computer-based resources and virtual experiences. In STEM education this includes digital animations, visualizations, or simulations of phenomena to make unseen concepts seen, illustrate complex concepts, allow experimentation, or simulate and test theoretical thoughts (Dori, Hult, Breslow, & Belcher, 2007). In the following sections, we introduce different virtual environments designed to teach science.

Educational Simulations Interactive simulations are one of the most powerful tools for teaching, learning, and understanding the behavior and characteristics of physical laws, processes or systems. Computer-animated science simulations allow users to observe a variety of phenomena more easily while also supporting the conduction of expensive or dangerous experiments

(Sanders, 2008). Educational simulations have the potential to enrich classroom learning with the possibility to include 'real-world' learning experiences. They provide an environment to engage students in problem-solving, hypothesis testing, and experimental learning (Lunce, 2006).

One example might be the interaction of electric fields with charges (Dori & Belcher, 2005). Neither textbooks nor the explanation of talented instructors can replace computer-based dynamic visualizations such as animations or simulations, which can conceptualize these effects. Invisible effects can be made visible, time and space can be stretched, and even dangerous or otherwise impossible experiments can be efficiently conducted (Lunce, 2006). Aldrich (2009) defines educational simulations as "[...] *structured environments, abstracted from some specific real-life activity, with stated levels and goals."* Dori and Belcher (2005) reflect on their impressions of simulations in the field of physics as follows: "*These visualizations enable students to develop intuition about various electromagnetic phenomena by making the unseen seen in game playing and experimentation."* (p. 252) Animations are passive representations of principles and phenomena and are only designed for students to watch. In contrast, simulations have a more interactive character and allow the manipulation of the conditions of the principles and the parameters modeled, and therefore the behavior of the visualizations (Lunce, 2006). Exploring and experiencing principles and phenomena on their own help students to link the abstract formulas with visible behaviors. Different educational tools such as Physlets ("Physlets Home Page," n.d.) and online platforms and collections such as Open Source Physics ("Open Source Physics," n.d.), PhET ("PhET Web," n.d.) or TEALsim (Belcher, Mckinney, Bailey, & Danzinger, 2007) are available to support the STEM curriculum. TEALsim will be discussed in more detail in chapter 5.

Research revealed that simply showing simulations to students does not enhance or prompt deeper understanding of concepts. Depending on the context of the learning content, the interactive character of simulations, however, can serve as an excellent tool to engage students and encourage them to explore difficult topics in more details. In an interview study with 89 students using different PhET simulations, W. K. Adams et al. (2008) observed that "simulations can be highly engaging and educationally effective, but only if the student's interaction with the simulation is directed by the student's own questioning" (p. 1). They also suggest that if students only observe simulations and do not interact, they do not ask questions and cannot make new connections. Different research groups have identified strategies and guidelines for enhancing the quality of educational simulations. Bell and Smetana (2008) highlight the importance of student-centered instructions, which mean that simulations supplement, but do not replace instructional modes. Windschitl (1995) found that constructivist simulations with exploratory character are "more effective in altering learners' misconceptions" in comparison to confirmatory simulations, where students are following clear instructions. The importance of adding exploration-based activities to enhance the students' understanding of the learning concepts was also observed by W. K. Adams et al. (2008). The authors found that factors such as interactivity, the presence of little puzzles, visual aids such as labels, and fun and playful elements influence the students' engagement. In the light of the discussion above, the following heuristics can be applied to guide the design process of instructional simulations:

- Educational simulations should be constructivist with exploratory character.
- Educational simulations should supplement and not replace instructions
- Instructions should be student-centered
- Limitations of simulations should be pointed out
- Simulations should be designed in an engaging manner to support conceptual learning

Virtual Laboratories Virtual laboratories simulate an entire laboratory experience and not only single experiments. But even a learning experience with well-designed simulations but without clear instructions and learning tasks can be frustrating and does not sufficiently focus on motivational aspects. This can reduce the learning outcome and efficiency. Motivational, interactive engagement formats as discussed in the previous chapter including a game-based or collaborative design, can be used to overcome or at least mitigate this issue. They can not only improve the students' understanding of the concepts but also increase their enthusiasm for the field.

Different studies suggest an increase in learning outcomes when remote but also simulated laboratories are used. In a large-scale study, Wieman and Perkins (2005) found that learning outcomes after performing assignments in remote or simulated laboratories are as high or higher compared to traditional hands-on laboratories. Students also saw different advantages in these virtual or remote scenarios such as convenience and the possibility of visualizing and perceiving otherwise hidden elements. However, they also found that students still expressed preferences for the hands-on laboratory. Based on their results, students see their actual physical presence in the lab as the most important aspect of lab effectiveness. Comparing remote and simulated labs, students rated the feeling of immersion and feeling in control of the experiments, as well as the sensation of reality, as being slightly higher in simulated labs. Additionally, the lack of possibilities for collaboration with peers in remote or simulated labs was noticed. Lindsay and Good (2005) investigated the impact of the separation from physical hardware in laboratory classes on students' learning outcomes and their perception of the setups. While students in remote laboratory setups perceived that the objectives of the class emphasized hardware, simulations were perceived as educational tools emphasizing theory. Additionally, the different virtual setups also support different learning outcomes based on these perceptions. Additionally, some students do not "trust" simulations the same way they would trust real experiments. Thus, often first experiences with real experiments help students to also work with simulations.

However, in simulated and fully virtual environments, the learning and working experiences are strongly dependent on the capabilities and constraints of the software and limits to specific simulation processes, including pre-designed input and output (Balamuralithara & Woods, 2009).

Physical Presence and Remote Laboratories The physical presence in real-world laboratories and different hands-on experiments can be used as part of the classroom to make science education more interesting and engaging. A blended form of computer-supported natural science or engineering education is the use of remote laboratories. They can facilitate the use of laboratories with remote access, which reduces the costs and dangers of traditional laboratories and allows distant learning and experimenting with real conditions (Balamuralithara & Woods, 2009). Their effectiveness for learning was discussed by Wieman and Perkins (2005) in a large-scale study, where it was shown that with remote labs, learning outcomes are as high or even higher compared to traditional laboratories.

Virtual Collaborative Worlds While blended learning scenarios support many features of different pedagogical models incorporating interactive and collaborative learning strategies, it is a challenging task to enable such activities in a fully digital and online setup. In particular, collaborative and cooperative learning forms are a significant activity in traditional setups to engage learners. However, such activities are often hard to implement in a digital environment.

In Pirker, Gütl, Belcher, and Bailey (2013) a collaborative virtual world environment for physics education is described. Various physics simulations are integrated into the environment and students can work together on the simulations and discuss the phenomena. While the overall experience with the system was rated very positively, and participants emphasized the importance of the collaborative aspects, the overall engagement and immersion could be improved.

In many of the above-discussed environments, often the lack of support and enhancement of student motivation were noted Pirker, Gütl, Belcher, and Bailey (2013). Additionally, a major issue of such environment still poses the challenge of motivating students in self-regulated environments, which also leads to high dropout rates in settings such as MOOCs (Rivard, 2013; Gütl, Rizzardini, Chang, & Morales, 2014).

As we have seen in chapter 2, engagement and immersion have been shown as valuable tools to motivate both players and learners. In the next section related work in the area of games and gamification in education is presented.

3.2.3. Games and Gamification in Education

Play is defined as *"activity done for its own sake, characterized by means rather than ends", [...] "flexibility", [...] "and positive affect."* (Smith & Pellegrini, 2008). Creative play for children and also young animals is an important aspect of learning through vicarious experiences and as part of imagination. Young animals, for example, play to recreate and simulate life experience and learn how to hunt and fight by playing with mates (Dix, 2003). Different forms of children play support different training and learning aspects: i.e., locomotor play supports physical training of muscles, skill-training, and endurance training; social play increases social skills; object play helps developing problem-solving skills (Smith & Pellegrini, 2008).

The idea of using digital games in contexts other than fun, leisure, and entertainment is not a new one. The first experiments with games with a serious purpose were grounded in military training (Deterding, Dixon, Khaled, & Nacke, 2011). In the last years, more and more game design elements were also making their way into the classroom to enhance intrinsic student motivation. With key statements such as *"games are a more natural way to learn than traditional classrooms"* (Aldrich, 2009), various ideas emerged how to integrate

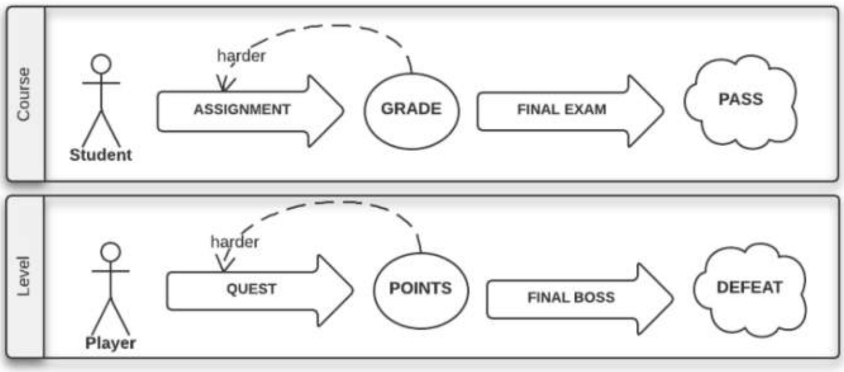


Figure 3.1.: Games and courses share a typical progress-process (Pirker & Gütl, 2015a)

games or game elements into learning settings in classrooms and online learning environments. Gee (2003) suggests that educators might benefit from studying how game players learn through game play. Schell (2014) even compared the traditional classroom design with a game. While we can identify various behavioral similarities between players and learners, similarities between the learning and playing process can also be described (see Figure 3.1). Students would learn new concepts and skills to pass assignments and tests for which they get grades. The assignments become harder and harder, and in the end they would need to pass the final exam and either pass or fail. In games players would need to learn new skills to finish quests, would get points for every completed quest and have to defeat a final boss in the end, which often requires the player to apply all learned skills (Pirker & Gütl, 2015a).

Playing a game is already a powerful learning tool in itself: players have to learn new skills in a new (but safe) environment (Koster, 2013). Mayo (2007) summarizes five reasons to not only support small computer games but also to invest in large scale parallel education in science and engineering via video games: (1) A single game can reach more people than one single lecture. (2) Video game-based education would attract students outside the classroom. (3) video games stimulate chemical changes in the brain that promote learning. (4) video games achieve higher effectiveness than a classic lecture. (5) video games are designed according to effective learning paradigms such as experimental learning, inquiry-based learning, self-efficacy, goal setting, cooperation, continuous feedback, tailored instruction and cognitive modeling. We have learned that games can be a powerful tool to support learning behavior. So, why aren't today's classrooms and learning strategies fully supported by these fun and motivation triggers? Schell (2014) summarizes the following challenges of introducing games and game-based approaches to learning settings:

Time constraints: Games usually require more time to impart the learning content. *Age constraints*: Usually, games are designed to attract the gamer generation, and therefore focus on learners who have experience with this kind of multimedia. *Expenses:* Usually, good games include a long and deliberate design process, which involves many developers, artists, and designers. This design and development process can be highly expensive. *Design challenges:* Designing a game which is fun for players but still educational is challenging.

In the next section, we analyze different aspects which can help to improve the design process and facilitate the involvement of games, game elements or game strategies in learning environments.

3.2.4. Designing Educational Playful Environments

When using game elements, strategies or fully-fledged games to support the educational strategies, various implications must be considered. When introducing games to teach content, it is important to find out which topics can and should be covered by a game, and which areas are either not suitable or would be too time- and cost-intensive for a game-based approach. Randel, Morris, Wetzel, and Whitehill (1992) examined different studies comparing the learning outcomes of simulations and games with those of conventional instructions and found that *"subject matter areas where very specific content* *can be targeted are more likely to show beneficial effects for gaming."* In particular, studies involving STEM fields such as math and physics showed that the instructional effectiveness of games was higher than that of conventional classroom instruction.

Game Design Elements Motivation and different forms of motivation have been shown as a key element in learning and gaming (Chapter 2 discusses aspects of motivation in more detail). Early studies have already resulted in taxonomies and strategies to enhance intrinsic motivations for learning based on fun elements of games. Malone and Lepper (1987) have identified heuristics for designing intrinsically motivating instructional environments based on studies identifying fun elements of games. They range from interpersonal motivators, including motivation, to cooperative or competitive activities or the receipt of social recognition, and individual motivators. Personal motivators can be one of the following. First, students should experience *challenges*, which require a balanced level of difficulty. Students should have *goals*, encounter *uncertain* outcomes (such as variable difficulty levels, multiple levels of goals, hidden information, or randomness) and need frequent, clear, constructive and encouraging performance *feedback*, including positive feedback to enhance self-esteem. Second, the curiosity of students should be encouraged. It is important to balance the level of informational complexity according to the students' current state of knowledge. Third, students should have a sense of control and a feeling of self-determination. Fourth, inspirational, playful environments and the involvement of imagination can promote intrinsic motivation.

Gamification Another approach to making the learning experience more incentive and enhance the students' motivation is the use of gamification strategies. Instead of designing an entire game, what is expensive and requires lots of resources and specialists, gamification is the *"use of game design elements in non-game context"* (Deterding et al., 2011). Adding these elements is a comparatively cost-effective way of adapting existing processes and services to make them more fun. One famous example of gamification in classroom education is *Quest to Learning* ("Quest to Learn (Q2L) – Middle School and High School," n.d.). *Quest to Learning* is a school in New York City which uses gamification strategies as a basis for the curriculum design. Instead of learning for exams, students learn by solving riddles, finishing missions, or enacting role-playing scenarios. Students are rewarded for their effort by getting points, instead of getting frustrated and stressed through failing exams (McGonigal, 2011).

An example for an online educational platform grounded in gamification strategies is Khan Academy. Khan Academy is a collection of different learning resources connected to courses created with the purpose of enabling users to learn various subjects, such as STEM fields, history, languages, or finance. It helps people to track their learning progress and uses gamification strategies such as points, badges, and awards to create a more fun, exciting, and motivating environment (Thompson, 2011).

Playful Science Education A playful form of virtual laboratories has been tested in the field biotech education by Bonde et al. (2014). They tested a laboratory designed with gamification elements and found that this form of environment significantly increased the students' learning outcomes and their performance compared with traditional teaching.

While the environments as discussed above focus on engagement in playful educational settings, immersion has been identified as an additional valuable driver in motivational environments. In the following section, virtual reality environments supporting full immersion in learning settings are discussed.

3.3. Learning in Virtual Reality Environments

As we have discussed in Chapter 2, environment, character, story, and activity design are important ways to create immersive experiences. Another way to create and enhance immersion is the use of technical aids such as virtual reality devices. The section is mainly based on Pirker, Lesjak, and Gütl (2017a, 2017b), Pirker, Lesjak, Parger, and Gütl (2017). The use of virtual reality headsets and technologies is a promising way to create a more immersive, engaging, and interactive environment. With the current efforts to produce VR headsets which are affordable for private users (e.g., PlayStation VR, Samsung Gear VR, HTC Vive), VR becomes also more attractive as a tool to enhance classroom experiences. Several studies have looked into the potential of virtual reality (VR) for educational scenarios.

In recent years, there has been a constant interest in using virtual reality (VR) for education. There is currently a new peak of interest in VR devices. The current state of available VR devices, such as Oculus Rift or HTC Vive, offers a sufficient level of maturity to be considered a serious tool for education or training scenarios.

The potential of immersive VR in different applications has been shown through a number of systems ranging from educational situations to medical subjects and therapy systems (Freina & Ott, 2015) such as phobia therapy systems (Bruce & Regenbrecht, 2009).

Already Bricken (1991) summarized the potentials of virtual reality environments in learning settings. The author notes the experiential character of VR as an important tool for learning, as also already mentioned by James (1983): *"Learning is the development of experience into experience"*. Additionally, virtual reality allows natural and intuitive interaction with information (moving, gesturing, and manipulating objects). Moreover, more recent research demonstrates the effectiveness of virtual reality environments. In a meta-analysis of students' learning outcomes in K-12 and higher education, Merchant, Goetz, Cifuentes, Keeney-Kennicutt, and Davis (2014) provide evidence of the effectiveness of virtual reality-based instructions for learning (Merchant et al., 2014).

Networked virtual reality experiences are additionally noted as a valuable tool for supporting learning experience in a social context. In contrast to real settings digital environments also support a high level of freedom and experimentation (e.g., control of time, scale, physics) and flexibility which often is not possible in real environments. Another important feature of virtual environments is their adaptability to different learners (e.g., design and various forms of interactions based on gender, age, learning styles, etc.) as well as letting users actively participate in experiences (Lee, Wong, & Fung, 2010; Wan, Fang, & Neufeld, 2007).

In 1991, the author (Bricken, 1991) described the main challenges like high costs and the lack of usability for classroom and school setups. With the emergence of the new VR technologies, many of those issues are resolved. Primarily, cost and usability issues are addressed. While the first research studies in different fields of applications were already conducted very early, the emerging consumer versions of full-fledged head-mounted displays supporting virtual reality experiences have the potential to take the VR-applications directly into the living rooms. Nowadays, different versions supporting different technologies can be found in stores (Eadicicco, 2016).

Important VR technologies at the moment are the Oculus Rift, the HTC Vive, and VR-headsets, which are used together with the mobile phone as a processor. The Oculus Rift("Oculus Rift Online," 2017) offers a virtual reality experience combined with tracking of the headset and is designed to support game and experiences in a sitting position. In contrast, the room-scale setup of the HTC Vive ("HTC Vive Online," 2017) offers motion-based and position-based activities and interactions and experiences (Eadicicco, 2016).

3.4. Summary and Discussion

In this chapter, we have investigated different contributions related to our conceptual model to create motivational environments, which motivate learners through engagement (e.g., learning in playful environments) or through immersion (e.g., learning in virtual reality environments).

Digital environments are becoming more and more important for the current generation of learners. Particularly in the area of science education, digital environments support motivational features such as collaboration, enjoyable activities, and playful design. They also enhance the current way of learning science through interactive visualizations and simulations. These visualizations and simulations are increasingly important in increasing learner engagement.

Immersive environments, supported by virtual reality technologies, have also been shown to be a valuable tool to help learners. Virtual reality for learning was shown very early on to be a useful tool for promoting meaningful experiential experiences, natural and intuitive forms of interactions and interesting social and cooperative experiences. But challenges such as high costs and usability flaws hindered VR in becoming a part of the everyday classroom experience.

However, with the emergence of new and affordable VR Head Mounted Display (HMD) such as Oculus Rift, HTC Vive (and even mobile solutions through using smartphones for VR experiences), VR has now become very attractive for large scale applications.

4. MAL: Motivational Active Learning

> ”...the harder you have to try, the more points you deserve!”
>
> Oregon Trail, 1971

This chapter gives an overview of engagement strategies inspired by gamification theory, as applied to different educational settings (blended learning and fully digital). It investigates how to use strategies of our conceptual model to create motivational environments with a focus on enhanced engagement. This includes the attraction of different player types by adding elements supporting achievements, exploration, and also social interactions.

The chapter is adapted from the following published papers and chapters:

- Pirker, J., Riffnaller-Schiefer, M., & Gütl, C. (2014). Motivational active learning: engaging university students in computer science education. In *Proceedings of the 2014 conference on innovation & technology in computer science education* (pp. 297–302). ACM

- Pirker, J., Riffnaller-Schiefer, M., Tomes, L. M., & Gütl, C. (2016). Motivational active learning in blended and virtual learning scenarios: engaging students in digital learning. *Handbook of Research on Engaging Digital Natives in Higher Education Settings*, 416
- Pirker, J. & Gütl, C. (2015a). Educational gamified science simulations. In *Gamification in education and business* (pp. 253–275). Springer International Publishing
- Pirker, J., Gütl, C., & Löffler, J. (2017). Ptd: player type design to foster engaging and playful learning experiences. In *Interactive collaborative learning (icl), 2017 international conference on* (in press). IEEE

Uses of "us", "we", or "our" refer to co-authors in the aforementioned publications.

4.1. Motivation

This section has been published as part of Pirker, Riffnaller-Schiefer, and Gütl (2014) and is extended with parts of Pirker, Gütl, and Löffler (2017). In computer science (CS) education an important issue is the successful transfer of not only theoretical concepts but also teaching skills, such as computational and mathematical thinking and creative problem-solving. However, many pedagogical approaches are still auditory, abstract, deductive, passive, and sequential (Augustine, Gruber, & it Hanson, 1991) and fail in teaching how to solve problems and recite the solutions instead (Freedman, 1996). This leads to student frustration, high drop-out rates, and does not match the objectives of engineering education. As discussed in the previous chapter, there is a growing interest in developing new teaching models based on constructivist models such as interactive engagement, problem-based reasoning, and collaborative problem-solving strategies (Hake, 1998; MacKay & College, 2006). One successful implementation of interactive and collaborative learning activities is

TEAL; the way introductory physics is taught at the Massachusetts Institute of Technology (MIT).

TEAL The teaching format TEAL *(Technology Enabled Active Learning)* is grounded in interactive engagement strategies and integrates hands-on experiments, collaborative experiences, interactive visualizations and simulations, and mini lectures with concept quizzes (used with personal response systems). Analyses have shown that the failure rate has decreased and learning gains have doubled ("Technology Enabled Active Learning (TEAL)," n.d.). TEAL achieves student motivation also by integrating collaborative activities, such as group discussions. The importance of such motivating and engaging activities in education is well known, and many studies promote cooperative learning strategies in order to enhance the students' motivation and raise the attendance rate (Augustine et al., 1991; Slavin, 1990).

As we have described in our conceptual model, a rather new approach to engaging students to achieve better learning gains and to push their own personal boundaries is the integration of gamification aspects to create a motivational atmosphere through constant feedback, mini challenges, and positive reinforcement (Sinha, 2012). Unfortunately, many approaches based on gamification only use elements such as badges, rankings, or points to motivate learners. However, as we have discussed in Chapter 2, it is crucial to design gamification strategies and game-based elements for different types of players.

In this chapter, we present our pedagogical approach ***MAL*** (Motivational Active Learning), which is grounded in TEAL and combines it with motivational gamification design elements based on the engagement elements introduced in Chapter 2. These features are intended to attract different player types. The motivational environment supporting the experience is an e-learning tool integrating various game-based elements. In the following, a study is presented to analyze and discuss the impacts, prospects, and issues of this model and its concepts.

Contributions to the Conceptual Model

As introduced in Chapter 2, MAL s learning environment was designed as a *Motivational Environment* with a focus on creating not only an immersive but an engaging experience. Thus, the main design strategies include (1) clear goals and objectives, provided in-time (2) feedback and accomplishments, (3) social interactions, and (4) clear activities. The engagement activities and elements were designed with our Player Type Design process. Tasks and elements were designed in line with the following action verbs to engage different styles of players: (1) achieving, gaining, and producing for achievers, (2) exploring, researching, and testing for explorers, (3) socializing, collaborating, and joining for socializers, and (4) competing, challenging, and bragging for killers. The design goal of MAL was to offer elements and activities for all four different player types.

4.2. Motivational Active Learning (MAL)

Motivated by the positive impacts on students' learning outcomes of different innovative learning formats such as TEAL, we designed an initial version of a pedagogical model combining different interactive strategies and concepts with game-design aspects. For a first case study, we have integrated this model into a blended learning experience, supported by an e-learning tool. We have integrated different game-based elements to create a motivational environment with a focus on student engagement. Motivational Active Learning (MAL) aims to help students understanding the concepts in an engaging way. This section has been published as part of Pirker, Riffnaller-Schiefer, and Gütl (2014) and is extended with parts of Pirker, Gütl, and Löffler (2017)

4.2.1. Objectives

Hand in hand with designing an actual course in the CS domain, the objectives of the initial pedagogical model were to:

- Design a course combining (1) theoretical background and concepts, (2) algorithmic understanding, and (3) analytical understanding of mathematical models
- Engaging students by interactions and motivational activities
- Increase the students' activities and motivation for hands-on exercises

4.2.2. MAL Design

The single elements and activities of the course format to achieve those goals include a variety of question types and interactive tasks. Based on TEALs example, each lecture is organized into mini lectures, each one starting with a concept question and ending with a small concept quiz, as to be able to observe the learning progress of the students and adapt the speed accordingly. The course structure is designed to balance hands-on activities, fundamental abstract theories, and creative tasks and assignments to address the different learning styles of students. Table 4.1 lists the various activity types. Automatic assessment systems deliver immediate feedback. Assignments such as discussion questions, however, need manual grading.

Quizzes, assignments, or results of group activities such as discussion or research outcomes are submitted in an accompanying e-learning system (e.g., Moodle) to be able to track the students' progress in-time. This also enables the

Table 4.1.: Content types and their feedback options

Content Type	**Feedback**	**Definition**
Lecture Block	-	The lecture is divided into blocks. Learning content and concepts are presented on power point slides
Recap Quiz	Immediate	A small quiz at the beginning of each lecture about last lectures content
Concept Question	Overview	Ungraded question about a new concept
Concept Quiz	Immediate	based on previous concept question
Discussion Questions	Deferred	Peer/group discussions about new concepts/ideas/issues
Research Questions	Deferred	Internet research assignments for peers/small groups
Programming Task	Deferred	Programming exercises to practice learned concepts
Small Calculation	Immediate	Very small calculation tasks to practice learned concepts
Advanced Calculation	Deferred	More complex calculation tasks to practice learned concepts
Reflection Quiz	Immediate	A small quiz after each lecture to revise the content
Reflection Forum	Deferred	In an online forum groups should discuss last lectures' content and issues

possibility of giving immediate feedback (by automatic question assessment) on the students' knowledge and skill improvement by automatically awarding points and providing motivational feedback (by assigning badges and tracking leadership information). These points do not affect their grading, but triggers competitive motivation. Most of the assignments are designed to be repeatable so that the students can achieve more points by working harder for them.

Summarizing, the main features of MAL include:

- **Small learning units** (typically lectures are split into several activities in, before and after class, and the current learning progress of the students is continuously assessed). Alternative task can be chosen
- **Collaborative learning** (many assignments, such as calculation problems, research activities, or discussions are designed as collaborative activities)
- **Constant interactions** (between the theoretical learning units given by the teacher, students' are asked to complete assignments, discuss the content with peers, or have some other form of interaction with the learning content as well as with other students or the instructor)
- **Immediate feedback** (for many interactions students receive immediate feedback on their performance through the lecturer or the e-learning systems)
- **Motivational feedback** (the feedback is also enhanced by different forms of engaging feedback types such as points, ranking information, or badges; these feedback types are also designed to engage different player types)
- **Flexible and adaptive class design** (through the constant assessment in the form of interactions between the small learning units, the current learning progress of the students can be assessed through the e-learning system)
- **Errors are allowed** (students can repeat assignments, quizzes, or other

interaction types to improve, gain more points, or step up in the ranking)

To engage the four different player styles we have used our design strategy "Player Type Design "(PTD, see 2). That way we ensure that we have included design elements attracting all four player types. Table 4.2 illustrates these elements intended to attract the four different player styles based on our PTD approach. The goal is to have elements attracting all four player types.

The next section describes the first integration of MAL into a CS course with a focus on mathematical and algorithmic concepts.

4.3. Analysis 1. Gamification in the Classroom with MAL

This section has been published as part of Pirker, Riffnaller-Schiefer, and Gütl (2014). MAL was first introduced in the course *Information Search and Retrieval (ISR)* in the winter term 2013 at Graz University of Technology. The objective of the course is to build a knowledge base in selected theory and practice in searching and retrieving information with a focus on the mathematical and algorithmic concepts. The content includes topics such as indexing and searching models, retrieval algorithm, or query languages. Hence, in each lecture, it is necessary to combine theoretical background with algorithmic or mathematical concepts. The course was split into seven lecture blocks. To study the progress of the students and to support activities delivering immediate feedback the course was accompanied by the learning management system Moodle, which was the basis for creating a motivational environment in a blended learning setting. Students had to bring their own technical devices, such as laptops or tablets, to the course. The course content was presented using power point slides and a textbook.

Table 4.2.: *Player Type Design* for MAL; the column type refers to the player type (A: Achiever, E: Explorer, S: Socializer, K: Killer) attracted by the element.

Engaging Elements	**Type**	**Goal Description**	**Feedback, Reward**	**Freedom**
Small learning tasks in e-learning system	A	Complete learning unit	Feedback in form of progress-bar	Alternative task can be chosen
Finishing research assignments in groups	E S	Find answers to specific questions in a team	Get to know solutions from other groups and discuss different aspects	The extend of collaboration can differ
Answering concept questions about learning progress with visible feedback and overall in-class statistics	A K	Answer a question	Get feedback and see statistics what the rest of the class answered	
Work on clearly defined assignments	A K	Finish an assignment	Points, Leaderboard for points	
Working on clearly structured and defined assignment series	A K	Finish an assignment series	Badge	Due to bonus assignments this activity is voluntary and the series can be chosen

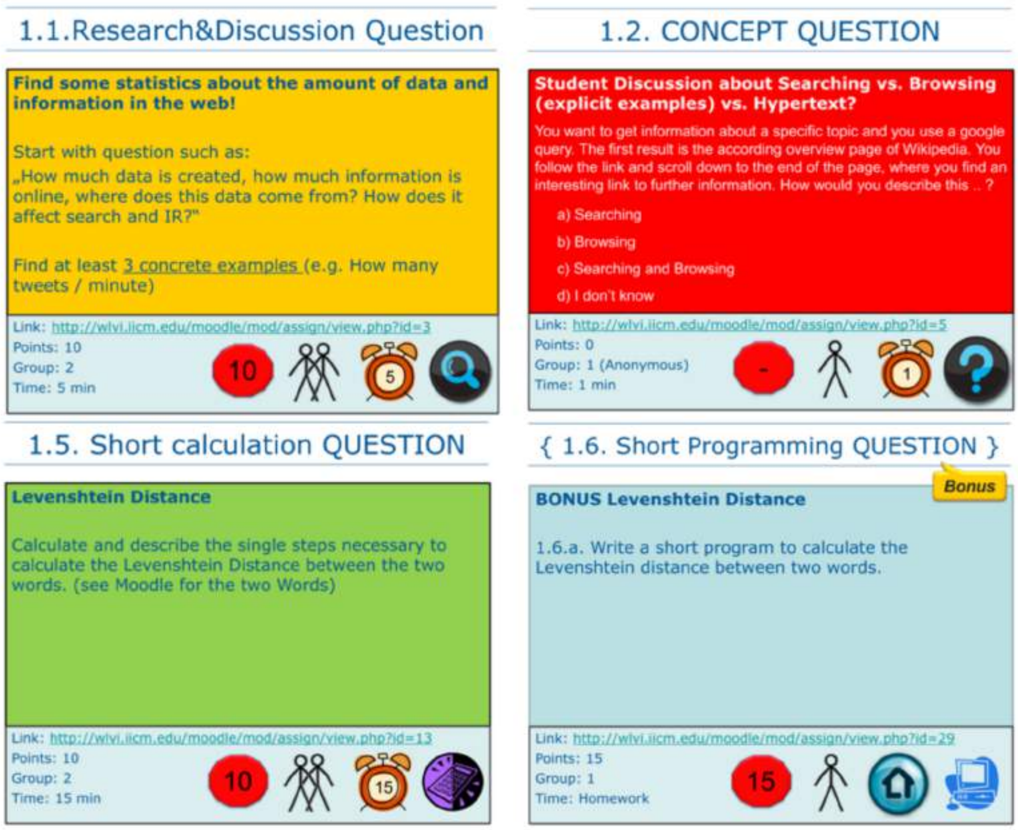


Figure 4.1.: Slides of different question types

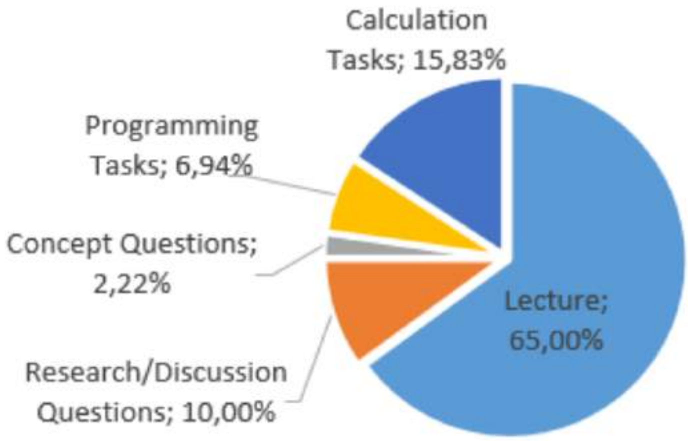


Figure 4.2.: Percentages of activities in lecture 1

Different colors and symbols highlighted special activities (see Figure 4.1). Depending on the content type, students worked individually, in groups of two, or in groups of four. The group formation did not change to make it easier for group assessment. Quizzes were designed as individual tasks, and most hands-on exercises were conducted with peers (group size 2 and 4). Most assignments were started during class and students had the possibility of finishing them as homework. Besides in-class assignments, they also had to submit homework assignments, which were in one part compulsory and in another part bonus tasks.

To track in-class activities, an external observer was taking notes and tracking the student activities. Hence, a detailed breakdown of the single lectures into the different content parts was possible. Figure 4.2 shows as an example the percentage of various activities in lecture 1. It shows a mixture of different sorts of activities such as lecture, questions, discussion, calculation, and programming tasks. Although the lecture part was predominant, Figure 4.3 and Figure 4.4 show the combination of lecture and interactivities for a single lecture and all lectures in more detail.

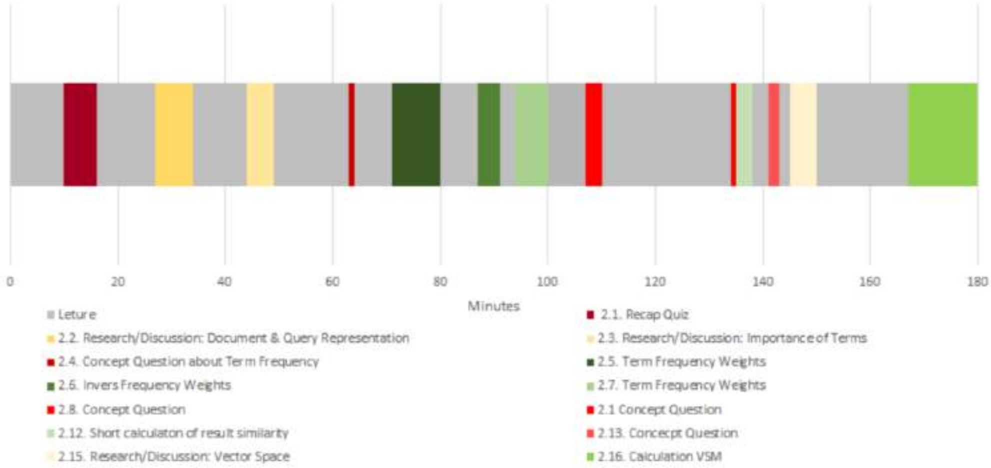


Figure 4.3.: Typical time-line of a single lecture

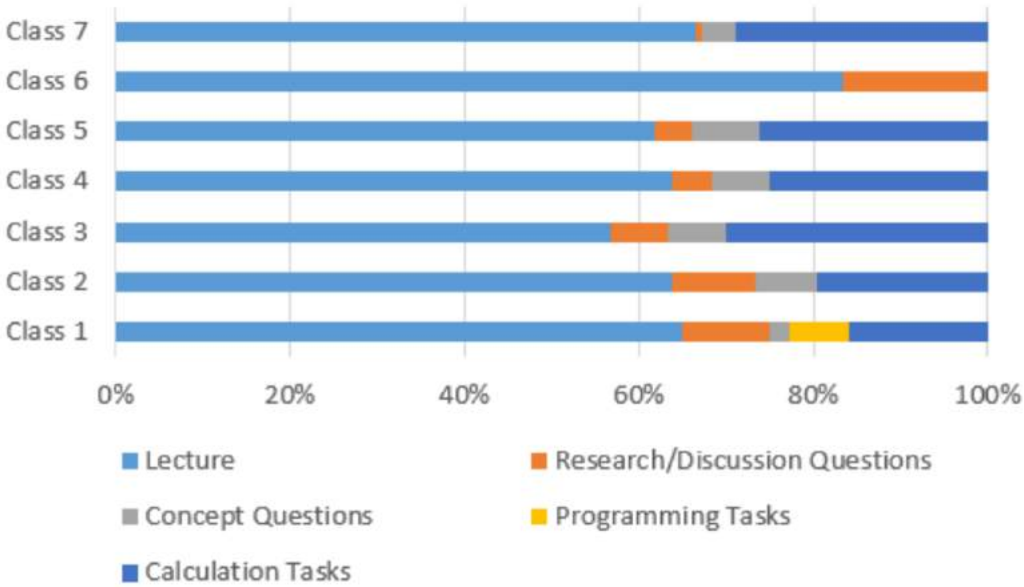


Figure 4.4.: Overview of content distribution in the lectures

4.3.1. Method

To analyze MAL, we conducted an initial study with the ISR course in winter 2013. We define the research goals as:

- Evaluate the students' understanding of the course content.
- Analyze the students' engagement and motivation.
- Analyze the students' attitude towards the new model and the e-learning environment used.

We used qualitative and quantitative methods to evaluate these goals. Moreover, a field observation during the course was used to analyze the students' behavior and engagement during the course.

Before the start of the course, we polled the students of the course via a web-based survey to learn about their expectations towards the course, their usual learning habits and motivation, their previous knowledge about the course content, and their experiences with similar learning methods. The survey consisted of Likert-scale (1 strongly disagree, 5 I strongly agree) and open-ended questions. During the course we measured the students' learning progress using small quizzes and concept questions. We collected qualitative data by observing their activity and active participation and by taking field notes. After the course and finishing the grading, we invited the students to complete a web-based post-questionnaire which should shed light on the students' motivation during the courses and their attitude towards the class structure and its content. Therefore the post-questionnaire consisted of reflection about the different content and activity types (see Table 4.1), their experiences with collaborative assignments, and questions focusing on gamification aspects. Additionally, we added 30 rating questions based on the Advanced Motivation Scale, which is used to measure different types of intrinsic and extrinsic motivation and amotivation (Vallerand et al., 1992).

4.3.2. Findings

A total of 28 students started the ISR course and one student dropped out. The pre-questionnaire was conducted by 26 (6 female) of 28 students between the ages of 22 and 31. The post-questionnaire was completed by 21 (5 female) of 27 students.

Experiencing Cooperative Learning. The tasks were balanced between assignments to be completed alone, collaborative assignments in pairs, group discussions in groups of 2, and collaborative assignments in groups of 2-4. We asked the students about their motivation towards these settings. The majority of the students stated that they preferred activities in teams and to experience advanced learning gains through group assignments. *"The group assignments during classes were the best concept. It was good to use the concept just learned to remember it better, but also eventual misunderstandings could be discussed."*

The results have shown that students prefer tasks in groups of two over individual tasks. (see Table 4.3) But it was difficult for students to solve tasks in a group of four people. In-class we observed, that even for tasks meant to be solved in groups of four, they preferred to work in groups of two and merged their results at the end. However, as the results illustrate, the learning styles of the single students differ dramatically. Even though the standard deviation indicated, that the majority of 21 students prefer assignments in teams of two over teams of four, five students would prefer bigger groups.

Experiencing Motivation. When we asked students what they did like in the course, many of them immediately mentioned that they preferred points to grades. "*[I liked] the chance to improve already graded work. It was also a motivating thing to see received points immediately*"; "*[I liked] 2nd chances"*;

Table 4.3.: Survey results of cooperative learning experiences. Arithmetic mean and standard deviation of the participants' answers on a Likert scale between 1 (fully disagree) and 5 (fully agree) are illustrated.

	AM	**SD**
I prefer activities in teams.	3.4	1.3
I prefer activities in groups of 2 over activities in groups of 4	4.1	1.3
I would have liked more activities in a team of four than in a team of two	2.3	1.6
I would have liked more single activities in this course	2.6	1.3
The topics were easier to understand in groups of 2	3.9	1.5
The topics were easier to understand in groups of 4	3.0	1.3
The topics were easier to understand alone	2.3	1.2
I prefer to be graded / get points individually	3.1	1.3
I prefer to get feedback individually	3.2	1.2
I learned more in group assignments than in individual assignments	3.4	1.1

"[I like that it is] hard to fail this course and hard to get lost and procrastinate". The study results show that students enjoyed the new grading system (see table 4.4). They prefer getting points over grades and were motivated to finish further assignments to receive additional points. Another feature was the importance of the grading book. However, the study data show that the students' engagement with the ranking information differed a lot. For example, five students agreed they were motivated to conduct further assignments, while six students disagreed. This is in line with our observation of the necessity of attracting different learning and playing styles and integrating both cooperative and competitive activities. The results also show that earning badges was neither important nor attractive to the majority of students. Just a few students noted them as engaging. This, again, is in line with our research statement that player styles also influence engagement in learning environments. However, badges can be used as positive enforcement and to give students an overview of their achieved masteries.

Experiencing Interactivities. Asking students open-ended questions about their attitude towards the course many mentioned the positive impression of the interactive content: *"I liked the interactivity of the course. It was not like in other assignment-based courses, where exercises must be done at home and then presented. There was time for researching or calculations, and then the results were discussed."*; *"I liked the interactive learning. The structure of the course, some parts lecture, immediately followed by exercises, was nice."* However, many students criticized classes with a large number of exercises. We also found that students get frustrated if they have to solve too many different kinds of tasks in one lecture. First, they are stressed because of the short time and cannot finish the task in class. Additionally, if students are interrupted in performing the tasks, they cannot concentrate on new content. They still think about the solution path of the unfinished task. Fortunately, due to the adaptive course design, it was possible to revise the course structure accordingly.

Table 4.4.: Survey results of playful learning experiences. Arithmetic mean and standard deviation of the participants' answers on a Likert scale between 1 (fully disagree) and 5 (fully agree) are illustrated.

	AM	**SD**
I liked getting points rather than grades for exercises.	4.0	1.1
I was motivated to do the bonus assignments	3.6	1.3
I liked earning badges	2.5	1.2
Earning badges was not important to me	4.4	1.2
I used the grading book to view my points	4.7	0.6
I used the grading book to view my ranking	3.7	1.4
I was interested in the ranking information	3.3	1.4
Seeing my own ranking motivated me to conduct further assignments	2.8	1.6

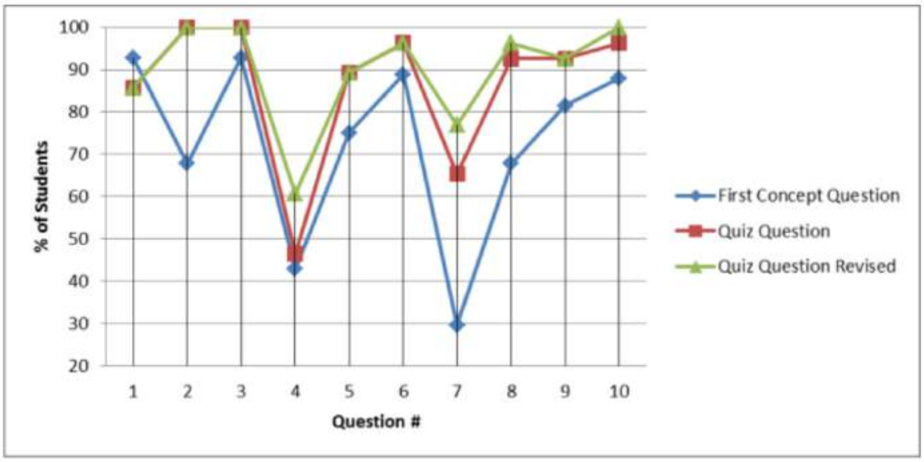


Figure 4.5.: Comparison of learning progress

Designed for Adaptability. An important part of the course was the constant attention to the students' feedback during and after the lecture. This feature, again, is inspired from game design theory and a key element when designing motivational environments. Using the concept questions, it was possible to adapt the learning content to their current knowledge base and allowed the instructor to slow down or skip topics accordingly. Moreover, after each block, we asked for feedback about the effort of the past lecture to adapt the lectures to the average class speed. According to the students' feedback this was an important step towards interactive, adaptable, and flexible class design: *"It was hard to follow all the stuff showed in the lecture, but the lecturer obviously read the feedback after each block and slowed down a little bit at the end which was much better"*.

Assessing Learning Progress. The learning progress was measured in-class before and after each mini-lecture. Students also had the possibility of revising the quizzes and assignments. Figure 4.5 shows the learning progress of the students, comparing the results of the first concept question with their answer after hearing the mini-lecture and their final answer after revising the question at home.

4.3.3. Conclusion and Discussion

Students had to finish a quiz to recapitulate the content of the previous lecture at the beginning of each lesson. We have found that the communication between instructor and students is lost if the recap quiz is the first part of the lecture. If the instructor discusses the main elements of the last lecture with the students and the recap quiz follows afterward, the loss of interaction can be prevented. One of the biggest challenges is the balance between presenting abstract concepts and interactive assignments. Also, attracting students with different learning styles is a challenging task. Having an adaptive teaching model helps in changing teaching speed and style accordingly, but also requires a customizable model for the course content. The studies showed that students preferred small calculations and programming examples over complex ones. In the following years, the exercises were redesigned to be smaller, but with the focus of having one project that grows with each exercise.

A severe issue in this course was the effort of assignments involved in grading. At this point, we have only automatized the correction of quizzes and small calculation assignments. The effort to assess and grade the rest of the assignments was higher compared to traditional lecture formats. To allow this model to work also on a larger scale, an automatic assessment of all programming and calculation assignments is crucial to the success of this format.

Learning in groups was analyzed as a valuable model for achieving optimized learning gains. However, the attitude of the students towards group sizes varies. A group size of three provides improved collaboration settings. Additionally, if one student misses a lecture, no student must work alone and the group is still able to finish the tasks in time. The current course format is designed for small classes. Constant interactions with the instructor and peers require larger courses (100+) to be split into smaller classes.

We also showed that students are engaged by different elements of this course. While some were engaged by elements such as badges, others were more interested in their rankings. To summarize, engagement through gamification elements and social features supporting different player types is a fruitful and valuable asset to create a motivational learning environment in a blended learning scenario. In the following section, we investigate the potential of this model in virtual environments.

In this section, we have shown the potential of our conceptual model to create motivational learning environments by introducing elements of engagement. In the case of MAL, engagement elements supporting different forms of engagement (through the different player types) were introduced. We have shown, how these methods can be used in a blended learning environment. However, virtual learning becomes more and more necessary and in a first small case study, we want to show also the potential of MAL in virtual environments.

4.4. Analysis 2. MAL in Virtual Learning Environments

In the previous section, we have discussed MAL in a blended learning scenario. Engagement elements based on gamification strategies and social features supporting the four different player types. Many of these elements used for MAL can also be used in a virtual environment. In this section, we want to show that the pedagogical format MAL can also be applied to other learning environments, such as entirely virtual distance-learning scenarios. Through cooperative research projects, we have developed and evaluated a virtual environment supporting MAL's features. In this section we want to shortly summarize the strand of research to demonstrate MAL's potential. Full details of this evaluation can be found in Pürcher et al. (2016) and Gütl et al. (2016). Parts of this section have been published in Pirker, Riffnaller-Schiefer, Tomes, and Gütl (2016).

4.4.1. Objectives

In this section, we want to demonstrate that engagement features of MAL can also be applied in distance-learning scenarios to meet the demands of geographically dispersed people. In this section, MAL as part of a virtual world design is discussed. In virtual worlds, people can meet independently of their current location to communicate or work together on a collaborative task. The main features of MAL should be integrated to allow engaging learning also in more immersive environments. This supports the design of motivational environments through engaging experiences in an immersive space.

4.4.2. Virtual Environment Design

To create a first prototype, the virtual world platform Open Wonderland (OWL) was extended in a way so that teachers could turn ordinary virtual worlds into learning environments for their students by providing information objects, so called *"Items"* for them. The environment was designed to support also activities attracting different player types.

Firstly, the virtual environment supports explorative and collecting tasks: Students can obtain the information by hovering over an item with their mouse cursor (they can see the information text in a pop-up window) or by clicking on the item and choosing "pick up". In this case, the information is transferred into their "inventory", which is a kind of virtual "bag" each student has.

Secondly, collaborative features are integrated. To enforce group work and collaboration, the teacher is able to assign roles to the students, which prevent them from obtaining information from all the objects. Only students with a particular role can pick up certain Items. OWL itself provides the students with a range of communication tools, including text and voice chat. Additionally, the "Itemboard", which is a kind of Whiteboard where students can share Items they found, was implemented (see Figure 4.6).

Finally, feedback options were integrated. A tool was integrated which allows teachers to assess students with a quiz functionality. If the students answer all questions of the quiz correctly, they are teleported to a new location, which could be, for instance, the next level.

4.4.3. MAL in the Virtual Environment

With the tools implemented, teachers can create a range of learning scenarios. As an example showcase, a collaborative learning scenario which follows the principles of MAL was designed. Table 4.5 summarizes processes of learning scenarios supporting MAL as part of the virtual world experience.

4.4.4. Evaluation

In a first evaluation of the virtual Egypt world (VEW) prototype test participants stated that they liked *"the constant communication and that teamwork was necessary to solve the final quiz"*. They also liked the fact that they had to search for the information and the "sense of adventure" which was conveyed that way. This is in line with the system design to support and motivate different player styles by adding elements supporting social, explorative, and achievement experiences.

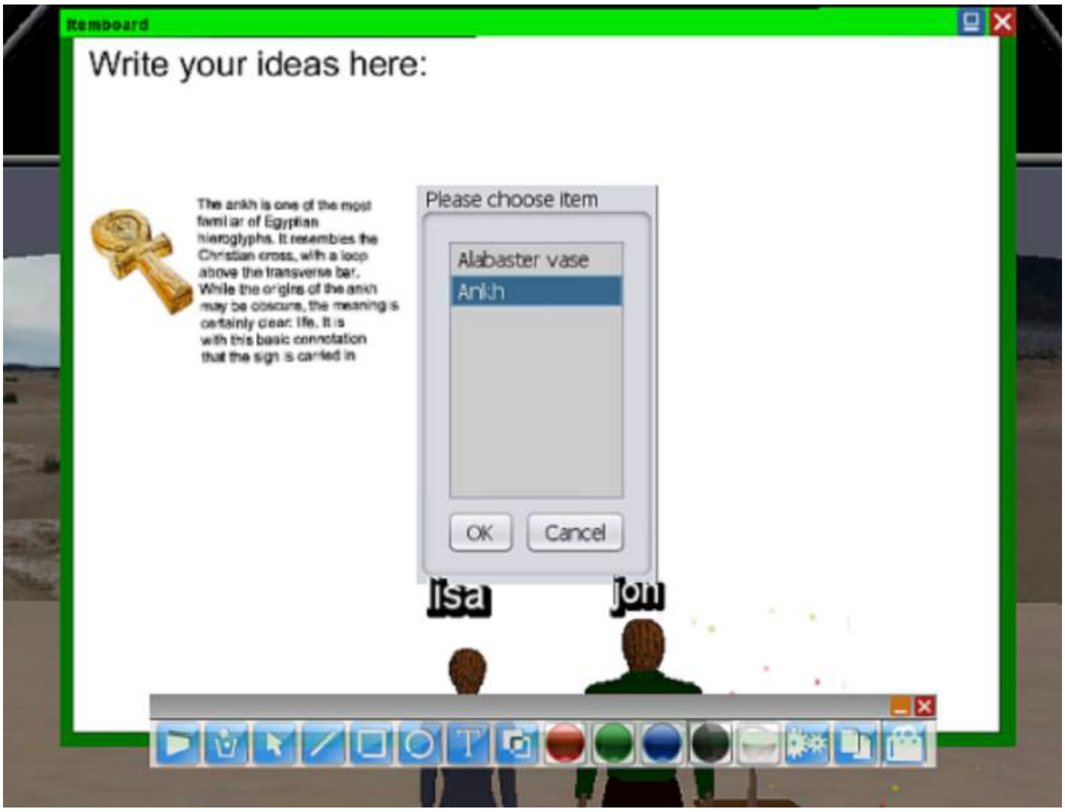


Figure 4.6.: Students sharing information in a collaborative way at the item board

Table 4.5.: Steps of the learning process in the virtual world and according MAL features

Step of learning process in the virtual world	**Feature of the MAL approach**
(1) The students meet online by logging into the virtual world.	
(2) The teacher assigns each student a role. Students can see their current role at any time.	
(3) The students start exploring the virtual environment and try to find all information objects the teacher has provided for them.	collaborative learning/interactions between students
(4) The students share the information they found. Ideally, one student gives away a piece of information he has in exchange for some information he was not able to obtain	collaborative learning/interactions between students
(5) Each student individually does a quiz on the learning topic to make sure he has understood everything. This also gives the teacher the possibility of assessing the performance of the students.	constant activities/immediate feedback/allowance for errors; if students are not able to answer a question of the quiz they can always go back to step (3) or (4)

Participants mostly agreed that the system would be a valuable addition to learning from textbooks in schools, because through collaboration with other students and the interactive environment the students are likely to feel motivated and encouraged. Moreover, through the virtual environment, the students would have a reference to the topic they are supposed to learn about. This could be especially useful in the subject of history where historical buildings or locations could be recreated. We conclude that MAL not only combines the benefits of blended learning and virtual learning but also adds gamification elements to foster student's motivation.

In this evaluation, we showed the potential of MAL as a tool to engage learners in virtual environments. The character of such virtual environments to create the feeling of immersion has been described by several participants. Especially the environments design and exploratory experiences have potential to create a feeling of immersion. In the following chapters, we introduce similar virtual environments designed to create immersion to support and motivate learners.

4.5. Summary and Discussion

MAL (Motivational Active Learning) is a learning format supporting different player and learner types. It is based on active and collaborative learning strategies and grounded on TEAL and combines it with elements inspired by game design theory. It is created based on the model presented in Chapter 2 to create motivational environments with a focus on engagement. Unlike previous approaches the model is designed to support various forms of game elements supporting different player styles: (1) cooperative elements, (2) competitive elements, (3) explorative elements, and (4) elements to display achievements. These elements have been incorporated in the e-learning software "Moodle".

In an initial study, we evaluate the attitude of the students towards MAL and its learning concepts. Stuart and Rutherford have shown that students can concentrate for a maximum of 10-15 minutes (Stuart & Rutherford, 1978). In contrast, we found that students can follow a more theoretical lecture in combination with some discussion questions up to even three hours. One reason for the long lasting concentration could be that in an interactive learning environment, students are more focused because there could be a new activity at any time. This result is important because McConnell has shown that learning content, which is difficult to understand, should be presented in the form of a lecture (McConnell, 1996). The teaching format was a good fit for the course content, which integrated theory, mathematical concepts, and algorithms. The combination of interactive and engaging strategies motivated students to finish more assignments on their own accord. Giving students points instead of grading them with traditional grades was an important step towards positive enforcement.

We have learned that it is crucial to design a learning environment by integrating different engagement elements, which attract different types of learners and players. Additionally, fast feedback and flexibility such as an adaptive course content allow instructors to adjust the speed and difficulty to the class' learning style and level.

5. Maroon: Immersive Physics Laboratory

> ”I don’t know what’s the matter with people: they don’t learn by understanding, they learn by some other way — by rote or something. Their knowledge is so fragile!”
>
> Richard Feynman

In this section, we introduce Maroon. Maroon is an educational virtual physics laboratory integrating different experiments, visualizations, and simulations. It supports different interactive engagement and immersion strategies. Looking at our conceptual model for creating motivational environments, we mainly use immersion techniques to design Maroon in a more motivating way. We primarily use tools such as a head-mounted display to boost the feeling of immersion. The devices we use for the implementation introduced are on the one hand mobile VR devices and on the other hand room-scale VR devices. In the second part of this chapter, we also discuss ways how to include more engagement elements (such as collaborative features and structured activities). This chapter aims at integrating and investigating design features based on immersion and engagement to create motivational environments for learning physics. We want to get a better understanding of the element immersion and engagement as part of our conceptual model.

This chapter is adapted from the following published papers and articles:

- Pirker, J., Lesjak, I., & Gütl, C. (2017b, July). Maroon vr: a room-scale physics laboratory experience. In *2017 ieee 17th international conference on advanced learning technologies (icalt)* (pp. 482–484)
- Pirker, J., Lesjak, I., & Gütl, C. (2017a). An educational physics laboratory in mobile versus room scale virtual reality–a comparative study (extended). *International Journal of Online Engineering (iJOE)*, *13*(08), 106–120
- Pirker, J., Holly, M., Hipp, P., Koenig, C., Jeitler, D., & Gütl, C. (2017). Improving physics education through different immersive and engaging laboratory setups. In *Interactive mobile communication technologies and learning (imcl), 2017 international conference on* (under review). Springer

Uses of "us", "we", or "our" refer to co-authors in the aforementioned publications.

5.1. Motivation

In this section, we discuss the Maroon's main motivation and inspiration. The section is mainly based on Pirker, Lesjak, and Gütl (2017b).

Students often describe natural science education as a "boring" and non-intuitive field. STEM (science, technology, engineering, and mathematics) classes are even described as "ineffective and uninspiring", and many students still indicate that they have little interest in studying such subjects (Olson & Riordan, 2012) and often have issues focusing on the learning tasks.

As discussed in chapter 2, active learning has been empirically validated as a valuable tool to improve student performance in examinations and decrease failure rates when compared to traditional teaching formats (Freeman et al., 2014). Active learning models such as TEAL (Dori & Belcher, 2005) promote direct interaction with the learning content: instead of simply passively listening to a teacher (as in traditional lectures), students are encouraged to actively discuss and solve problems, work together in groups, interact in role-playing scenarios, or use interactive simulations (Meyers & Jones, 1993). In particular in physics education, the use of interactive simulations has been proven to be a valuable tool for active learning scenarios. They provide a powerful environment to let students experiment with concepts and understand underlying physical phenomena and processes (Jimoyiannis & Komis, 2001). Digital simulations and virtual laboratories allow students to experiment with the physical phenomena in a safe environment. Simulations enable them to see concepts which are not visible in real life (e.g., field lines). This helps them to understand the underlying concept better and link it to the theoretical formulas (Dori & Belcher, 2005; Pirker & Gütl, 2015a).

TEALsim (Belcher et al., 2007) is a standalone open-source Java-based simulation framework developed at MIT. It provides different electromagnetic physics simulations and visualization to support students in learning the underlying concepts (see Figure 5.1). TEALsim has been shown to be a valuable tool in supporting different pedagogical approaches such as TEAL. However, TEALSim's is designed to run on desktop-computers, and its support for different learning environments and different engagement types is limited. For this purpose, we introduce *Maroon* as a framework in the form of a virtual laboratory environment enabling the integration of various simulation and visualization tools such as TEALsim. Additionally, Maroon enables different forms of integrations and interactions for the support of different engagement styles.

Maroon is inspired by TEALsim and extends it with new interaction forms

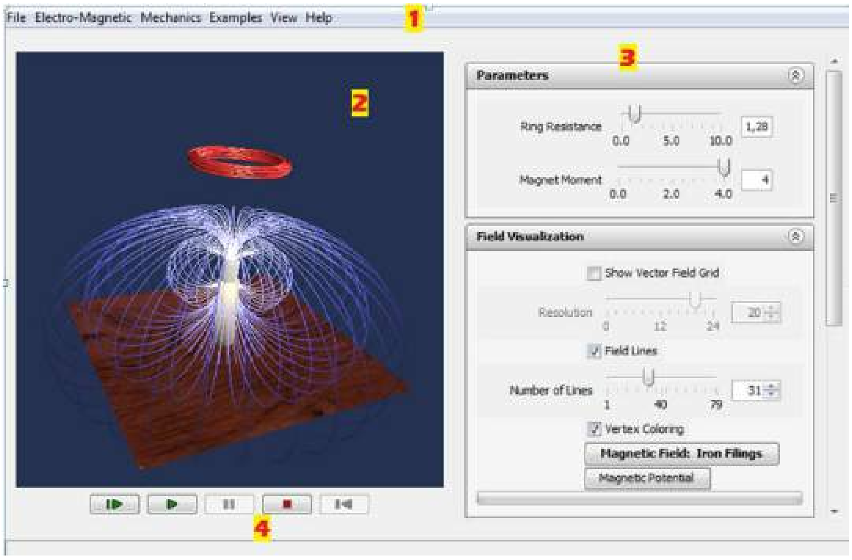


Figure 5.1.: Original stand-alone version of TEALsim simulating a Falling Coil experiment (Pirker, Berger, Gütl, Belcher, & Bailey, 2012)

supporting *engagement*, such as virtual collaboration features, and *immersion* such as virtual reality setups in an extensible and flexible virtual laboratory setup. For this purpose, in a first step an updated version of TEALsim has been implemented with the Game Engine Unity [1] (see Figure 5.2). Unity supports the deployment of applications to multiple platforms including mobile phones, VR, AR, consoles, or the web. This support enables a more flexible and dynamic integration of TEALsim to different environments such as web-based stand-alone version, mobile applications, MOOC integrations (with the web-based version), or the integration into a virtual laboratory such as described in this thesis through the implementation of Maroon.

In the following sections, the design and implementation of Maroon and forms of Maroon supporting different forms of engagement (Multi-user Maroon) and immersion (Maroon VR) are introduced.

[1] http://unity3d.com

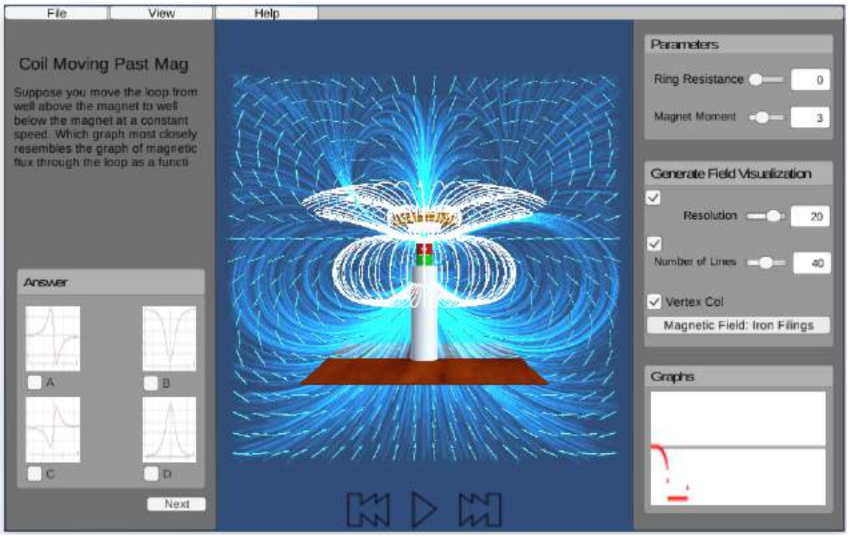


Figure 5.2.: TEALsim ported from Java to the Game Engine Unity

5.2. Maroon

In this section, we introduce Maroon. The section is mainly based on Pirker, Lesjak, and Gütl (2017b). *Maroon* is designed as a three-dimensional extensible virtual laboratory developed in Unity[2]. Maroon supports the integration of various physics experiments, which illustrate and simulate physical phenomena.

Maroon is designed based on our conceptual model with a focus on supporting student motivation through design concepts to enhance immersion and engagement.

For this thesis different versions of Maroon supporting various forms of immersion and engagement have been developed as prototypes. These prototypes are used to test, evaluate, and compare these environments and technologies (with a focus on virtual reality setups) in their support of immersion and engagement

[2] http://unity3d.com

(see Chapter 6). We aim at creating this comparison to give recommendations for further educational scenarios and models to engage and immerse students.

Requirement Design

Maroon was designed based on the following requirements. The primary focus is a flexible and extensible design and the support of different forms of engagement and immersion:

i) a flexible system that can be used either as stand-alone application or as an extension of other systems and tools such as learning management systems or MOOCs
ii) the possibility of integrating new learning elements and experiences (such as simulations, learning content, experiments, or visualizations)
iii) deployment to different platforms (including mobile applications, web applications, or as applications for different operating systems)
iv) the possibility of supporting various forms of immersion through the integration of emerging virtual reality technologies
v) the possibility of integrating activities and features supporting different forms of engagement (e.g., multi-user features, exploration, interactivities,..)

Immersive and Engaging Form of Maroon

Based on the list of requirements, we have developed and investigated the following main versions of Maroon supporting different concepts to design motivational environments:

- **Maroon**: The standard version of Maroon is designed as a virtual laboratory for the PC (through a desktop application or a web application as "screen-based variant") containing different simulations and experiments. Moreover, a first prototype of a multi-user setup has been implemented. This version forms the basis for Maroon VR and is extended with new features to support those technologies.

- **Maroon VR**: Maroon is extended by the support of different virtual reality technologies. For this thesis, we have implemented and investigated two major VR technologies:

  - **Maroon Mobile VR**: Maroon Mobile VR supports interactions with Maroon and its content through a mobile virtual reality head-mounted display (implemented with the Samsung Gear VR). This solution is designed mainly as a tool to support in-class scenarios. The first prototype of a multi-user setup has been implemented supporting two different scenarios: (1) free interactions; (2) guided interactions.
  - **Maroon Room-scale VR**: Maroon Room-scale VR supports interactions with Maroon through a room-scale virtual reality setup implemented with the HTC Vive.

Figure 5.3 summarizes the different version of Maroon as designed and prototyped based on our conceptual model supporting immersion and engagement. On the x-axis, we illustrate the support through immersive technologies (from a standard screen-based version to a room-scale virtual reality setup). On the y-axis, we demonstrate the support through engagement strategies (in that case social interaction and activities such as exploration and hands-on interactions). Engagement through activities is achieved with exploration in all versions of Maroon. Additionally, Maroon Room-scale VR supports hands-on interactions. Engagements through social interactions are mainly collaborative activities, which are part of Maroon's multi-user variants.

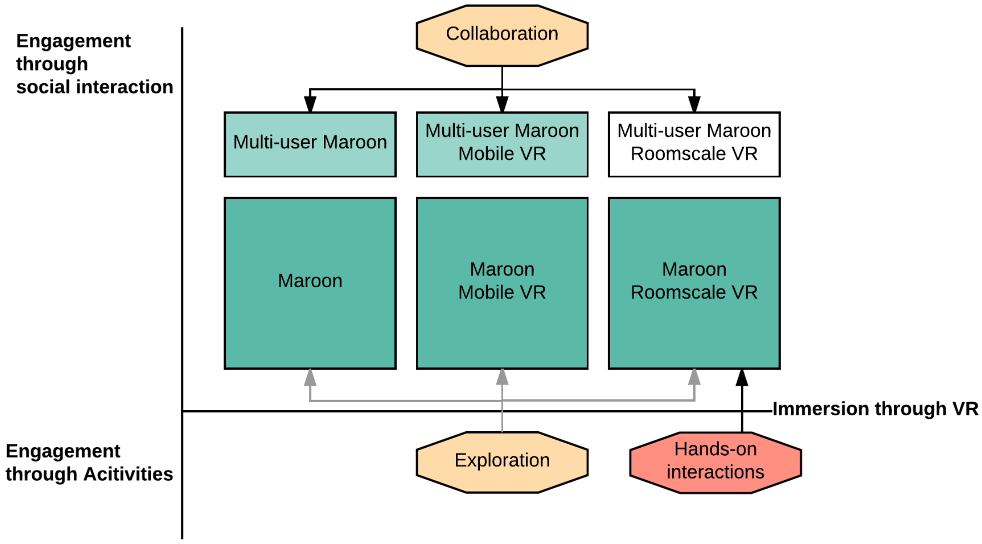


Figure 5.3.: Different version of Maroon environments supporting different engagement and immersion strategies

5.2.1. Main Concepts and Principles

The main idea of *Maroon* is to provide a laboratory space which enables the integration of different learning experiences such as experiments, simulations, or learning objects. Users should be able to walk through this laboratory and start different learning experiences. The main laboratory room shows demonstrations of every learning experience, and is designed as a virtual "main menu". Each learning experience is implemented as a separate room and users can start those experiences by entering the dedicated room through the main laboratory.

In the first prototype, we have integrated two main experiments and two interactions. The environment is designed as an open laboratory room with different "stations", which represent experiments or activities (see Fig. 5.4). In the main version (for support of interactions via web and desktop applications), the controls are designed similar to those of computer games. Interactions are designed for keyboard and mouse controls (Pirker, Lesjak, & Gütl, 2017b). A first prototype contained different electromagnetic and electrostatic experiments, an interactive white-board, where users can scroll through various learning concepts (images explaining learning concepts loaded into the world, e.g., by a teacher), and a multi-choice quiz, which is started when a user approaches a 3d model of a laptop.

Van de Graaff Generator The first experiment (see Figure 5.5) visualizes an electric field (including field lines) between a Van de Graaff Generator ("Van de Graaff generator - Wikipedia," n.d.) and a grounding sphere. When the Van-de-Graaff-generation is switched on, a positive charge is created, and the paper at the top of the generator will rise. If the voltage is high enough and the distance between the generator and grounding sphere is close enough, electrons spark through the grounding sphere to the earth, and the paper stripes stop rising until the charge in the Van der Graaf sphere is rebuilt. Users can change

Figure 5.4.: Overview of Maroon's lab interface with different stations as the starting points for different experiments and learning epxeriences

the distance between the grounding sphere and the generator to see how the frequency of the discharges changes.

Balloon at Van de Graaff generator The second experiment (see Figure 5.6) simulates the behavior of a balloon which is placed between the grounding sphere and Van de Graaff Generator ("MIT TechTV – Inducing Dipoles with a Van de Graaff Generator," n.d.). When the generator is started, a positive charge is built in the generator's sphere, and the balloon is pulled towards the sphere. As soon the balloon touches the sphere, the charge of the balloon is changed from minus to plus, and the balloon is repelled from the generator and is pushed toward the grounding sphere. When it touches the grounding sphere, the charge again reverses, and the balloon is pushed away from the grounding sphere.

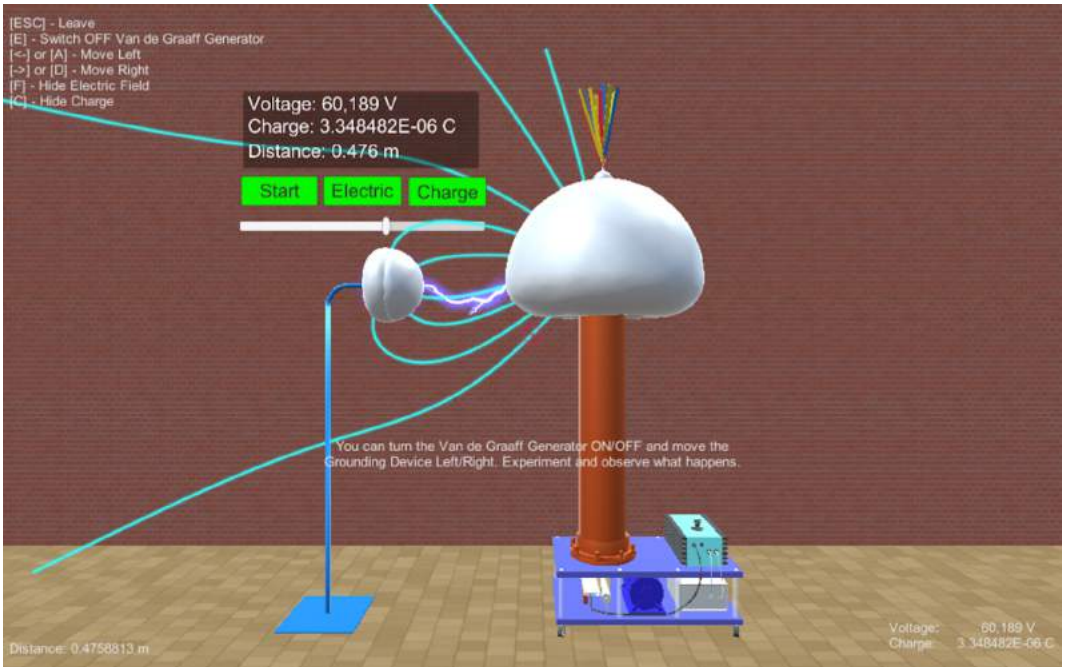


Figure 5.5.: Van de Graaff generator in Maroon

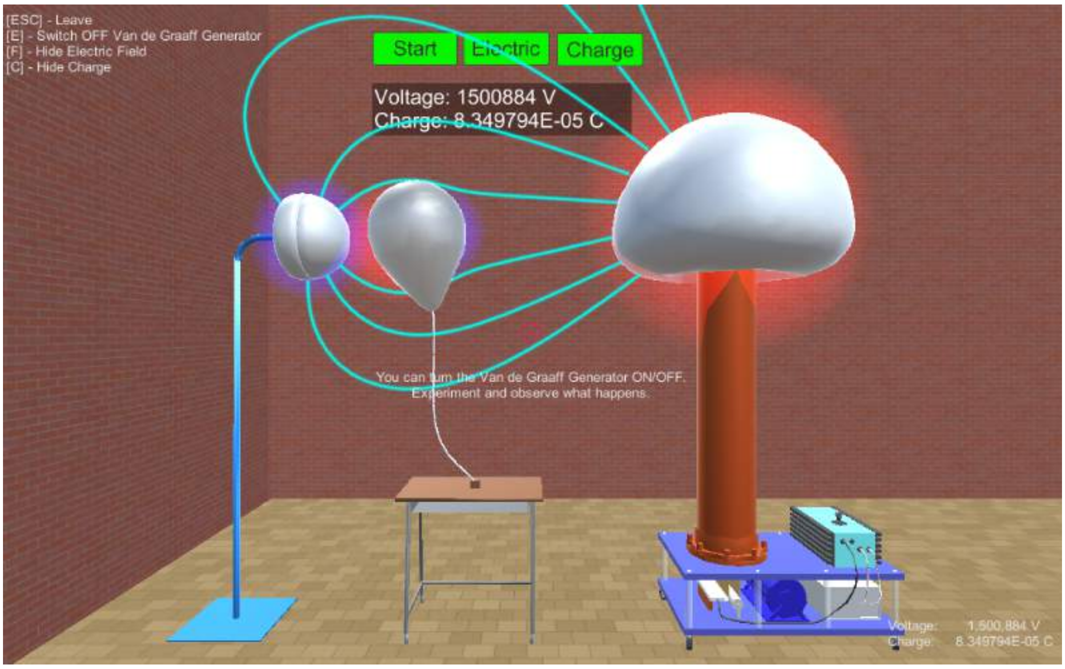


Figure 5.6.: Balloon between Van de Graaff generator and grounding sphere

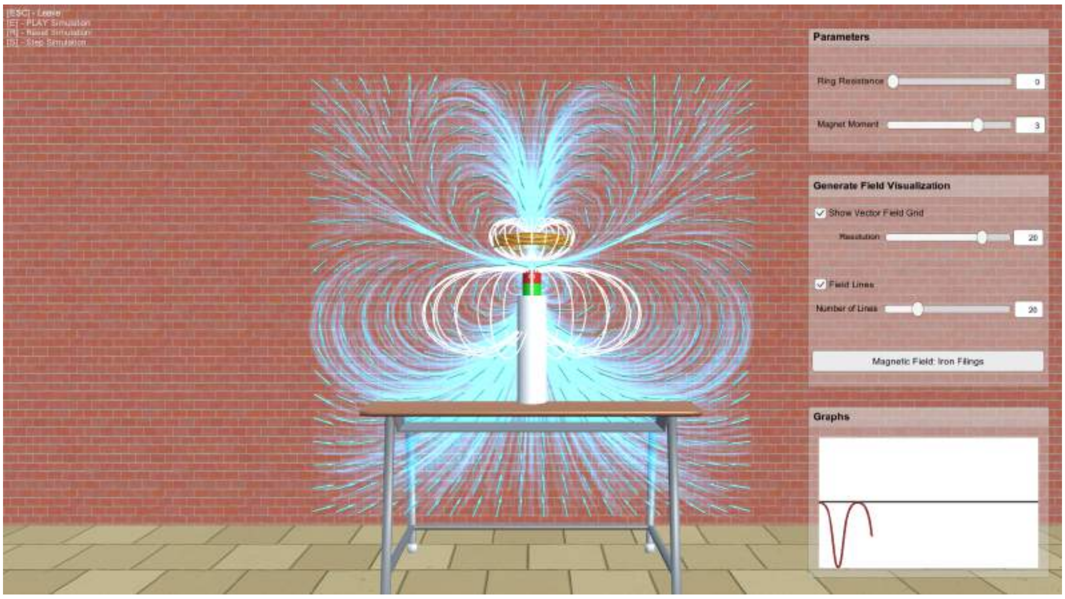


Figure 5.7.: Falling Coil simulation

Falling Coil The third experiment (see Figure 5.7) is a simulation from the original TEALsim (“TEAL3D - The Falling Coil Applet,” 2004). It demonstrates the dynamics between a non-magnetic ring and a fixed magnet. Elements such as the current in the ring and the *magnet moment* can be changed by the user. Additional visualizations such as field lines, vector fields, or an iron filing make the experiment more interactive and help students to understand the underlying concepts.

Faraday’s Law The fourth experiment (see Figure 5.8) is also a simulation from the original TEALsim (“TEAL3D - The Faraday’s Law Applet,” 2004). It demonstrates the electromagnetic interactions between a non-magnetic ring with a resistance and an inductance and a magnet. The interaction possibilities and the interface design are very similar to the Falling Coil simulation. Ring resistance, inductance, and the magnet moment can be changed, and visualization of field lines, vector fields, flux graph, and iron filings are supported.

Additionally, users can click and drag the ring or the magnet.

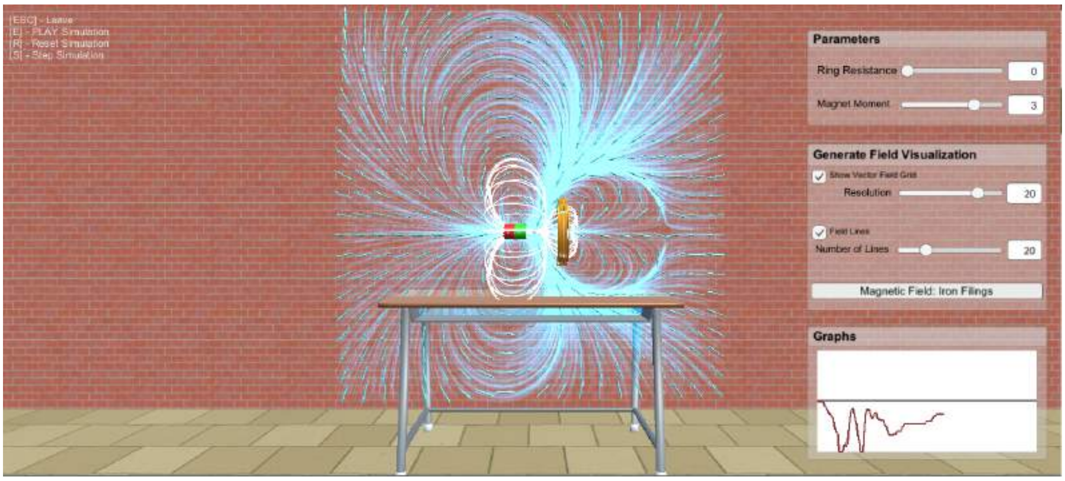


Figure 5.8.: Faraday's Law simulation

5.2.2. Design and Implementation

In the following sections, we discuss the design and implementation details of Maroon.

Conceptual Architecture

As illustrated in Figure 5.9, Maroon builds the core as laboratory framework and is extended with different experiments, visualizations, and simulations. The standard desktop application can be extended with VR support through *Steam VR*[3] for the HTC Vive. The Android application is extended with the Oculus Mobile SDK [4] to deploy Maroon Mobile VR with Samsung Gear VR support. Maroon, built as a web-based application, builds on WebGL.

[3]https://www.assetstore.unity3d.com/en/content/32647
[4]https://developer.oculus.com/downloads/package/oculus-platform-sdk/

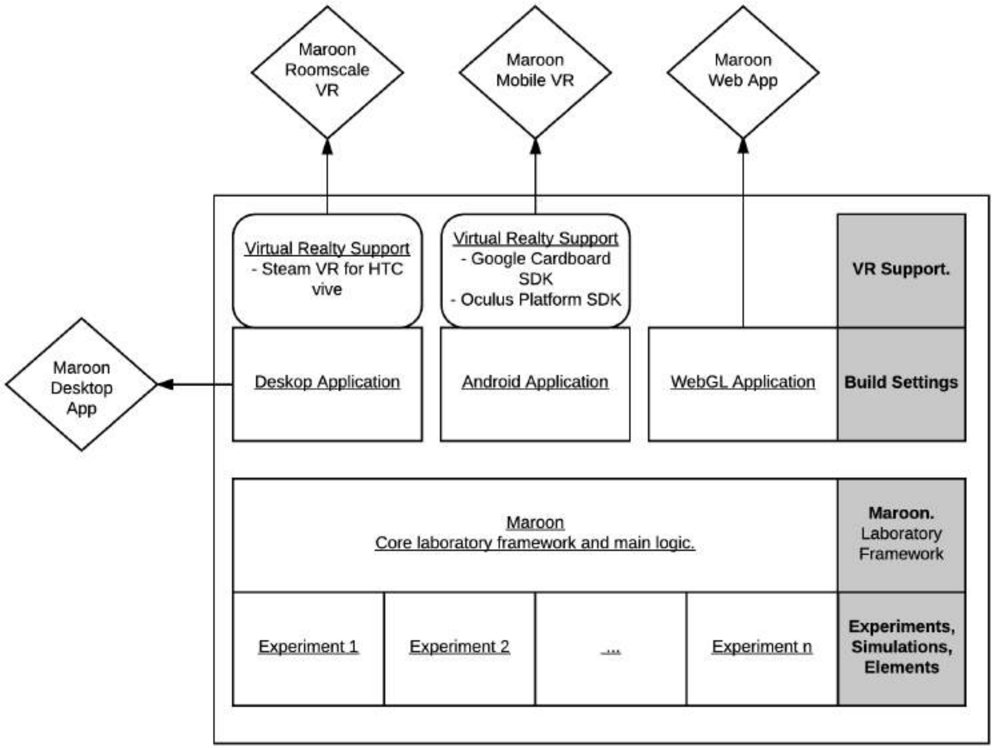


Figure 5.9.: Conceptual architecture of Maroon and the deployment to different virtual reality technologies

Unity

Unity[5] was used as a game engine to realize the prototypes. Unity enables the creation of 2D, 3D, VR and AR applications, and games. Unity comes with a powerful graphics engine and an editor that makes the creation of applications easier. Additionally, Unity supports the deployment of the same application to different media types and devices. This includes the deployment to mobile devices, PCs, consoles, the web, virtual reality devices, or home entertainment systems ("Unity - Fast Facts," n.d.). As Unity is also very popular among developers and often also used by non-programmers to develop game-related experiences or environments, it was also used as the basis to develop Maroon. This makes it easier for future editors and creators (such as teachers) to also extend Maroon with new content such as learning concepts or experiments.

Procedural Generation of the Environment

Maroon was designed to support procedural generation of the laboratory. This means that the content of the lab should be placed dynamically based on an algorithm and not manually. This should help non-programmers to create and add new learning experiences to the lab more quickly. Models or image representations are placed in the lab as starting points to enter the actual learning experiences which are placed in a different scene (room). A teacher would, for example, assign specific learning experiences to the learning room. The learning room is generated automatically based on the settings of the teacher containing only the selected learning experiences. While the final steps to integrate features supporting the procedural generation of lab-spaces with any content is not part of this thesis, the design of this lab already fully supports this procedure. Further details are described as part in the future work section.

[5] unity3d.com

5.3. Maroon VR

In this section, we introduce Maroon VR. The section is mainly based on Pirker, Lesjak, Parger, and Gütl (2017), Pirker, Lesjak, and Gütl (2017a). Adding immersion as a central concept to the learning experience adds new ways to create professional and motivating working and learning environments. The use of virtual reality headsets and technologies is a promising way to create a more immersive, engaging, and interactive environment. With the current efforts to produce VR headsets, which are affordable for private users (e.g., PlayStation VR, Samsung Gear VR, HTC Vive), VR is also becoming more attractive as a tool to enhance classroom experiences.

As described in our conceptual model, adding immersion is one key element to create motivational environments. Already the screen-based version of Maroon is designed as an immersive experience. Users visit the laboratory in a first-person view. In this mode, however, full immersion and concentration on the learning environment, is disrupted through elements outside the computer screen. Compared to that, head-mounted displays usually allow a more immersive and focused experience.

The immersive physics laboratory Maroon is designed as a reduced and simplified showcase of an interactive educational physics laboratory. It contains a subset of educational experiments to evaluate usability and user experience in VR and to measure factors such as engagement, immersion, and learning progress.

Unity supports stereoscopic rendering for different VR devices, including the Samsung Gear VR[6], HTC Vive[7], and Oculus Rift[8]. We aim at investigating on the one hand a mobile virtual reality experience (Maroon Mobile VR) and

[6] http://www.samsung.com/us/mobile/virtual-reality/gear-vr/
[7] https://www.vive.com/
[8] https://www.oculus.com/rift/

on the other a fully immersive and more interactive room-scale VR experience (Maroon Room-scale VR). With the Samsung Gear VR and the HTC Vive, we have selected two very different popular, state-of-the-art VR devices to base our prototypes and a comparative evaluation on. The original Maroon lab prototype was the design basis for the two VR variants. Depending on the purpose of the prototype, different learning experiences of the Maroon lab were integrated into the two VR versions. In particular for user interaction, navigation, manipulation, and selection of UI elements with the virtual world, we chose two different design approaches to consider various limitations of these two VR devices. For the mobile VR variant, interactions with the environment and the experiments are mostly performed through gaze. Users of the HTC Vive use two tracked controllers to navigate and interact. Samsung Gear VR additionally provides possibilities for interacting through touch and slide input. The HTC Vive benefits from several buttons on both it's tracked controllers which can be specifically programmed and also visually adapted for individual user actions. The navigation designs for the two VR alternatives are discussed in more detail in the following section.

5.3.1. Maroon Mobile VR

The Setup

Samsung Gear VR (see Figure 5.10 and Figure 5.11) is a virtual reality headset released in 2015 and is compatible with Samsung Galaxy mobile devices. The Samsung Gear VR headset acts as a mount for the mobile device rendering the VR applications, but also as a controller. The field of view is controlled through movement of the head. The headset also includes a touchpad on the side to enable interactions with the application such as a button-press ("Gear VR Samsung US," n.d.; "Samsung Gear VR - Wikipedia," n.d.).

Figure 5.10.: Maroon Mobile VR in the Samsung Gear VR

Figure 5.11.: User with Samsung Gear VR

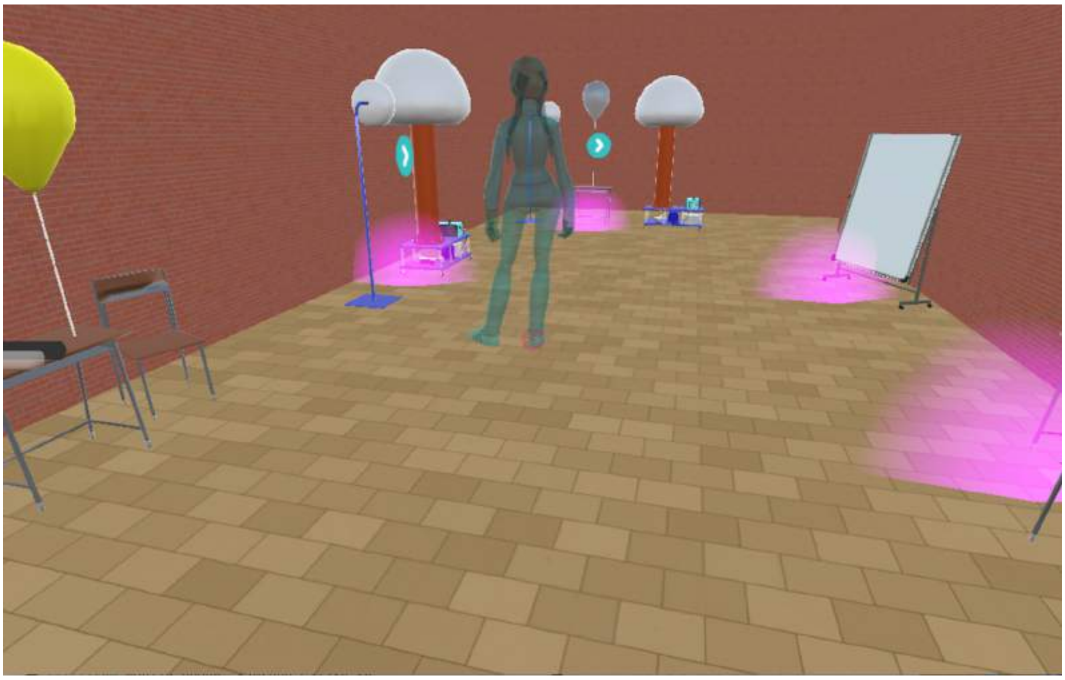


Figure 5.12.: Laboratory view with the avatar to represent a new teleportation point

Design and Interactions

Given the Samsung Gear VR system with the smartphone inserted into the HMD, a real-life like user experience is achieved through a combination of eye gaze, a virtual avatar, and a touchpad mounted on the side of the device, with user actions such as double tap, long press and swipe to rotate. Here, the user controls are mostly designed for gaze and tap interactions. An avatar (see Figure 5.12) is controlled with a gaze point to move through the laboratory. The avatar is always placed on the gaze point - the center of the screen - and can be moved by moving the gaze. Simulations can be started by moving the gaze cursor to the start button (see Figure 5.13). Movement is designed by teleporting the avatar to different locations. Sliding (only supported by Samsung Gear VR) can be used optionally to rotate the character or to move

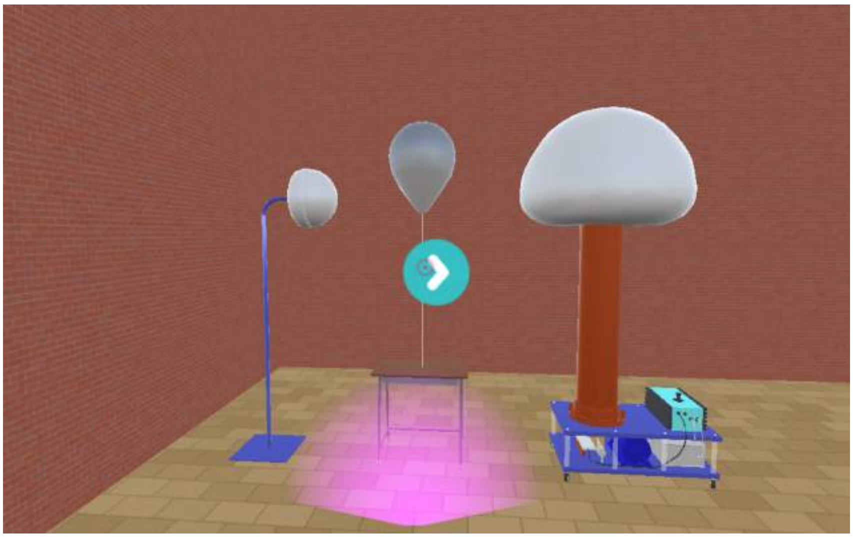


Figure 5.13.: To start experiments users need to focus the gaze on the start symbol (play button)

specific controls (sliders) of experiments.

An implementation for Google Cardboard would feature an interaction with buttons through gazing for a specific amount of time on a button to active it.

5.3.2. Maroon Room-scale VR

The Setup

In contrast to mobile virtual reality environments, the HTC Vive system consists of a larger HMD connected to the PC as well as two additional controllers, which include a highly-sensitive touchpad and individually programmable buttons with haptic feedback for improved user interaction within virtual worlds (see Figure 5.14 and Figure 5.15). Two base stations (lighthouses) track each hardware element in the Vive setup, This eliminates the need for an avatar and further enables the user to move around freely. This creates a more immersive

Figure 5.14.: HTC Vive setup

room-scale VR experience. For the HTC Vive, the official SteamVR[9] plugin and framework were used.

Design and Interactions

The main difference between the implementation for Samsung Gear VR and HTC Vive was the addition of objects, which allow user-interactions in the HTC Vive version and its lack of a virtual avatar. By using several programmable controller buttons as well as touchpad press, HTC Vive users can benefit from further real-life like interaction possibilities. The necessity of a virtual avatar was not necessary for these since users carry both HMD and controllers which are being tracked by the lighthouse system. Simulations are started by entering a portal-like object through a button press on the controllers. Movement as in teleporting is achieved by pressing the touchpad on one of the controllers, which in turn acts like a pointer, as the user aims at the preferred target and displays a precise colored beam for visual orientation.

[9]http://store.steampowered.com/steamvr

Figure 5.15.: User with HTC Vive

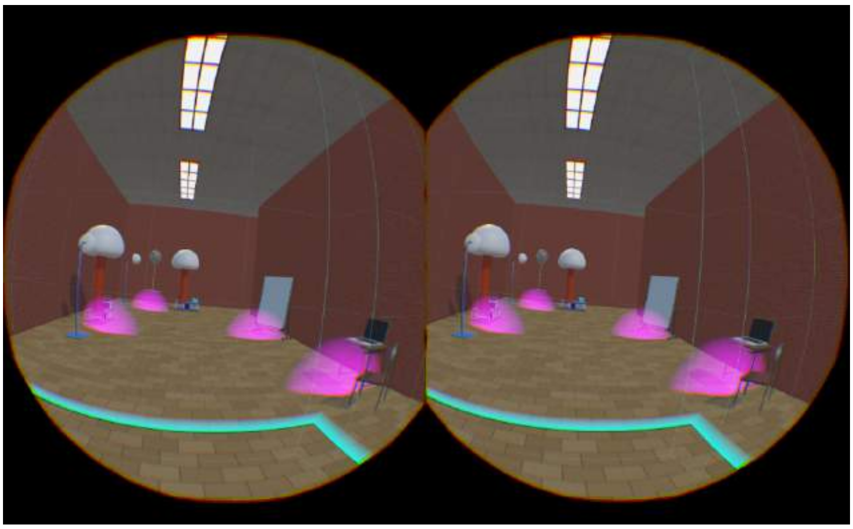


Figure 5.16.: Laboratory with different stations in a stereoscopic view

Figure 5.17.: Laboratory with different stations new design

Ultimately, the goal in developing these simulations in a room-scale VR scenario is to let users more or less act the same way as if they were placed in a real-life physics laboratory. As of now, users are - to some extent - able to immerse themselves into this world while being shielded from (visual) influences of their actual physical surrounding. As such, immersive 3D has shown to be a beneficial aid to present difficult concepts in physics, such as the effect of switching a Van De Graaff generator on and off.

In order to showcase the manifold possibilities of user interaction with virtual objects using controller mechanisms, the HTC Vive version of this station additionally features an interactive playground with different textured objects such as throwable and grabbable cubes and metal balls.

Figure 5.16 and Figure 5.17 illustrate two different design version of Maroon in the room-scale setup. Figure 5.18, Figure 5.19, and Figure 5.20 illustrate the different experiments as described in Maroon in the setup with the HTC Vive. Interactions were moved from a traditional HUD screen to a more intuitive in-world design to make the experience more immersive and lab-like.

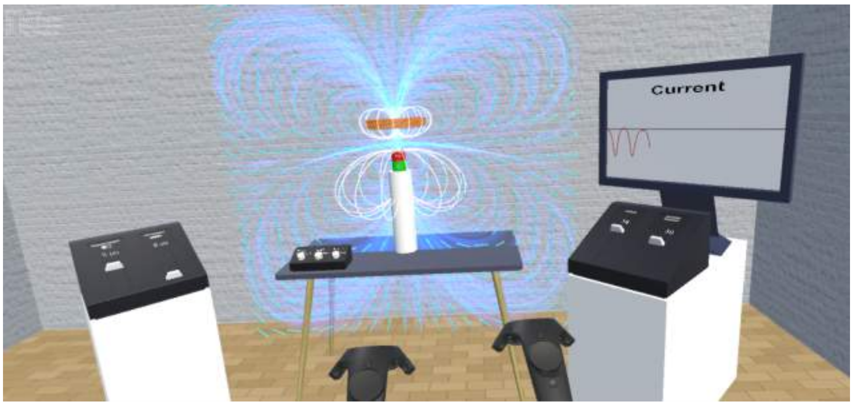


Figure 5.18.: Falling Coil experiment with the HTC Vive

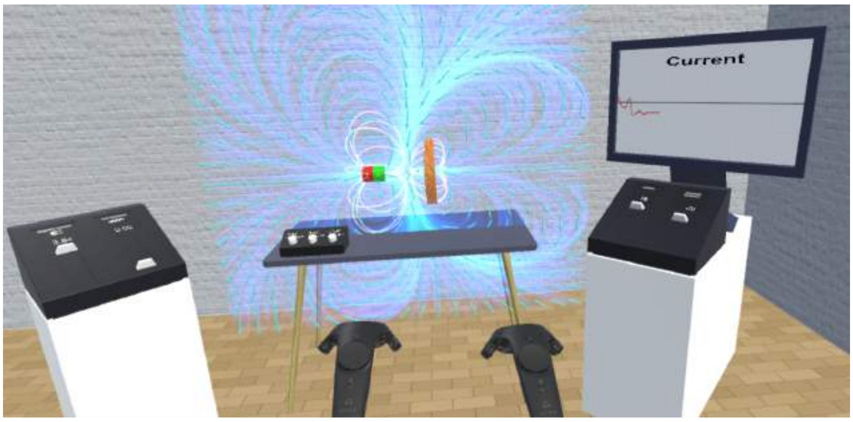


Figure 5.19.: Faraday's Law experiment with the HTC Vive

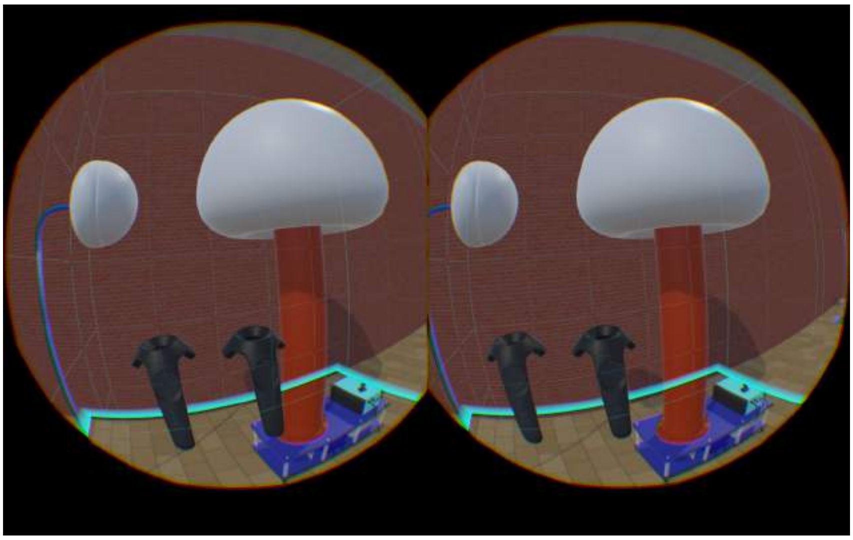


Figure 5.20.: Stereoscopic view of the Van de Graaff experiment

5.4. Multi-User Maroon Variants

While Maroon and the two VR variants focus on immersion as a central motivational element, we have also tried to integrate first prototypes showing the potential of engagement through social interaction. Social interaction (such as collaboration) has been identified as valuable asset in a learning and playing environment. Therefore, one goal of this thesis is to investigate and discuss multi-user variant of Maroon. As the focus was on motivation through immersion, only early prototypes of multi-user variants of Maroon are presented and reviewed only briefly. We aim to give an overview of potential use cases and the impact on student engagement and immersion.

We added a network manager to Maroon to enhance the desktop-based version with networking features to support multi-users access and communication (see Figure 5.21. The network manager handles the server-client communication and the synchronization of experiments.

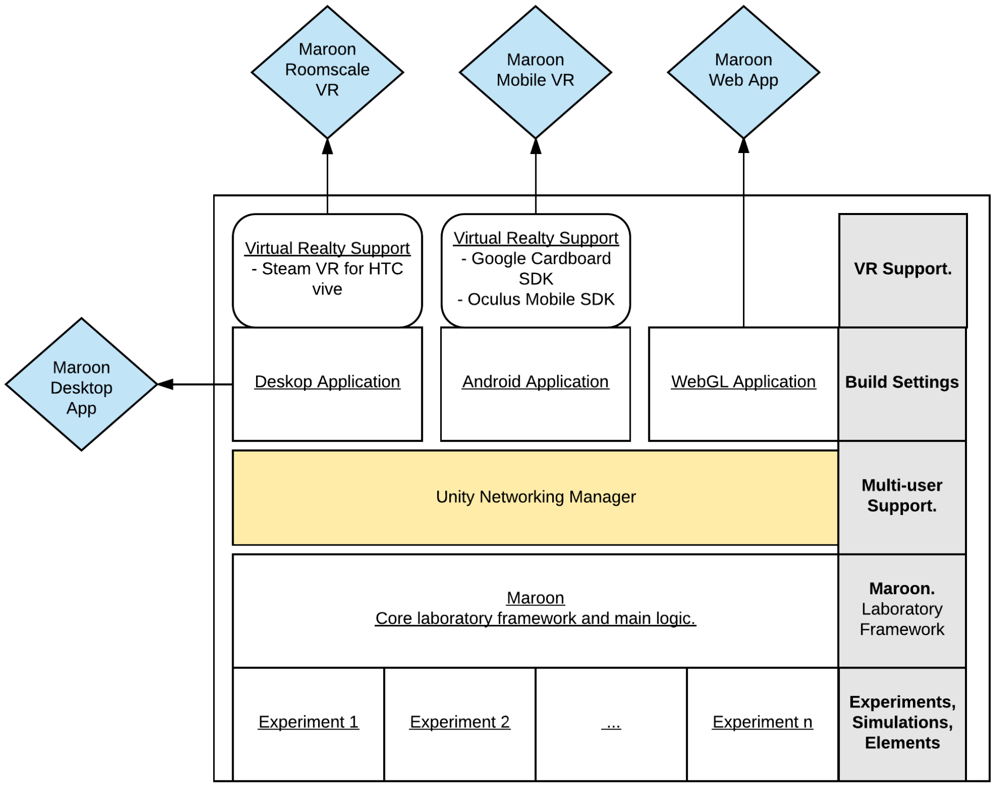


Figure 5.21.: Conceptual architecture of Maroon including Unity's Networking Manager

(a) Avatars in the screen-based variant

(b) Avatars in Mobile VR

Figure 5.22.: Neutral avatar design in a multi-user setup

One significant design aspect to rethink was the player avatar. As the interaction of users within virtual reality learning environments has not been researched yet sufficiently and first cases of sexual harassment in virtual reality environments have already been observed ("Sexual harassment in virtual reality feels all too real – 'it's creepy beyond creepy' — Technology — The Guardian," n.d.) we decided to keep the student avatars gender-free and to use a neutral avatar design in the form of robots (see Figure 5.22) .

5.4.1. Maroon Multi-User

In the simple screen-based variant of Maroon, the multi-used version is designed to support collaborative learning in the virtual environment. Students would join a learning room through a matchmaking system. As the main communication tool, they use chat. All experiments are synchronized. As one student starts or interacts with experiments, the other students would always see the same state. This version was designed for e-learning sessions, where students are encouraged to learn about concepts together in a remote setup to discuss the experiments for better understanding.

5.4.2. Maroon Mobil VR Multi-User

To provide a cooperative VR classroom experience, the second multi-user prototype of Maroon was developed for Maroon Mobile VR with Samsung Gear VR as mobile VR display. As Maroon Mobile VR does not support any input through mouse or keyboard, it is important to simplify the interaction and processes such as the creation of multi-user-rooms.

Hence, in contrast to the screen-based version, multi-user-room-names are already provided. As the application is designed to enhance in-class experiences, no chat functionalities are provided. While wearing the VR headsets, students can talk to each other in the classroom. In a future prototype, a VOIP integration could also support remote Mobile VR learning scenarios in Maroon.

The multi-user variant of Mobile VR supports two scenarios. First, a free mode, which supports free interactions with the learning experiences. Second, and a streaming mode, which supports a guided learning experiences through one user (e.g., a teacher). This user controls the experiences (e.g., an experiment setup) for all other users.

Free Mode

The free mode is the traditional multi-user mode, which allows users to interact with learning experiences in Maroon freely. Users can interact with learning experiences such as experiments at their own pace and based on their own interest.

Streaming Mode (Teacher Mode)

Students in-class wearing mobile HMDs can still talk and listen to other students or the teacher next to them. To support this setting, we have also designed a mode, in which the teacher can take control to guide students through a learning experience or another student can explain elements to peers.

As soon the teacher starts the streaming mode to take control over the learning environment, all other connected clients would only see things the teacher would see in his or her client. An example use-case would be that the teacher explains an experiment in the streaming mode, and then releases control again to let students explore the experiment at own pace to get a better understanding of the underlying concepts.

5.5. Discussion, Implications, Limitations

In the current state, the different versions of Maroon are designed as a series of prototypes to evaluate and compare different features and design aspects. One major limitation is therefore that changes in one of these prototypes do not affect the other prototypes and every prototype must be updated separately. Thus, different versions of Maroon feature a different design or only a sub-set of learning experiences.

Since the development of Maroon and the different forms of Maroon, the design and the learning experiences were subject to constant change over the course of this dissertation and were constantly improved and adapted based on user feedback.

Editors and creators (e.g., teachers) can currently only edit and update Maroon by editing the whole project directly in Unity. In a future version, teachers should be able to add new learning content by web-based integrations to the framework.

5.6. Summary and Discussion

In this chapter, we have introduced a series of prototypes of Maroon supporting different extents of immersion and engagement. Maroon was designed and implemented to support different aspects of our conceptual model. Immersion was designed through environment design and technology support (VR). Engagement was mainly designed with features supporting exploration and social interaction through collaboration.

Maroon describes the main physics learning setup in a laboratory scene and supports a deployment to standard screens supported by a web application or desktop application. Interactions are similar to interactions within a computer game. *Maroon VR* supports at the moment two different virtual reality setups: first, a cost-effective mobile setups, which supports flexible and mobile learning experiences, but only provides limited possibilities to interact with the laboratory. Second, a room-scale virtual reality experience implemented with an HTC Vive setup supported interactions through two tracked controllers and actual movement. Additionally, two early prototypes of promoting collaboration in multi-user settings of Maroon have been presented. The first prototype extends Maroon and supports screen-based remote interaction on PCs through a web application. Similar learning environments have been discussed already in earlier efforts to make physics education in digital ways more collaborative (Pirker, Berger, Gütl, Belcher, & Bailey, 2012). The second prototype presents multi-user mobile VR setups and scenarios. This enables a new way of learning in a social in-class setup.

In the next chapter, we want to analyze and compare these prototypes. Through a series of studies focusing on measuring immersion and engagement in the context of learning, and interviewing users about their experience, we can make recommendations about the potential of such learning environment in different educational settings.

6. Investigating Experiences in Virtual Reality Setups

> ”At its very core, virtual reality is about being freed from the limitations of actual reality. Carrying your virtual reality with you, and being able to jump into it whenever and wherever you want, qualitatively changes the experience for the better. Experiencing mobile VR is like when you first tried a decent desktop VR experience.”
>
> John Carmack

In this chapter, the different immersive experiences are evaluated and investigated with a focus on understanding the effect of various VR setups on the two main elements of motivational environments: immersion and engagement. First, the general comparison of different VR setups is presented. Then the versions of Maroon as shown in Chapter 5 are evaluated and compared. Our purpose is to get a better understanding of the potential and issues of different technologies and strategies supporting immersion.

The chapter is adapted from the following published papers and chapters:

- Settgast, V., Pirker, J., Lontschar, S., Maggale, S., & Gütl, C. (2016). Evaluating experiences in different virtual reality setups. In *International conference on entertainment computing* (pp. 115–125). Springer
- Pirker, J., Lesjak, I., & Gütl, C. (2017b, July). Maroon vr: a room-scale physics laboratory experience. In *2017 ieee 17th international conference on advanced learning technologies (icalt)* (pp. 482–484)
- Pirker, J., Lesjak, I., Parger, M., & Gütl, C. (2017). An educational physics laboratory in mobile versus room scale virtual reality – a comparative study. In *Remote engineering and virtual instrumentation (rev), 2017 14th international conference on* (in press). IEEE
- Pirker, J., Lesjak, I., & Gütl, C. (2017a). An educational physics laboratory in mobile versus room scale virtual reality–a comparative study (extended). *International Journal of Online Engineering (iJOE)*, *13*(08), 106–120
- Pirker, J., Holly, M., Hipp, P., Koenig, C., Jeitler, D., & Gütl, C. (2017). Improving physics education through different immersive and engaging laboratory setups. In *Interactive mobile communication technologies and learning (imcl), 2017 international conference on* (under review). Springer

Uses of "us", "we", or "our" refer to co-authors in the aforementioned publications.

6.1. Motivation

With the current rise of virtual reality (VR) technologies, we can provide more engaging and realistic experiment setups than has been possible before. In this chapter, we want to investigate new forms of immersive and engaging active learning tools using VR technologies in the classroom that make interacting with physics simulations even more realistic and engaging. We explore different interactive virtual reality experiences implemented with the HTC Vive and a flexible mobile solution as an alternative form of a learning tool. First, we investigate emerging virtual reality setups and their potential to support observations, activities, and emotions in a playful setup. After that, we examine the user experience and the effect of immersion and engagement in a learning setup. We evaluate and compare the different version of Maroon as presented in Chapter 5 with the aim of getting a better understanding of immersion, engagement, motivation, usability, and learning scenarios.

First results indicate that experiences supporting immersion (especially presence) with head-mounted displays are well suited as a supplement to traditional in-class learning and that they support realistic laboratory setups and simulations in an engaging, interesting, and immersive way.

6.2. Analysis 1: Observations, Activities, and Emotions in VR

To understand better the potential of emerging VR technologies to boost immersion and engagement for learning environments, we first need to get a deeper understanding of different VR technologies in different application scenarios. In the following, we present a preliminary study to investigate the users' perception of a rather new customer-ready VR technology in comparison to a more traditional VR experience (a CAVE environment) in different experiences. This helps us to understand better engagement and immersion so as to be able to design more immersive and engaging learning experiences in Maroon VR.

While there have been exhaustive investigations of user experiences in traditional VR experiences, such as in the fully-immersive CAVE environment, the research of user experiences in emerging VR technologies such as the Oculus Rift[1] or

[1] https://www.oculus.com/rift/

HTC Vive[2] is still its infancy. Additionally, to understand better the experience and behavior of learners in a virtual space, it is not only important to focus on learning situations but to gain a better understanding of their emotions and experiences and issues such as cybersickness in different setups. This section describes the evaluation of three different scenarios in a more traditional fully immersive room-based virtual environment DAVE (Definitely Affordable Virtual Environment)[3] and a head-mounted display, the Oculus Rift. The evaluation focuses on comparing the two immersive environments and three different scenarios (observation, emotion in a roller coaster, and interaction) in regards to typical virtual-reality characteristics, such as immersion, engagement, but also on cybersickness and the overall experience. First results indicate that the DAVE environment better supports scenarios which require the user to directly interact with the environment. The roller coaster scenario creates stronger immersion and a higher nausea-level, while the interactive task is more engaging regarding fun. This section has been published previously as part of Settgast et al. (2016). The author of this thesis was mainly contributed to this work in designing and implementing the study to get deeper insights into engagement elements and the effectiveness of VR in different scenarios.

6.2.1. Motivation and Contributions

Over the last years, the potential of immersive virtual environments (VE) has been described for various application scenarios. In particular, the current trend of affordable head-mounted displays (HMD) allows a wide range of users to access different virtual reality (VR) applications. Such immersive experiences are not only interesting for entertainment, gaming, and simulations, but also for training and education scenarios (Stone, 2002; Kim, Rosenthal, Zielinski, & Brady, 2014). However, in particular, in learning and training applications,

[2]https://www.vive.com

[3]https://www.tugraz.at/institute/cgv/research/vr-lab/dave/

different scenarios often require different interactions and activities in the virtual reality. For example, specific training tasks would require rich and realistic user interactions (e.g., learning how to use a particular machine). Other tasks require more freedom in the environment such as the possibility of freely examining the objects and the environments. For other experiences often only the observation and the experience of the virtual scenario is sufficient. Different virtual reality devices and setups support different degrees of freedom, of immersion, and interactions with the environment. In a room-based fully immersive virtual environment (such as a CAVE) users are still able to see their own body and surroundings in relation to the virtual world. It is possible to use additional tools in a natural way (e. g. a map or a smart phone) to interact directly with other users. Head-mounted-displays support more flexible forms of experiences and activities; for example, they can show a different body for the user or trick the sense of orientation. However, they often do not give users the possibility to directly interact with the environment, since the representation of their own body is missing or poorly represented. Different forms of interaction are challenging, since consumer HMDs only give a limited range of sensors for tracking the body (McGill, Boland, Murray-Smith, & Brewster, 2015). To design rich learning and training scenarios in a virtual environment it is not only necessary to focus on the different interactivities, but also to design the experience with consideration of different virtual reality characteristics and problems, so as to create a sound user experience. This, in particular, includes immersion and cybersickness. In this section, we present a first comparison of different activities (observations, strong emotions, interactions) in two virtual reality systems (CAVE, Oculus Rift DK2) with a focus on typical virtual-reality characteristics, such as immersion and engagement, but also on the potential issue of cybersickness.

We can summarize the following main contributions and observations to create motivational environments:

- The demonstration that interactive scenarios can create a high level of engagement by means of fun and involvement
- The demonstration that also non-interactive environments and scenarios can create a high level of immersion

Contributions to the Conceptual Model

The contributions of this section form the basis for the design and creation of motivational environments supporting engagement and immersion. We focused on investigating immersion through the use of different technologies (different VR HMDs) and interaction design to create a stronger feeling of immersion and engagement. In this section, we describe how immersion can be created through interactive and non-interactive design and the influence of emotions on immersion and engagement.

6.2.2. The Setting

For this study we used 2 ((a) Oculus Rift DK2, (b) DAVE) x 3 (tasks based on (1) observation, (2) emotion, (3) interaction) experiment as setup with a focus on comparing immersion, cybersickness, and the overall experiences.

The Environments

Oculus Rift The Oculus Rift[4] is a head-mounted display (HMD) developed by Oculus VR beginning in 2012. The first commercial version was released in March 2016. For this work, we used the second pre-released developer kit (DK2)[5] of mid-2014. DK2 has a display with full HD resolution which is divided

[4] https://www.oculus.com/rift/
[5] https://www.oculus.com/dk2/

vertically showing the stereoscopic image for both eyes. Compared to prior HMDs, the Oculus Rift was able to increase the field of view to 110 degrees by using lenses and adjust the rendered images accordingly. An optical tracking system is used in combination with an orientation sensor for the localization of the users head. A sitting and a standing setup are possible. but the range of movement is limited to less than two meters because of the cable-based video transmission.

DAVE The *Definitely Affordable Virtual Environment* (DAVE) is an immersive projection room with three side walls and one floor projection (Lancelle, Settgast, & Fellner, 2009). The projection screens are 3.3 meters wide and 2.7 meters high. (see 6.1). Stereo projectors with HD resolution are updated at 60 Hz. Stereoscopic shutter glasses are used, similar to the ones familiar from 3D TV sets or 3D cinemas. In addition, an optical head tracking system allows a correct parallax and creates an undistorted view for the main user. Within the 3.3 by 3.3 meters, the user can walk around an object to see it from all sides (Settgast et al., 2014). A significant advantage compared to most HMDs is the very wide field of view. Such a CAVE provides a visually convincing immersive experience while allowing the user to see her own body.

The Implemented Scenarios

For the study, we implemented three different scenarios (see 6.2) with the goal of creating three different experiences (observation, strong emotion, and interaction).

Task 1 (Observation) The first task was mostly designed to familiarize users with the systems. It is designed as a stationary scene where the users were asked to find a certain object on a complex model (see Figure 6.2-a). Users

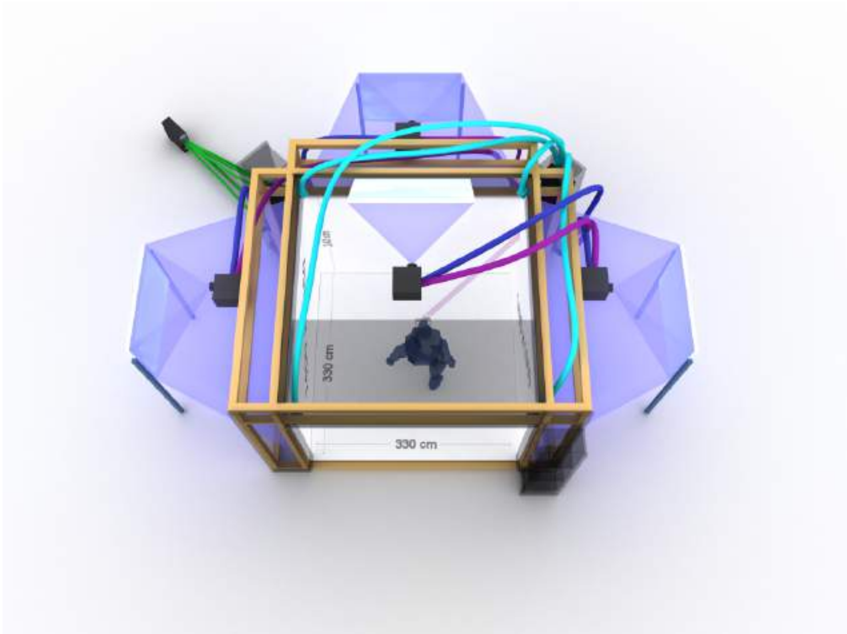


Figure 6.1.: The DAVE: A four-sided CAVE-like immersive environment (Settgast, Pirker, Lontschar, Maggale, & Gütl, 2016)

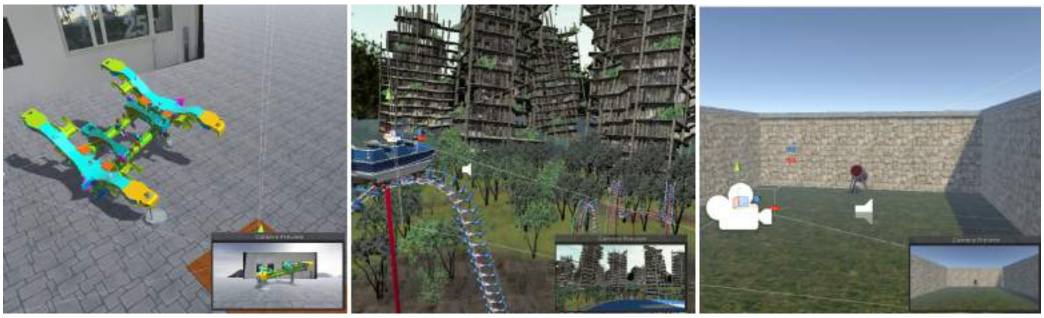


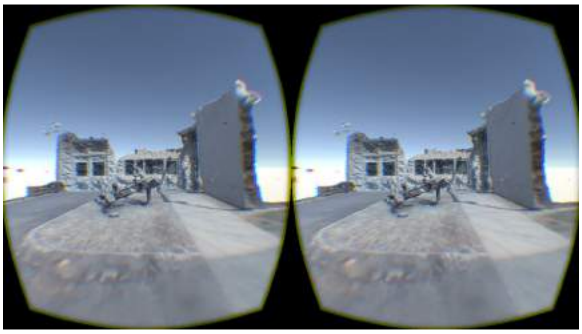
Figure 6.2.: The three scenarios from left to right: complex model for observation, roller coaster and catch-the-ball game (Settgast, Pirker, Lontschar, Maggale, & Gütl, 2016)

had to move around the model to find the object. The difference between the task with the Rift and in the DAVE was the object on the model they had to find.

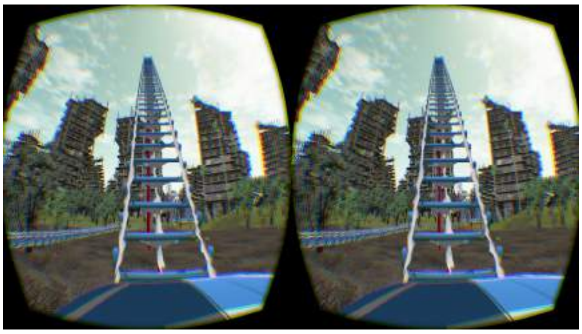
Task 2 (Emotion) This was designed as a more passive experience. Users take a ride on a virtual roller coaster (see Figure 6.2-b). The users only sit on a chair and experience the virtual ride. Afterwards, they had to describe their feelings while riding. The task was exactly the same with the Oculus Rift and in the DAVE.

Task 3 (Interaction) The last task was an interactive scene where the users had to interact with the virtual environment. The goal of this task was to catch or deflect as many balls as possible in a certain time. The balls came flying towards the user from a virtual canon. There was no difference between the task with the DK2 (see Figure 6.2-c) and in the DAVE. In both setups, a Microsoft Kinect[6] was used for tracking the user's hands.

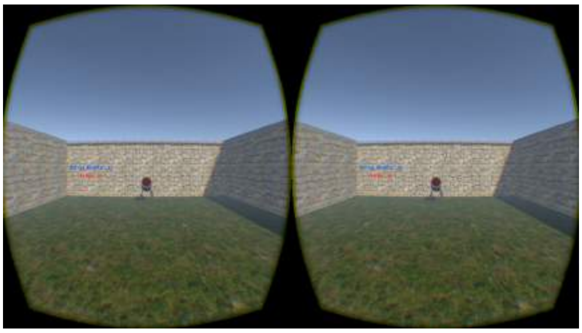
[6]https://developer.microsoft.com/en-us/windows/kinect



(a) Task 1 - Observation



(b) Task 2 - Emotion



(c) Task 3 - Interaction

Figure 6.3.: The three different tasks as rendered in the Oculus Rift DK2 (Settgast, Pirker, Lontschar, Maggale, & Gütl, 2016).

6.2.3. Study Setup

To evaluate the different scenarios, we devised a study setup which shed light on the participants' experience in the two virtual environment setups with a focus on various aspects, such as immersion, nausea level, and engagement. The tasks, as described above, were designed to cover activities focusing on (1) observations, (2) emotions, and (3) interactions in virtual environments. In this study, we compared the two different virtual reality environments through a qualitative study with eight users. One environment was an HMD, and the other one was the DAVE. The participants had to finish the three tasks in each of these two virtual environments. Before they started with task 1, they had to fill out a pre-questionnaire. After each task they rated the immersion, nausea level, overall experience, and fun. After completing all 3 tasks in the DAVE, they filled out a post-questionnaire At the end they had to fill out the task questionnaire of part two and a specific cybersickness questionnaire.

Participants

To evaluate the scenarios 8 participants (5 female) between 21 and 48 (M =28.4, SD = 8.3) were recruited. After a first introduction, participants completed a pre-survey with demographic information (e.g., age, gender, profession), experience with games and virtual realities. Six participants were students. On a Likert-scale between 1 (not at all) and 5 (definitely), the participants rated their experiences in computer usage with an arithmetic mean of 3.1 (SD = 1.4) and their experience with video games with a mean of 2.0 (SD = 1.6). All of them mentioned that they were not experienced with VR technologies. Only two play often or relatively often computer games, three like playing video games, and four have heard of a CAVE/DAVE environment, and one of them had already used one. The Oculus Rift was known to four, and three had already used one.

Equipment and Setup

The virtual reality Oculus Rift Developer Kit 2 (DK2) and the DAVE environment as described above were used for the evaluation. For the task design, the scenarios (Task 1: Observation, Task 2: Emotion, Task 3: Interaction) as described in the previous section were used. Fig 6.4 illustrates the three tasks as rendered in the DAVE.

Figure 6.4.: The tasks in the DAVE; from left to right: Task 1 - Observation: The participants were asked to find a specific part of the machinery by observing the scene; Task 2 - Emotion: The participants had to ride a roller coaster; Task 3 - Interaction: In a mini game the participants had to catch balls shot in a random angle at them (Settgast, Pirker, Lontschar, Maggale, & Gütl, 2016).

Method

Immersion, Engagement, and Experience. To evaluate aspects such as immersion and fun we used two different measures. (1) After each task we asked the participant to rate immersion, fun, and if they have liked the experience on a Likert scale between 1 (not at all) and 10 (very) to receive immediate feedback. (2) After they have completed all three tasks for one device, we asked them to complete a slightly modified version of the Game Engagement Questionnaire (GEQ) (Brockmyer et al., 2009). GEQ is designed to measure engagement in games. It provides a set of 19 questions (we used 18 for our study) to measure absorption, flow, presence, and immersion. Since we measure the "game engagement" after the interaction with each setup, we are able to compare these values for the two different virtual reality setups.

Cybersickness As cybersickness is still a major issue and obstacle to the widespread use of VR technologies (Davis, Nesbitt, & Nalivaiko, 2015), it was also an important element of this study. Cybersickness is described as an uncomfortable feeling when using VR technologies and results in symptoms similar to motion sickness symptoms such as nausea, headache, disorientation, sweating, general discomfort, and even vomiting (LaViola Jr, 2000; Kolasinski, 1995). As also described by Davis et al. (2015), we used a subjective individual rating of the participant's perception of their nausea level to evaluate cybersickness. The participants were asked after each task to rate their nausea level between "0 - no discomfort" to "10 - feeling like vomiting".

6.2.4. Findings

Immersion Participants rated their immersion level on a scale from 1-10 after each task slightly higher in the DAVE. Even though the roller-coaster experience was designed as a passive and not interactive experience, it was perceived as a very immersive 6.6a. Looking at the GEQ (see Figure 6.13) the overall immersion-level in the DAVE is also rated higher compared to DK2.

Engagement, Fun, and Overall Experience As illustrated in Fig. 6.6c the participants enjoyed all experiences, but task 3 was rated as the "best" experience. They also mentioned to have the most fun in the interactive experience (see Fig 6.6d). Figure 6.13 illustrates the four main (absorption, presence, flow, and immersion) concepts as a result of the 18 different GEQ-questions. All engagement metrics were described as slightly higher in the

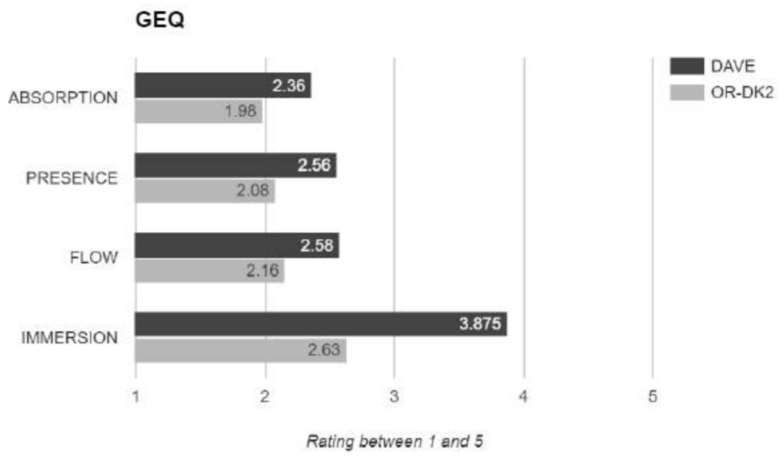


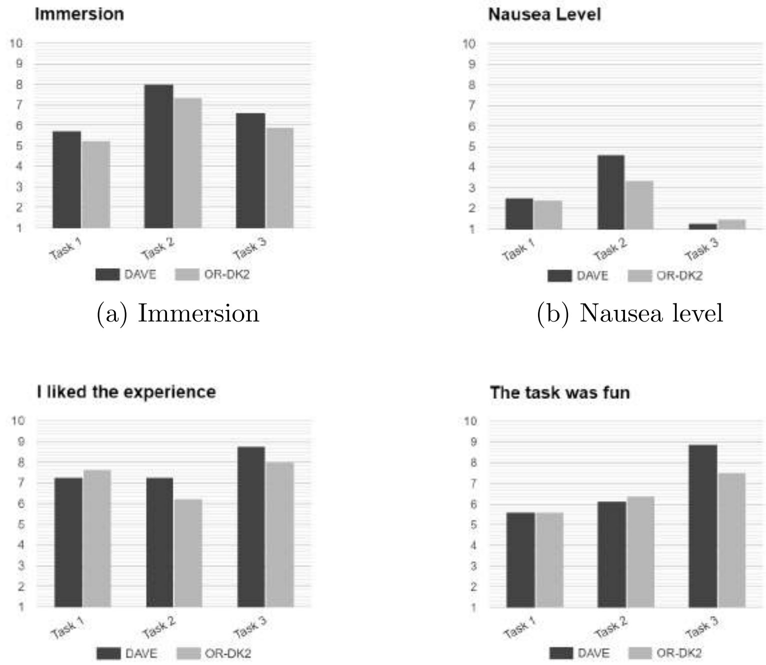
Figure 6.5.: Game Engagement Questionnaire (GEQ) results

DAVE compared to DK2. In particular Immersion as a factor of engagement was rated extremely high in the DAVE environment.

Cybersickness After each task the participants were asked to describe their nausea-level on a scale between 0 - no discomfort" to "10 - feeling like vomiting". Figure 6.6-b gives an overview of the participants' nausea level in the two different virtual environments. The value was very high for both devices after the Rollercoaster task (Task 2). The nausea level difference between DAVE and DK2 indicates that this feeling is only slightly higher in the DAVE.

Different Experiences with the Tasks

The DAVE was preferred over DK2 by 7 out of 8 participants for the observation tasks. Reasons for that were described as *"more realistic interactions"* or "*better graphics"*. Participants rated the difficulty of finding the object in the DK2 (M=2.5, SD=1.4) slightly higher compared to the DAVE (M=2.0, SD=1.1).



(a) Immersion (b) Nausea level

(c) Experience (d) Fun

Figure 6.6.: Subjective rating of immersion, nausea level, experience, and fun after each tasks - 1 (not at all) 10 (very)

The experience in the virtual roller coaster was rated by 7/8 as a fun experience, although three users experienced *fear* at some point of the ride. Four would want to use this simulation again. Two prefer DK2 for this simulation (*"movement more realistic in DK2"*), six the DAVE (*"feels more real"*). On a scale between 1 (not at all) and 5 (very), participants described the fun while playing the minigame with an arithmetic mean of 3.9 (SD=1.3). Interest in a more developed version of this game showed six participants and seven prefer the DAVE over the DK2 to play this game (*"not so heavy glasses"*, *"display of hands not realistic in DK2"*, *"hand movements more realistic in DAVE"*).

6.2.5. Conclusion and Discussion

The study presented was designed as the beginning of many tests with this setup and gives a first overview. Early results indicate that a DAVE environment gives participants more freedom with regard to body perception, small-scale movement, and more realistic images. However, all tasks were mainly designed for small movements in a limited space. While the roller coaster scenario (designed to create strong emotions) gives participants a strong feeling of immersion and creates a higher nausea level, the interactive, playful task is rated as a more fun task. Further studies should also include scenarios which require participants to for example travel distances. Also due to the small study setup and the natural differences between the two virtual reality environments (HMD vs. room-based virtual environment) the study outcomes give only first insights. Given the current rapid development of HMDs, it will be important to extend the current study with the latest HMD-technologies and other platforms. Future studies investigating more specific emotions and different forms of interactions with a larger participant base will extend the present findings.

Immersion and engagement are key elements of designing and creating motivational environments. We have learned that immersion can also be created in passive experiences when the presented experience creates strong emotions. High engagement can be supported through interactive tasks. Cybersickness was not identified as a major issue in the environments as presented above. These observations form the basis for our design of Maroon VR as a learning environment, with a focus on engagement and immersion in VR setups.

Observation

Observation 1. For designing engaging learning experiences, this study illustrated that more ***interactive tasks*** and environments can create a deeper **engagement**, a high level of immersion, and more fun compared to environments, which allow one only to ”watch” or ”experience” an activity. Also, passive activities (e.g., sitting in a roller coaster) can create a high level of **immersion** if they are designed as strong and emotional experiences.

6.3. Analysis 2: Maroon Room-scale VR

In this section, we explore interactive virtual reality experiences implemented with HTC Vive as an alternative form of learning tool supporting engagement and to support the ability to concentrate better on the learning tasks. The primary goal is to evaluate this motivational environment with a focus on the two elements of our conceptual model: *technology-enabled immersion (also presence)* and *engagement through interaction design*. We ran a user study in which 19 students evaluated the experience looking at engagement, immersion motivation, usability, and learning. First results indicate that such experiences are well suited as a supplement to traditional in-class learning and that they support realistic laboratory setups and simulations in an engaging, interesting, and immersive way and help students to focus more on the learning task compared to traditional applications. This section is based on work previously published in Pirker, Lesjak, and Gütl (2017b)

6.3.1. Motivation and Contributions

Immersion and engagement are important factors for creating exciting and involving experiences and *motivational environments*. Immersion describes an experience of being part of the digital experience (Brockmyer et al., 2009). Flow is a targeted feeling in many domains (games, learning, training) for creating engaging experiences. It is described as full involvement in an activity. As discussed in Chapter 2 flow is achieved by balancing skill level and challenge and describing clear goals (Brockmyer et al., 2009; M. Csikszentmihalyi & Csikszentmihalyi, 1992). The current state of available VR devices, such as Oculus Rift or HTC Vive, offers a sufficient level of maturity to be considered as a serious tool for education or training scenarios. In this section, we want to evaluate the immersive physics laboratory ***Maroon Room-scale VR*** as a new form of immersive and engaging active learning tool, using VR technologies to make interacting with physics simulations even more realistic and engaging. In this section. we focus on investigating the room-scale variant of Maroon VR implemented for HTC Vive (see Chapter 5). By performing a user study, we demonstrate the capabilities enabled by this immersive environment and show the first evidence that such experiences support engaging and immersive learning experiences and can be used to visualize laboratory setups in a realistic and engaging way.

The contributions of this section can be summarized as follows:

- Demonstration that users are engaged and immersed by Maroon Room-scale VR by means of a user study (questionnaires and quotes while conducting the experiment)
- Description of set up as a valuable learning asset for classroom scenarios

Contributions to the Conceptual Model

In this section, we analyze the impact of simple interaction design and VR technologies on immersion and engagement. We focus on investigating the impact of the VR device HTC Vive on the users' immersion and how an interactive virtual environment design influences the feeling of immersion and user engagement.

6.3.2. The Setting

In the prototype of Maroon Room-scale VR used for this evaluation, two main experiments and two interactions were integrated. The environment is designed as an open laboratory room with different stations, which represent experiments or activities. The two experiments in the current prototype are two electrostatic experiments. The first one demonstrates the electric field (including field lines) between a Van de Graaff Generator and a grounding sphere. Users can change the distance between the grounding sphere and the generator to see how the frequency of the discharges changes. The second experiment simulates the behavior of a balloon, which is placed between grounding sphere and Van de Graaff Generator. The two activities are an interactive whiteboard and a multiple-choice quiz.

6.3.3. Study Setup

To evaluate Maroon Room-scale VR, a study has been conducted, to measure the potential of the setup to engage participants, with a focus on measuring experience, engagement (flow, absorption, immersion, and presence), and learning potential. The details of the setup, the equipment, and the materials are given below. We divided this problem into a number of sub-questions we wanted to answer:

- Q1: *Is the lab perceived as a* ***valuable learning tool****?*
- Q2: *Would users suggest that the lab should be used in a* ***classroom setting*** *or at home?*
- Q3: *Would users use it as a* ***mobile*** *virtual reality solution?*
- Q4: *How* ***engaged*** *are users?*
- Q5: *How* ***immersed*** *are users?*
- Q6: *How important are the* ***controllers*** *for the experience?*

Participants

The number of participants was 19 (5f). They were between 18 and 53 (AM=26.6, SD=8). Most participants were students (12), the other 7 were employees. On a Likert scale between 1 (fully disagree) and 5 (fully agree), 16 participants self-identified as computer experts (AM=4.4; SD=1.2). Three considered themselves as experts in VR (AM=2.1; SD=1.2), two in physics (AM=2.8; SD=0.8). Only five participants had used the HTC Vive before.

Equipment and Setup

We used the HTC Vive[7] as the HMD for the virtual reality scenarios and the shipped controllers as in-world interaction possibility (see also Chapter 5 for details). The room-scaled setup was used in roughly a 2mx2m setting. In order to be able to smoothly run interactive, immersive simulations in VR with the HTC Vive, it is also necessary to use high-end gaming PC hardware. Thus our setup for this study also includes a high-end PC designed for gaming

[7]https://www.htcvive.com/

and external speakers. On the software side, Unity v5.3.1[8] together with an up-to-date SteamVR[9] application was used to build and run the interactive Immersive Physics Laboratory.

Method

The experiment was set up in two iterations. First, eleven participants tested the environment without a focus on interaction. Since many participants had issues learning the VR controls, the environment was extended with an additional tutorial zone. In this zone, participants were able to try out the controls and learn how to interact with in-world objects (picking-up, throwing). In the second part, eight users evaluated the environment with this extension. As this was only a minor extension, the results are not interpreted differently, and we will not focus on any differences between these two test iterations.

Before the experiment, the participants had been informed about the outline and process of the experimental session and filled out the background questionnaire (demographic data; experience with computers, games, virtual reality devices, and physics). As an introduction, participants were informed about the main interaction possibilities with the controllers and how the VR experiment works. Then participants were asked to use Maroon Room-scale VR (duration: 10-20 minutes). The participants constantly remained in contact with the study supervisor, who also consecutively introduced them to the different experimental tasks: (T1): Look around and familiarize yourself with the environment and the controls. (T2): Use the teleporting functionality to beam yourself to different locations. (T3): Start the experiment (Van de Graaff generator with grounding sphere and balloon). (T4) (optional): Find the "Easter egg" (hidden room with Tesla coil).

[8] https://unity3d.com/

[9] http://store.steampowered.com/steamvr

The overall goal of this experiment was to showcase different functionalities and possibilities of interaction of immersive interaction in VR to be also able to evaluate the future potential of a fully implemented Maroon VR with several lab stations for understanding the physical concepts. After the VR-experience, the participants filled-out a post-questionnaire and were interviewed on their experience. These items are described as follows:

Background Questionnaire Before the interaction with the virtual reality experience, participants completed a background questionnaire in which they indicated demographic data (age, sex, profession), and their experience with computers in general, games, virtual reality devices, and physics.

Post-questionnaire The post-questionnaire was divided into three main parts: (1) open-ended questions about overall experience (2) experience scale (21 items), (3) Game Engagement Questionnaire (GEQ) developed by Brockmyer et al. (2009), to measure engagement based on immersion, presence, flow, and absorption.

i) **Open questions about user experience (Impression)** The first part of the post-questionnaire consists of eleven open-ended questions asking the users about their overall experience, what they liked/disliked, their perception of the learning possibilities, and their experience with interactions, usability, and controls.
ii) **Experience Scale (Motivation)** The second part was a scaled questionnaire, consisting of 21 items asking users to rate their experience in terms of engagement, learning, and preferences on a Likert scale between 1 (not at all) and 7 (fully agree).
iii) **Game Engagement Questionnaire (GEQ)** To measure engagement we used a slightly updated version of the standardized questionnaire Game Engagement Questionnaire (GEQ) (Brockmyer et al., 2009), which

measures different sub-elements indicating game involvement including immersion (*"becoming engaged in the game-playing experience while retaining some awareness of one's surroundings"*), presence (*"being in a normal state of consciousness"*), flow (*"feelings of enjoyment that occur when a balance between skill and challenge is achieved"*), and absorption (*"total engagement in the present experience"*). Instead of using the 19-item version, we used a reduced 17-item version. Two questions were not included because of the lack of relevance to the study setup (*"I don't answer when someone talks to me"*, and *"If someone talks to me, I don't hear them"*).

6.3.4. Findings

Engagement and Immersion Data

In this section, we want to discuss the participants' engagement with the interactive and immersive physics laboratory and answer the following questions (Q4,Q5): ***How engaged are users? How immersed are users?*** The first part of the post-questionnaire (11 questions) dealt with the overall user experience and impression. To find out about engagement, the participants were asked the following question: ***"Do you find it engaging and motivating?"***. Overall, participants found the experience interesting and motivating and would use it to learn concepts interactively, which are easier to understand when visualized or simulated. Selected responses are listed: *"It was interesting because it was my first time engaging with VR."*; *"Yes, and if you use it for learning, it would probably be the most interactive form there is after real-life learning."* On a Likert scale between 1 and 7, participants rated the learning experience as engaging (AM=5.6, SD=1,6) and more motivating than regular exercises (AM=5.8; SD=1.3). Based on GEQ results, the overall engagement with the experience was rated as high. On a Likert scale between 1 and 5, in particular, immersion (3.4; 1.1) and flow (AM=3.4; SD=0.8) were rated as high. Presence was rated with an arithmetic mean of 3.4 (SD=0.1) and absorption with 3.4 (SD=0.2). (Comparative data can be found in [9], where the authors also used GEQ to evaluate different VR setups.) Participants highlighted the feeling of immersion: *"..it felt like I was really there."*.

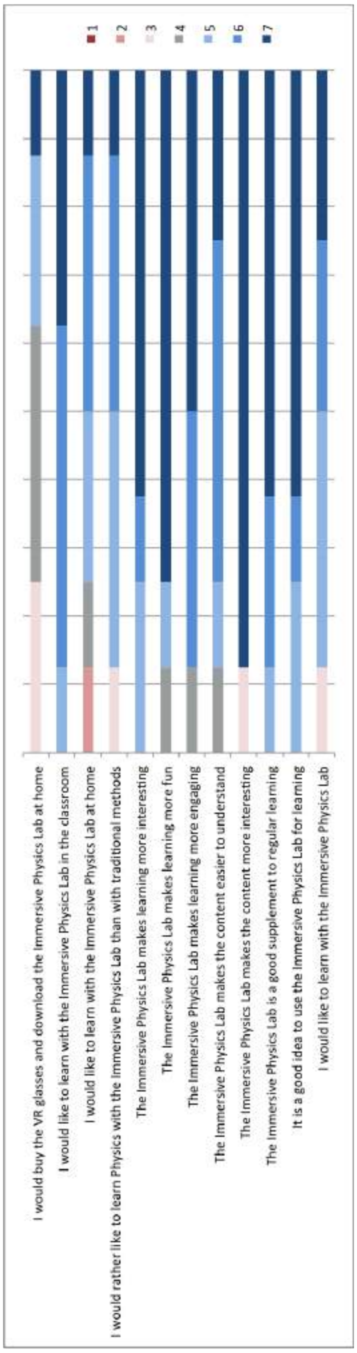


Figure 6.7.: Experience data.

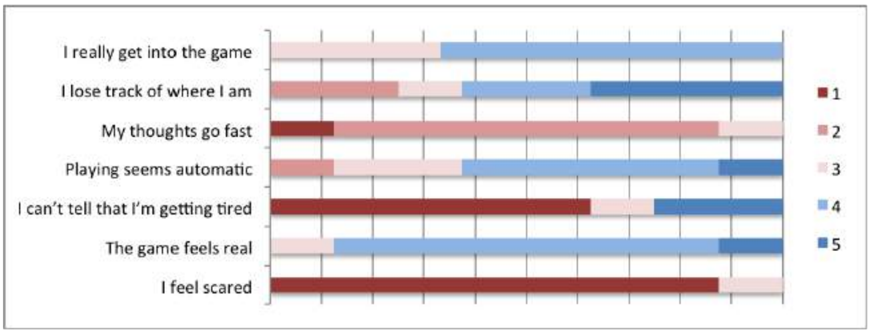


Figure 6.8.: Selected results of the game engagement questionnaire

Experience and Usability Data

In order to assess user experience and identify different issues (e.g., usability or controls), participants were also asked open questions such as: ***"How did you like the Immersive Physics Lab?"***, ***"What did you like?"*** and ***"What did you not like?"***. In particular, the controls as well as the immersive and interactive features were highlighted: *"The possibility to get into a huge world while standing in one place"; "The impressive fact that you could move around the physics lab freely"; "It does, however, take some getting used to as you can easily get sick if there's a lot of movement.."* While the overall experience was described as interesting and realistic, some users mentioned usability issues, such as the cable, cybersickness or dizziness. Also, the real room (2mx2m) was described as too small for the actual setup. The controls, the user interface, and the beaming functionality were received positively by 14 participants: *"The user interface was easy to learn and handle. The beaming function compensated the lack of physical space so it was actually possible to see the simulations from every side".* Two participants had issues with learning to use the controls: *"although they were visible in VR there were buttons I could not touch/find."*. It was important to the participants to see the controller in VR.

Learning in VR

Furthermore, we were interested in the learning possibilities in the physics laboratory and aimed to answer the following questions: *Is the lab perceived as a* ***valuable learning tool***, *Would users rather suggest that it be used in a* ***classroom setting*** *or at home?*, *Would users use it as a* ***mobile*** *virtual reality solution?* and what advantages and disadvantages do they see in Maroon VR compared to the web/PC version of Maroon (Q1,Q2,Q3,Q6). When asked if they would use it for learning, participants responded quite positively: *"Yes, it is for sure advantageous for visual learning types like me."; "Yes, with different contents: solar system, earth's rotation and orbit around the sun."; "Definitely, because you can try things multiple times without any drawbacks."* When asked about whether Maroon VR was good for learning: *"Yes; it would be practical to use for experiments that might require too elaborate or expensive of a setup in real life. Or for experiments that might be dangerous.."; "there are opportunities to learn a lot, and it even makes fun"* On a Likert scale between 1 and 7, participants would like to learn with the lab (AM=5.33; SD=1,51). Most participants think it is a good supplement for regular learning (5.88;1,45). 12 fully agree that the physics lab makes learning more fun (6;1,64) and interesting (5.89;1,63). They would rather use it in the classroom (5.42;1.54) than at home (4.63; 1,74). Only a few would buy the VR glasses at the current price of the setup and download the physics lab at home (4.18; 1,28).

6.3.5. Conclusion and Discussion

In this section, we have presented the first evaluation of an interactive and immersive physics lab integrated with the VR device HTC Vive (Maroon Room-scale VR). We have explored the users' experience with a focus on engagement, overall experience, and perceived learning value. The results indicate that participants would recommend this setup for learning about subjects, which benefit from the use of simulations and visualizations. They see a potential of such settings for creating more engaging, focused, and interactive forms of learning. It was noted that this is particularly well suited for experiments, which are either too dangerous, expensive or simply not visible. The participants would recommend using this form of learning in classroom scenarios and in addition to traditional lectures. Immersion and presence were rated as very high and mentioned as a valuable element to enhance the concentration. Even though the design of the environment was described as “not realistic” in terms of graphics, the immersive experience was described as very realistic. Cybersickness and dizziness remain a problem, but the number of participants reporting such issues was relatively low.

In comparing Maroon and Maroon Room-scale VR, the participants see more potential in Maroon Room-scale VR for learning, because they relate immersion to full concentration on the learning tasks. In traditional digital learning environments, students can get distracted more easily. However, for short experiments, Maroon is preferred since the effort of setting up VR environments is quite high. Additionally, high costs and lack of portability were mentioned. As revealed by Wieman and Perkins (2005), students find not only the feeling of being present in a virtual laboratory important but also the ability to discuss and collaborate with peers. While such environments still allow students to interact with the “real” world (e.g., discussing concepts with persons next to them), this might reduce immersion.

Observation
Observation 2. Interactive setups such as room-scale environments can be used to create engaging and focused learning experiences. A non-realistic design does not negatively impact immersion. Due to the complex setup, room-scale VR setups are only recommended for longer learning experiences. Immersion is noted as an important factor of this experience and helps students to concentrate on learning tasks.

6.4. Analysis 3: Maroon Room-scale VR vs. Maroon Mobile VR

As we have learned in the previous sections, emerging technologies such as HTC Vive and Oculus Rift are valuable tools to create environments supporting immersion and engagement. However, it was discovered that room-scale setups also need a lot of space, a complex set up process, and are cost-intensive. Hence, mobile virtual reality solutions could provide a more flexible and cost-effective solution, which can open up new paths for distance, but also classroom learning. In this section, we discuss experiences with Maroon VR in a cost-effective mobile setup with a mobile VR experience through Samsung GEAR and compare it with the more interactive VR experience with room-scale VR with HTC Vive. We describe a comparative evaluation of these two setups in order to identify the possibilities and challenges of both setups. The focus will be again to evaluate the aspects of immersion and also engagement of our conceptual model to create motivational environments. Since the two different virtual reality setups provide various factors supporting engagement and immersion, we focus on identifying use-cases for how to utilize these versions for learning scenarios optimally.

First results indicate that there is more flexibility and portability with the mobile setup, while the room-scale setup profits from its highly interactive and hands-on experience. We discuss and compare the two settings based on immersion, engagement, presence, and motivation. This section is based on Pirker, Lesjak, Parger, and Gütl (2017) and the extended journal version published in Pirker, Lesjak, and Gütl (2017a).

6.4.1. Motivation and Contributions

With the emergence of different virtual reality head mounted displays (HMD) such as Oculus Rift or HTC Vive and also cost-effective mobile VR solutions (such as Samsung Gear VR[10], Google Cardboard[11]), there are now new interaction and learning possibilities and scenarios for virtual physics laboratories and interactive simulations. However, various devices support different forms of interactions and learning solutions. In this section, we explore the potential of the interactive room-scale solutions with the HTC Vive compared to the cost-effective mobile virtual reality setup through the Samsung Gear. The goal is to evaluate usability and user experience in VR and to measure factors such as engagement, immersion, and the learning progress. This should contribute to identifying new possibilities for engaging in-class learning and education. The focus of the evaluation is to research interactive and immersive forms of education as improved engaging learning experiences.

We can summarize the following contributions of this section:

- Mobile virtual reality setups allow more flexibility and portability
- Room-scale VR setups enhance learning environments which require interactive and hands-on experiences

Contributions to the Conceptual Model

In this section, we analyze the impact of less interactive but more mobile and flexible VR technologies (mobile virtual reality application) on immersion. They allow fewer interactions and the design must support a higher level of guidance in order to engage and immerse users. We compare the different forms of immersion through technical support in two similar setups. Also, we analyze

[10]http://www.samsung.com/us/mobile/virtual-reality/gear-vr/
[11]https://vr.google.com/cardboard/

and discuss application scenarios for the two different immersive settings for the design of motivational learning environments.

6.4.2. The Setting

For the following two-fold study, we set up two different forms of Maroon VR supporting various virtual reality technologies. We selected two distinct VR technologies to base the comparative evaluation on. The Samsung Gear VR was selected in order to evaluate mobile and more cost-effective environments (Maroon Mobile VR). The HTC Vive was selected as a state-of-the-art interactive room-scale VR technology (Maroon Room-scale VR). We chose a mobile VR setup in order to support a widely accessible and cost-effective way to interact with the laboratory. As described in Chapter 5, it could be used in classroom environments (e.g., guided by an instructor) or for self-regulated learning at home. We chose the room-scale setup in order to assess the potential of more interactive, hands-on experiences. They could, for instance, be used at in-school learning laboratories.

For this study, five main educational experiences were used in our study setup of Maroon VR (see also Chapter 5): (1) the Van de Graaff Generator, (2) the Balloon at Van de Graaff Generator experiment (3) a whiteboard with information and labeled pictures to explain the theory behind the Van De Graaff experiments. To introduce inter-activities with the HTC Vive, we added an experience to the Maroon Room-scale VR version. (4a) This experience was an interactive playground with different objects such as throwable and grabbable cubes and metal balls. This specific station was replaced by another station on the Maroon Mobile VR version where it features a (4b) laptop with an interactive, feedback-supported quiz session in order to test theoretical knowledge. (5) The final experience is designed as optional "easter-egg". An accurate model of a Tesla coil can be found behind a hidden corner by users for further exploring the virtual laboratory world.

Ultimately, the goal in developing these simulations is to let users act more or less the same way as they would act when placed in a real-life physics laboratory. As of now, users are - to some extent - able to immerse themselves into this world while being shielded from the (visual) influences of their actual physical surrounding. As such, immersive 3D has shown to be a useful aid for presenting difficult concepts in physics, such as the effect of switching a Van De Graaff generator on and off.

6.4.3. Study Setup

We performed two preliminary user studies with a total of 17 participants to evaluate the system and the experience. In a first study (with 9 participants) we focused on testing the Maroon VR with the mobile setup only. In the second study (with 8 participants) we focused on evaluating (1) engagement, (2) immersion, (3) learning experience, (4) virtual reality experience, and (5) usability and user experience in comparison to a more interactive VR experience with the HTC Vive (comparison between Maroon Mobile VR and Maroon Room-scale VR).

Participants

We conducted the two case studies described in this section separately and independently from each other. There is no overlap between the two study groups; one of which tested Maroon Mobile VR only (9 subjects), while the other group (8 subjects) tested Maroon Mobile VR in comparison with Maroon Room-scale VR.

Experiment 1. In the first study, nine students (2 female) between 23 and 27 (AVG=24.8, SD=1.5) tested Maroon Mobile VR. All students were in the field of computer science or electrical engineering and rated their experience with computers as very high. Eight participants liked playing video games and even six students self-rated themselves as very experienced (AVG=4.1, SD=1.2) in the video-gaming. All of them rated themselves as not very experienced in using VR (AVG=1.9, SD=1.0). Only seven had heard of mobile VR devices before, four have used Google Cardboard, five the Samsung Gear VR. When rating their physics expertise, the results were very mixed (AVG=2.9, SD=1.1).

Experiment 2. In the second study, eight (1f) participants were asked to test the mobile (Maroon Mobile VR) as well as the interactive physics lab (Maroon Room-scale VR). In this group, seven are very experienced in the use of computers (AVG=4.4, SD=1.4), two in the usage of video-games (AVG=3, SD=1.2), and only one in VR (AVG=2.3, SD=1.4), although four have used a mobile VR setup before (but not the HTC Vive). Almost all of them (seven) rated their physics knowledge as 3 or below (AVG=2.6, SD=0.9), rather low.

Equipment and Setup

The VR setup Maroon Mobile VR consists of the following hardware components: the portable, mobile HMD (Samsung Gear VR) and the smartphone Samsung Galaxy S6. The setup for HTC Vive contains the HMD, two base stations, and the two controllers. For a room-scale setup setting, we provided an area of about 2m x 2m. Furthermore, a powerful high-end hardware PC was necessary.

Method

Experiment 1. For the first study with Maroon Mobile VR, we first asked the participants to fill out a pre-questionnaire. The pre-questionnaire was used to get information about the participants' experience with virtual experiences, VR technologies, and their expertise in physics. They were then briefly introduced to the system. After this, they were asked to start Maroon Mobile VR. After the experience, the participants briefly described their impressions in the form of an open dialog. Finally, we asked them to complete a post-questionnaire with ten open-ended question about their experience and 20 single-choice questions with ratings on a Likert scale between 1 (fully disagree) and 7 (fully agree).

Experiment 2. The second (extended) study was designed as an A/B study to evaluate the experience with both devices. In the A/B study, the first group (group A) evaluates the version with the Samsung Gear VR first, before interacting with the second technology. After that, the second group (group B) evaluates the version with the room-scale technology first, before interacting with the Samsung Gear VR. First, participants filled out a pre-questionnaire with standard personal background information. This was followed by a brief introduction on the experimental setup. Next, they were supposed to complete different tasks in Maroon Mobile VR and Maroon Room-scale VR. Since we examined the differences and similarities of both devices, our eight test subjects were divided into two separate groups of four persons each. Four users evaluated Maroon with the Vive first (group A), and the other four tested the Samsung Gear VR first (group B). After each single run, users completed a corresponding post-questionnaire containing 19 standardized questions from the Game Engagement Questionnaire (GEQ, Brockmyer et al. (2009)) to measure the level of engagement based on absorption, flow, presence, and immersion, as well as ten open-ended questions on the experience and 20 single-choice questions with ratings on a Likert scale between 1 (fully disagree) and 7 (fully agree).

For a comparative evaluation, all participants had to complete a "combined" post-questionnaire with open-ended questions about their experience with both setups.

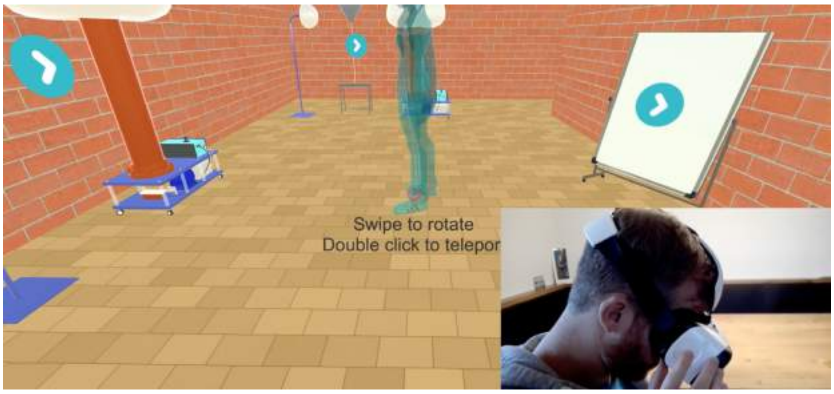
6.4.4. Findings

We compared key elements of engagement and immersion between Maroon Mobile VR and Maroon Room-scale VR with the Game Engagement Questionnaire. An overview of the results for each GEQ statement is shown in Table 6.1 and Table 6.2. There are a few significant differences in the average value results for mobile and room-scale VR setups. Users rated the room-scale VR experience on the HTC Vive as (feeling) more real (AVG=3.3, SD=0.9) than the mobile VR experience on the Samsung Gear (AVG=2.5, SD=0.5). Furthermore, users felt more like they were losing track of time while using the HTC Vive (AVG=3.4, SD=1.6).

As it is illustrated in Table 6.2, each statement in the GEQ can be assigned to one of the four main categories which contribute to game engagement: presence, absorption, flow, and immersion. An overview of the overall results for each category is listed in 6.1 and illustrated in Figure 6.13. The Maroon Room-scale VR scores slightly better compared to the Maroon Mobile VR in each of the four categories.

Experiencing Immersion and Engagement

Experiment 1. In the first user study testing the mobile VR setup on the Samsung Gear, most of the participants mentioned that they find learning in this manner more engaging (AVG=5.7, SD=1.8) and fun (AVG=5.6, SD=1.9). When asked if they find it engaging and motivating, most of them agreed: *"very motivating way of demonstrating stuff"*. The lack of content and variety



(a) The mobile VR experience with the Samsung Gear VR

(b) The room-scale VR setup with the HTC Vive

Figure 6.9.: Samsung Gear VR and HTC Vive setup

Table 6.1.: Comparison of GEQ main elements between HTC Vive (Maroon Room-scale VR) and Samsung Gear (Maroon Mobile VR) setup using a Likert-scale of 1 to 5

	HTC Vive		Samsung Gear	
Category	AVG	SD	AVG	SD
Presence	2.6	0.2	2.4	0.4
Absorption	2.4	0.1	2.3	0.1
Flow	2.5	0.2	2.3	0.3
Immersion	2.9	1.4	2.6	1.5

Table 6.2.: Detailed comparison of GEQ elements between HTC Vive (Maroon Room-scale VR) and Samsung Gear (Maroon Mobile VR) setup using a Likert-scale of 1 to 5

		HTC Vive		Samsung Gear	
GEQ Statement	Category	AVG	SD	AVG	SD
1I lose track of time	Presence	3.4	1.6	2.8	1.7
2 Things seem to happen automatically	Presence	2.0	1.2	2.3	1.0
3 I feel different	Absorption	2.9	1.6	3.3	1.5
4 I feel scared	Absorption	1.5	1.4	1.5	1.4
5 The game feels real	Flow	3.3	0.9	2.5	0.5
6 If someone talks to me, I don't hear them	Flow	1.5	1.1	1.6	1.4
7 I get wound up	Flow	2.6	1.4	2.4	1.5
8 Time seems to kind of stand still or stop	Absorption	2.9	1.5	2	1.3
9 I feel spaced out	Absorption	2.3	1.5	2.3	1.5
10 I can't tell that I'm getting tired	Flow	2.5	1.3	2.3	1.8
11 Playing seems automatic	Flow	2.5	1.3	2.3	1.3
12 My thoughts go fast	Presence	2.5	1.3	2.0	0.9
13 I lose track of where I am	Absorption	2.5	1.4	2.4	1.4
14 I play without thinking about how to play	Flow	3.0	1.4	2.6	1.1
15 Playing makes me feel calm	Flow	3.0	1.2	2.9	1.1
16 I play longer than I meant to	Presence	2.5	1.5	2.6	1.5
17 I really get into the game	Immersion	2.9	1.4	2.6	1.5
18 I feel like I just can't stop playing	Flow	2.6	1.2	2.1	1.0
19 I don't answer when someone talks to me	Flow	1.6	1.1	1.9	1.5

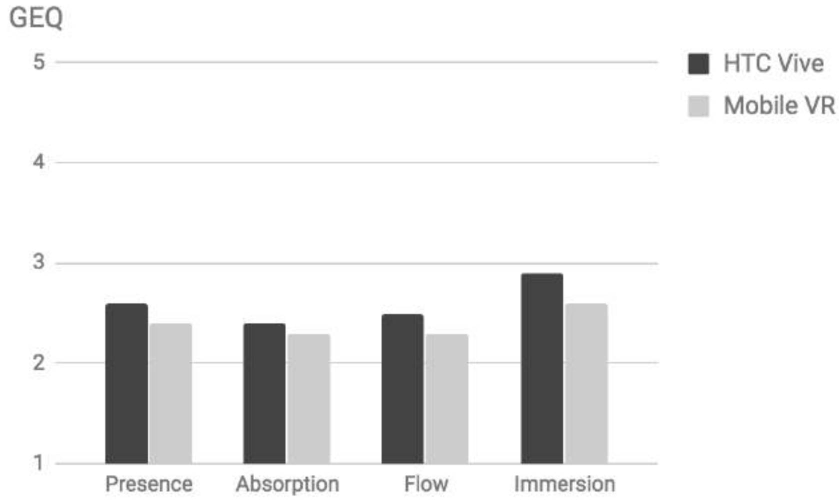


Figure 6.10.: Results of the game engagement questionnaire using a Likert-scale of 1 to 5

was mentioned as a drawback here: *"Not yet, but I can see how the concept would be engaging once more variety exists."* When asked what they liked about the system, immersive and three-dimensional characteristics were mentioned: *"Immersion makes me remember stuff better"*. Overall, the VR experience was received very positively and described as very immersive experience.

Experiment 2. In the second part of the study, we compared factors contributing to engagement and immersion such as presence, absorption, and flow (as part of the GEQ). Maroon Room-scale VR achieved only slightly better results in all four categories of the GEQ.

Immersion and engagement were not only evaluated via the 19 standardized questions of the GEQ but also through 20 single-choice questions with Likert-scale ratings and ten open-ended questions on the experience. Findings of these two question formats are presented below. Participants interacting with the Maroon Room-scale VR on the HTC Vive found this way of learning more engaging (AVG=5.4, SD= 1.8) and more fun (AVG=5.4, SD=2.1) than on the Samsung Gear, which participants found slightly less engaging (AVG=5.1, SD=1.6) and less fun (AVG =4.8, SD=1.8) for learning. When asked the question ***"Do you find it engaging and motivating?"*** , comments on the HTC Vive highlighted the aspect of fun: *"Yes it is quite engaging and motivating to use. Learning seems much more fun this way."* and *"The simplest things become fun in Virtual Reality"*.

Remarks on the Samsung Gear included very positive statements such as *"Definitely. Playing and instant feedback (something is moving, machine working, flashes striking..) catches my interest and makes me want to find out more."* as well as statements indicating a stronger bias towards HTC Vive: *"yes, maybe more if I didn't know the Vive"* as well as *"A bit less than with the Vive"*. In fact, two users of this second study did not find the mobile VR experience engaging and motivating at all.

Experiencing Learning

Experiment 1. In the first study, on a Likert scale between 1 (not at all) and 7 (fully agree) most of the people said they would like to learn with Maroon Mobile VR (AVG=4.7, SD=1.9) and feel that the content is easier to understand (AVG=4.9, SD=1.8) and more motivating than ordinary exercises (AVG=4.9, SD=2.0). However, the environment inspired only a few to learn more about physics (AVG=2.7, SD=1.4). When we asked them if they would use it for learning, all but one of the participants were positive about this idea. Many positive comments mentioned the experimentation and visualization of usually unseen things: *"I would use it immediately for my mechanical engineering studies, because it is an advantage to see and rotate the machines in a 3D space; also it can be an advantage when learning about dangerous machines: one can still see everything without a distance"*. It was mentioned that they would like to use the immersive lab as a supplement for learning (AVG=5.7, SD=1.4). The participants would rather use Mobile VR in a classroom environment

(AVG=4.8; SD=2.1) than at home (AVG=4.2, SD=2.0). *"There are a few elements missing that would produce a good learning environment for me. The first thing is explanations. If someone learns about the illustrated concepts beforehand (maybe in class), the game could certainly help with that, but it is far from a standalone learning tool right now."*.

Concerns using this system for learning include: (*"It's good for demonstrating something, maybe not as good for learning facts, etc., because you can't, for example, take notes"*).

The VR aspect was very well received for learning. Participants thought it was engaging to see the physics simulations with the VR glasses (AVG=5.8, SD=1.9) and also more engaging than without VR (AVG=5.4, SD=1.4) as is reflected in the statement *"learning with VR is gonna be awesome and I never thought about what happens to a balloon if we place him between a Tesla-coil and a grounding sphere. Funny"*.

Experiment 2. For the interpretation of results from the second user study, it is important to consider that each of the eight study participants had experienced and tested the physics laboratory with both VR devices, albeit in different order via A/B, B/A testing. Most participants of this experiment stated that they would like to learn with Maroon Room-Scale VR (AVG=5.1, SD=2.1) and think that the content is easier to understand (AVG=5.5, SD=1.4) and more motivating than regular exercises (AVG=5.4, SD=1.41. However, only a few participants would consider buying the VR glasses and downloading the Maroon Room-scale VR for use at home (AVG=3.0, SD=2.1).

When users had the chance to test both devices (as in experiment 2), they would prefer Maroon Room-scale VR over Maroon Mobile VR for learning. This sentiment is also reflected in the fact that users of the Samsung Gear did not find the content as easy to understand (AVG=4.6, SD=1.9) and as motivating (AVG=4.3, SD=1.67) as on the HTC Vive. When asked: ***Would you use it***

for learning?, answers about Maroon VR on HTC Vive were quite varied, ranging from very positive like *"Absolutely! It is very fun and makes learning to an activity to look forward to"* to rather critical such as *"Not really, the "game and fun factors" are too high so it could be hard to focus on the important things for learning."* and *"Depends on the subject. For something like physics, where there is actually something to see yes. Others, like mathematics I am not sure whether this would be helpful"*.

Users liked the fun part, but are not entirely convinced about the learning aspect. In contrast to the first user study, only half of the test users of this second study would like to use the Samsung Gear for learning, after also having experienced VR on the HTC Vive. Users' answers mentioned drawbacks such as user interaction (*"the handling takes away a bit of the joy of exploring the VR world"*) and also mentioned the effort of the setup (*"not worth the effort, because the visualization could be done on the computer as well"*, *"Depends on the subject again. Physics yes. Other subject: I am not convinced."*).

When users were asked about whether they find Maroon VR good for learning, both the HTC Vive and the Samsung Gear version received mixed responses. With Maroon Room-scale VR, users liked the possibility of actually exploring the virtual world up close and in real-time (*"I can imagine it to be very good for learning. Seeing the Reactions in real time and up close gives a better understanding of many physical processes, which are happening"*) but also remarked on the necessity of providing further theoretical background (*"If one would be more familiar with this topic area, then yes, it would probably be good for learning. Without that, one felt a bit helpless without knowing what this simulation is supposed to show"*). For Maroon Mobile VR, users would like to use it for learning but again saw the limited handling and low resolutions as a drawback: *"it's ok, but the limited handling takes some of the motivation for engaging with the environment away"* and *"The experiments for sure. The resolution of the board with the lecture slides was too low to recognize it as a means to convey actual content. Reminded me much of FPS (First Person*

Shooter) games like HL (Half Life), Doom3 where text was merely a deco on virtual computer consoles."

Again, users see this as an additional tool to supplement or deepen existing knowledge about physics (*"Maybe it could be used as an additional tool for better understanding of experiments." "maybe if I knew more about the field of physics"*).

Usability and User Experience

Experiment 1. In the first study, usability and user experience with the Samsung Gear VR version differed from person to person. While some of the people had no issue with the gaze-based controls and the interface, others had problems with learning the movements. Minor usability issues were mentioned. These included, in particular, the unusual movement (teleporting instead of walking; how to turn the avatar) and interactions (e.g., clicking twice on the door to exit a simulation instead of just once). *"Moving in the environment was not very intuitive but worked well. The UI was not very hard to figure out."* Additionally, the idea of giving more feedback on interaction possibilities was mentioned *"I wished for some visual feedback on what's clickable. I wasn't sure what I can click and what not so I clicked around quite a lot."*

Experiment 2. Findings from the second study are as follows: With the Samsung Gear VR, most study participants had a good overall impression. The main usability issues expressed by users were possibilities for interaction and movement, including a mention of cybersickness (*"I'd like more options for interacting with the generator devices, e.g., Fiddle around with the equipment, find out what it can do. Experiencing the VR environment was a bit unsettling sometimes. Sensory input from the natural environment mismatched what I saw in VR. Think, I felt slightly dizzy. The teleport for moving around gave* *me a punch in the stomach the first few times. Maybe the radical change of scenery in front of my eyes, but no physical movement whatsoever."*). One person thought about potential effects of nausea: *"..I wonder if nausea might have a negative impact on learning experience"*. Users also mentioned the low quality of graphics resulting in a low readability: *"The text on the whiteboard and the computer was very hard to read (maybe because of wrong resolution?); movement not intuitive and a bit complicated."*

With the HTC Vive, study participants enjoyed, in particular, the interaction with objects as well as the high graphics resolution: *"I liked that I can actually touch and move things with my hands. Graphics are awesome too."* Again, a feeling of dizziness characteristic of cybersickness was reported by some users: *"After some time (20 minutes), I started feeling a noticeable dizziness and a hint of nausea (but nothing serious)."* Other drawbacks remarked by students include the handling of controllers (*"In the beginning, one needs a certain time to get used to it (which buttons are used for which action). However, controllers are definitely more convenient than the trackpad on the headset of Samsung Gear VR. Nevertheless, in the long term, it might not be pleasant always to have to hold two extra things in the hands."*). Users also mentioned limitations within the physical room: *"Being able to grab and move things was great. Enjoyed that much. That I could move my body and was not confined to a chair was great. I grew a bit weary of hitting something in the real world. Always checking the confines of my personal physical movement space."*

Some users also came up with suggestions for additional features such as collaboration between students and museum-like experiences within the lab: *"Maybe it could fun to learn with others in VRs, but only as an additional tool."* *"Information could be given to the exhibitions. Either in the form of a Text or a Museum-like Announcer voice. Actually, a virtual museum would be quite exciting."*

6.4.5. Conclusion and Discussion

In this section, we have described and investigated two different forms of immersive learning experience in virtual reality environments for physics education. The goal was an exhaustive comparison between learning experiences in a virtual physics laboratory with cost-effective mobile VR technologies and with interactive room-scale VR setups. First results indicate positive experiences in both virtual reality experiences with the immersive physics laboratory "Maroon VR". Learning in such an immersive environment was described as an engaging and exciting experience. Results also indicate that students would be in favor of using such technologies for learning and that they find it more engaging and also effective when compared with traditional learning scenarios. With this work, we have shown the potential of emerging immersive and interactive technologies of becoming an integral part of future in-classroom learning. Many participants would recommend the use of virtual reality learning experience as a supplement to in-class learning models as opposed to using it as a stand-alone application to learn in a self-regulated way at home. Mobile VR setups such as experiences with the Samsung Gear VR or the Google Cardboard provide cost-effective, dynamic, and mobile learning experiences and can be quickly set up for in-class learning experiences. One way to introduce virtual reality learning experiences in educational settings is to extend active learning strategies with short digital mobile VR experiences as part of the class room environment. Additionally, mobile virtual reality scenarios which support networked capabilities can be used to show all students experiences with experiments, visualizations, or simulations at the same time while the teacher guides them through the experience. Compared to mobile VR, room-scale VR setups are more cost-intensive, need specific hardware and a lot of space, and only support a limited number of users at the same time. However, many users feel more immersed and engaged by interactive room-scale setups. Additionally, the controllers give users more possibilities for interacting with experiments. This often creates more interesting hands-on experiences. Such virtual reality settings could be used in addition to classroom scenarios, for instance as a part of self-directed learning labs provided for the class.

Observation
Observation 3. Virtual reality setups promote engaging and immersive learning scenarios and are described as more engaging when compared to traditional setups. As cost-effective and flexible learning tools, mobile VR experiences can be used to extend blended learning environments. Room-scale VR variants support better hands-on experiences. Both variants described are more immersive and engaging compared to traditional learning experiences. Hands-on interactivities can better motivate flow experience compared to passive experiences.

6.5. Analysis 4: Maroon vs. Maroon Room-scale VR

In the previous sections, we have discussed advantages and issues of Maroon Mobile VR and Maroon Room-scale VR. One open question is: how does Maroon VR improve educational and motivational environments when compared with standard computer-based variants (Maroon). In this section, we compare the experience within a interactive virtual laboratory environment in a room-scale virtual reality setup with a traditional computer-based solution. In an A/B study with 20 participants, we investigated the two settings with a focus on comparing immersion, engagement, usability, and learning experience. The Maroon Room-scale VR setting used in this section is a extended a more interactive version compared to the last section. The section is based on Pirker, Holly, et al. (2017).

6.5.1. Motivation and Contributions

In this section, we want to investigate and compare learning experiences with the room-scale virtual reality setups of Maroon and compare it with a traditional computer-based version. The focus is on identifying benefits and downsides, and realistic and interesting application scenarios for both setups. Room-scale virtual reality setups can provide new and more immersive and realistic forms of interactions with experiments and can help students stay focused on the learning experiences. In the following, we compare such VR learning experiences with traditional computer-based solutions to explore and discuss potentials and downsides of both. This should contribute to a better understanding of the potential of the different technologies and should help to identify application scenarios in learning settings for both tools.

The contributions of this section can be summarized as follows:

- Computer-based setups allow a better overview, are better suited for tasks requiring reading and note-taking
- Interactive, realistic, and natural design in room-scale VR setups better support interactive and hands-on experiments to support immersion
- Interactive experiments such as experienced in room-scale VR can better support conceptual understanding
- VR variants help students to focus on specific learning tasks
- Guided step-by-step experiences can be better for computer-based variants whereas a more explorative approach is suitable for VR experiences

Contributions to the Conceptual Model

In this section, we analyze the impact of VR technologies on immersion. We evaluate and compare two settings, one implemented with a computer-based setup, the second one implemented with a room-scale VR setup. Based on this evaluation and comparison we create recommendations and analyze application scenarios and design guidelines to create motivational learning environments. We also look at engagement strategies to better support computer-based variants to motivate learners.

6.5.2. The Setting

For this study, a version of Maroon and Maroon Room-scale VR supporting four experiments was used. As introduced in Chapter 5, the experiments "Va de Graaff Generator", "Balloon at Van de Graaff Generator", "Falling Coil", and "Faraday's Law" are used for this setup. Compared to the HTC Vive configuration, as evaluated in the previous section, this version was designed in a more interactive way. In particular the experiments "Falling Coil" and "Faraday's Law" were designed in a very realistic and interactive for the room-scale variant (e.g., also supporting haptic feedback when moving magnets together). Hence, we will also investigate and compare the different versions with a focus on this aspect.

6.5.3. Study Setup

We performed a user study with 20 participants with a focus on evaluating engagement, immersion, learning experience, virtual reality experience, usability, and user experience. To compare the computer-based environment with the HTC Vive variant, we made a multivariate AB/BA test. The first 11 users started with the HTC Vive (A) and continued with the computer-based version (B). The second 9 users began in the reverse order. In the first phase, environment users had to answer physics questions after each experiment to measure the learning progress and compare the two environments.

Participants

In the study, 20 participants (3 female) between 20 and 28 (AVG=24.05; SD=2.31) tested Maroon and Maroon VR. A total of 18 of the participants were students. Most of them were in the field of computer science; four participants were from the fields industrial design, media design, mechanical engineering and business economics. A total of twelve are very experienced in the use of computers (AVG=4.4; SD=0.82), eleven are experts in the usage of video-games (AVG=4.2; SD=1.06), and 18 like playing video games. In average the test group tends to play video games more often (AVG=3.45; SD=1.28). All of them rate themselves as not experienced in the usage of VR (AVG=1.65; SD=0.81), 18 had heard about VR devices, and 11 have already used such devices; 2 have used HTC Vive before. Only two had experienced cybersickness before. None of them rate themselves as very experienced in physics.

Equipment and Setup

The computer-based setup consists of a standard workstation with keyboard and mouse. The setup for the HTC Vice contains the head-mounted display (HMD) itself, the two base stations and the two controllers. The room-scale experience was about 2m x 2m. For both environments, an Alienware AREA with two NVIDA GeForce GTX 960 was used because the room-scale VR setting needed a powerful high-end hardware PC.

Method

At the beginning of the study, every participant had to fill out a pre-questionnaire. The pre-questionnaire was used to gather demographic data and background information including experience with computers, VR technologies, and video games and their physics knowledge. The participants then got an exact introduction into the test systems. We explained to them how to move in room-scale VR and how to interact with objects. Participants also got an introduction into how they can interact with the computer-based setting. After that, participants were given different tasks within the two environments. As the test was designed as an A/B study, users would either start with the VR experience or with the computer-based experience.

The first task was to look around in the environment for two minutes to get an impression of the lab environment.

The second task was to start the falling coil simulation and try to identify the relationship between the magnetic field and the electrical current. They were asked to launch the simulation, interact with its elements such as changing the current in the ring or the magnet moment and use visualization elements such as field lines, vector fields, or an iron filing (see Figure 6.11).

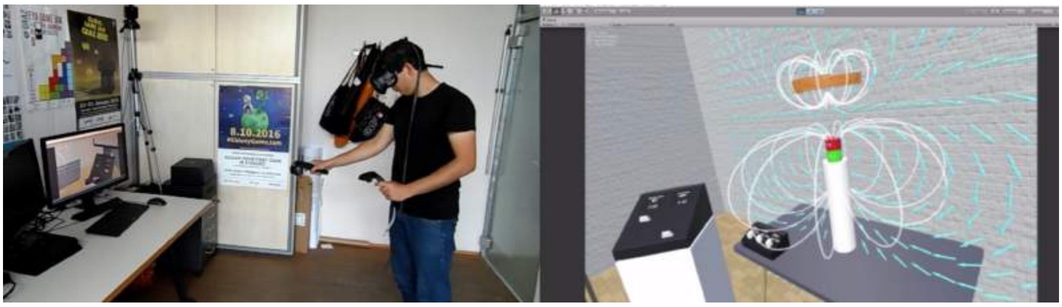


Figure 6.11.: Faraday's Law experiment with the HTC Vive

In the next task, participants had to start the Faraday's Law experiment and move the magnet towards the coil to understand the force effects for a conductor in a magnetic field. Again, participants were asked to interact with the simulation by changing elements such as the current in the ring or the magnet moment and visualization aspects such as field lines, the vector field, and an iron filing (see Figure 6.12).

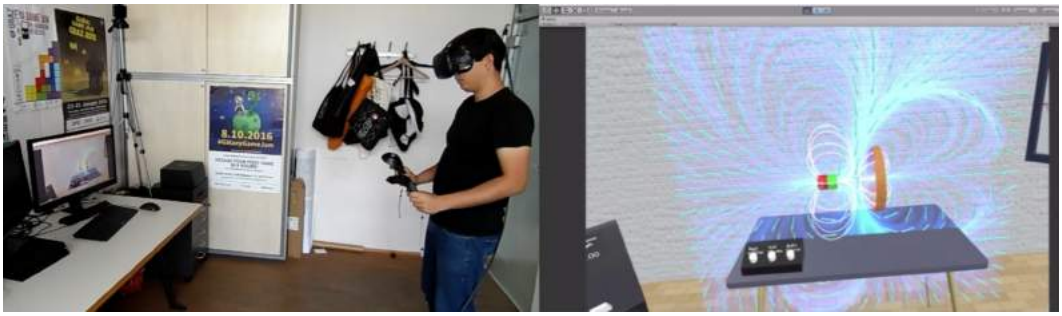


Figure 6.12.: Faraday's Law experiment with the HTC Vive

After each experiment in the laboratory, participants had to answer questions to the experiment to measure their learning progress. The questions are summarized in Chapter A.

After finishing the two tests the participants had the possibility of looking at the rest of the environment. Moreover, they were asked to describe their impression of the environment in a short interview. After each iteration, users completed a corresponding post-questionnaire. The questionnaire contained 10 open-ended questions about impression, 20 single-choice questions with ratings on a Likert-scale between 1 (fully disagree) and 7 (fully agree) and 19 standardized questions from the Game Engagement Questionnaire (GEQ) to measure the level of engagement on absorption, flow, presence, and immersion with ratings on a scale between 1 (not at all) and 5 (extremely). Finally, at the end of the test, each participant had to complete a common post-questionnaire with five open-ended questions about their experience in both environments.

6.5.4. Findings

Similar to the study described in the previous section, we used the GEQ to evaluate and compare the two different experiences in this A/B study. Table 6.3 and Table 6.4 summarizing the results. As expected, we can especially see differences between statements suggesting presence and immersion, but interestingly also flow.

Experiencing Immersion and Engagement

As we can see in Figure 6.13, immersion was perceived much higher in the virtual reality version compared to the computer-based version. One user even mentioned in the discussion that one would not lose track of time in the computer-based version compared to the VR version.

The experience in the room-scale variant was described as more attractive (AVG=6.0, SD=1.3) compared to the computer-based variant (AVG=5.3, SD=1.3). One interesting point to highlight is that the room-scale variant was described as much more fun (AVG=6.1, SD=1.5) than the computer-based variant (AVG=4.9, SD=1.8).

Participants described the VR experience as *"more cool and more fun, because one can touch everything"* and mentioned that they think that *"the learning experience is the same, but more motivating in VR"*.

One user also indicated that he or she would prefer a step-by-step guided experience in the computer-based variant, whereas, in VR it is more interesting to try out different things in the form of a playground.

Experiencing Learning

Both experiences were received very positively. The participants would like to use them for learning and believe they are valuable for learning. However, they would prefer to learn with the VR version and think that it is a useful tool to supplement regular learning. They found learning in the VR version much more fun (AVG=6.1) compared to learning in the computer-based version (AVG=4.9).

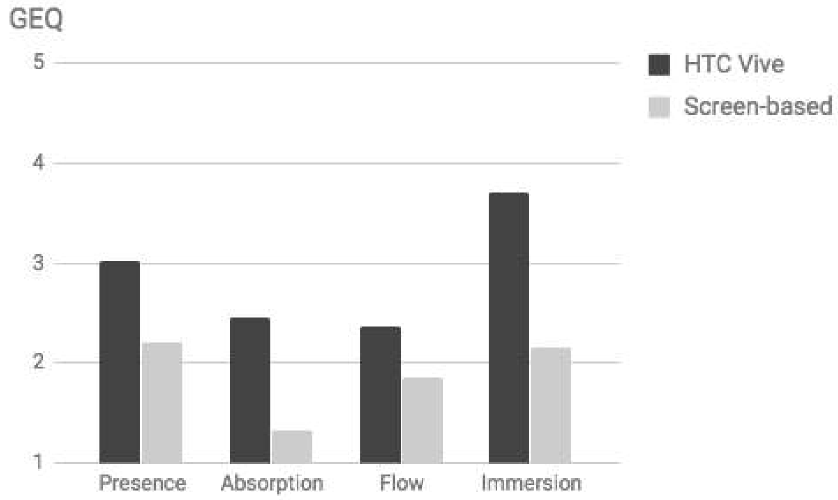


Figure 6.13.: GEQ results comparing average between HTC Vive and computer-based version

Details are illustrated in Table 6.5. Additionally, participants would rather recommend both setups for learning in the classroom than at home. But they would prefer learning in VR at home over learning with the computer-based variant.

Even though many users mentioned that they learn better with the computer-based version, it seems that participants got a better conceptual understanding

Table 6.3.: Comparison of GEQ main elements between HTC Vive and a computer-based setup

	HTC Vive		Screen	
Category	AVG	SD	AVG	SD
Presence	3.0	1.4	2.2	1.4
Absorption	2.5	1.2	1.3	0.6
Flow	2.4	1.1	1.9	1.0
Immersion	3.7	1.1	2.2	1.1

Table 6.4.: Detailed comparison of GEQ elements between HTC Vive and a computer-based setup

		HTC Vive		computer-based	
GEQ Statement	Category	AVG	SD	AVG	SD
I loose track of time	Presence	3.5	1.6	2.3	1.4
Things seem to happen automatically	Presence	2.6	1.2	2.4	1.5
I feel different	Absorption	2.7	1.6	1.4	0.7
I feel scared	Absorption	1.1	0.3	1.1	0.2
The game feels real	Flow	3.3	1.0	1.7	0.9
If someone talks to me, I don't hear them	Flow	1.2	0.5	1.3	0.6
I get wound up	Flow	1.8	1.1	1.6	0.9
Time seems to kind of stand still or stop	Absorption	2.3	1.4	1.3	0.6
I feel spaced out	Absorption	3.0	1.3	1.4	0.7
I can't tell when I'm getting tired	Flow	2.1	1.3	1.7	0.9
Playing feels automatic	Flow	3.1	1.3	2.3	1.4
My thoughts go fast	Presence	2.8	1.5	2.3	1.5
I loose track of where I am	Absorption	3.2	1.5	1.5	0.8
I play without thinking about how to play	Flow	3.5	1.5	2.7	1.6
Playing makes me feel calm	Flow	2.8	1.5	3.1	1.6
I play longer than I mean to	Presence	3.4	1.4	1.9	1.1
I really get into the game	Immersion	3.7	1.1	2.2	1.1
I feel like i just can't stop playing	Flow	2.4	1.0	1.6	0.8
I don't answer when someone talks to me	Flow	1.2	0.5	1.1	0.2

Table 6.5.: Statements to different experiences on a Likert scale between 1 (not at all) and 7 (fully agree), which were asked after the VR and the computer-based experience

	HTC Vive		Computer	
	AVG	SD	AVG	SD
I would like to learn with the this Lab	5.3	1.8	5.0	1.6
It is a good idea to use this Lab for learning	6.0	0.9	5.6	1.6
The Lab is a good supplement to regular learning	5.6	1.4	5.4	1.4
I learned something with the Lab	4.1	1.6	4.4	1.8
The Lab makes the content more interesting	6.0	1.3	5.3	1.3
The Lab makes learning more fun	6.1	1.5	4.9	1.8
The Lab makes learning more interesting	6.0	1.2	5.3	1.3
The experience Lab inspired me to learn more about physics	4.0	1.9	4.1	1.8
Learning with the Lab was more motivating than ordinary exercises	5.6	1.5	5.1	1.5
It makes course content more interesting to learn about	5.4	1.6	5.0	1.5
I would rather like to learn Physics with the Lab than with traditional methods	6.5	5.9	4.5	1.7
I find regular physics classes boring	4.8	1.9	5.1	1.8
I would like to learn with the Lab at home	5.0	1.6	4.4	2.1
I would like to learn with the Lab in the classroom	5.6	1.7	5.2	1.4

of the experiment concepts in the VR version. To learn about their understanding of the experiments, we asked them two conceptual questions to describe the physical phenomena they saw in the experiment setup and asked them to rate how sure they are about their answer". The first question was answered by 37% of the Maroon Room-scale VR users almost right, and by 18% completely right. In the screen-baser variant only 34% replied to the question almost right and nobody completely right. The second question was answered by 82% almost right, and by 18% completely right in the VR setup. A total of 78% answered the question almost right in the computer-based configuration and again nobody completely right.

When interviewing the participants, some mentioned that they believe that the learning effect is the same with the computer-based version, because of a better overview. Additionally, learning content such as written learning concepts or field-lines is easier to read and see in the computer-based version. Many participants mentioned that they believe that learning in VR is more fruitful because they would spend more time and are concentrating more when trying out the experiments. When interacting with the experiments, we added haptic feedback through the controllers (e.g., they start to vibrate when two magnets are moved together). They mentioned this "extra-dimension" (e.g., giving force-feedback when moving magnets) as important for their learning experiences. Also, the natural "physical" interaction with the learning elements was described as an improvement on the learning experience. Participants felt as they would conduct the experiment in real life.

Usability and User Experience

As the laboratory was designed as large laboratory room and every experience was in this room, several users had issues with the scaling and the size of this room. Users have positively mentioned realistic elements, such as a practical and working clock.

Table 6.6.: Overview of the correctness of answers given by participants about the experiments. Additionally, we asked them to rate on a scale between 1 (not at all) and 5 (very) how sure they are about their answer. The ratings and the average are listed in the last row.

	Question 1				Question 2			
	HTC Vive		Screen		HTC Vive		Screen	
not correct	5/11	45%	6/9	55%	0/11	0%	2/9	22%
almost correct	4/11	36%	3/9	33%	9/11	82%	7/9	78%
correct	2/11	18%	0/9	0%	2/11	18%	0/9	0%
How sure?	24/55	2.18	23/45	2.56	26/55	2.36	29.5/45	3.28

The computer-based variant was described to give a better overview and the controls (mouse and keyboard) are more familiar. However, the interaction with the lab in the VR variant more realistically and naturally was received by many users very positive. Therefore, many of the participants would prefer this interaction - even if it is not familiar - over the interaction through mouse and keyboard.

Limitations

This study was limited to a small number of participants, but already gives a good overview of potentials of the two different learning experiences. Many new research questions were opened up in this study. While the focus of this work is to learn more about motivational aspects such as immersion and engagement, we also identified several open questions looking at the participants' learning behavior in VR. Especially getting a deeper understanding of the differences in learning. Different kinds of learning concepts can be perceived differently in the two experiences. It would be important to understand how students learn, what concepts are suitable for what experience, and where (in the classroom or at home) students should learn these.

6.5.5. Conclusion and Discussion

We can conclude, that the room-scale VR experience was received as more engaging and immersive when compared with a traditional computer-based variant. Participants mentioned that the interactive, realistic, and natural design in room-scale VR setups better support interactive and hands-on experiments. This also improved the feeling of immersion and the lose the track of time. When assessing their understanding of the experiments in a small quiz, the participants were able to explain the experiments after the VR experience better. VR also supports better concentration on learning tasks. However, it was also mentioned that it is easier to read and to take notes in the computer-based option. Participants would recommend the computer-based variant in the form of guided step-by-step experiences, whereas in VR, especially the exploratory approach was valued.

Observation

Observation 4. Interactive virtual reality setups support learning of conceptual concepts. Immersion supports concentrated learning is a key feature of VR learning environments. Natural and realistic design elements (e.g., a clock) can support immersion. Computer-based setups are better suited for learning tasks requiring a lot of reading or taking notes.

6.6. Analysis 5: Maroon vs. Maroon Mobile VR in Multi-User Setups

In the previous sections, we have discussed advantages and issues of Maroon Mobile VR, Maroon Room-scale VR, and a computer-based version of Maroon. In a last preliminary experiment, we also investigated the influence of multi-user capabilities in a Mobile VR setup compared to a computer-based setup. While this the design and the development of Maroon was focused on creating immersive and engaging experiences through VR technologies and immersive design strategies, we already started in setting up first and very early prototypes of multi-user experiences. In this section, we discuss a first preliminary evaluation of the experiences in a multi-user experience in Maroon Mobile VR and compare it to a multi-user setup in a computer-based version of Maroon. We investigated two settings with a focus on comparing immersion, engagement, usability, and learning experience in an A/B study with 20 participants. The section is based on Pirker, Holly, et al. (2017).

6.6.1. Motivation and Contributions

In this section, we investigate first prototypes implementing engagement elements inspired by multi-user setups. The prototypes tested are in a very early stage. However, as social experiences are an essential feature in engaging learners, we discuss potential and issues of these prototypes as part of this thesis. Following, we compare a multi-user setup of Maroon in the computer-based version with a multi-user implementation of Maroon Mobile VR.

The contributions of this section can be summarized as follows:

- Virtual reality experiences are perceived as much more fun, engaging, and immersive learning experiences compared to computer-based experiences
- Seeing other avatars in the learning environment is described as engaging
- A streaming mode in multi-user environments is described as valuable social learning tool

Contributions to the Conceptual Model

In this section, we look at collaboration as engagement strategy to create motivational environments and investigate the influence of technologies creating immersion (mobile VR setups) in collaborative settings on motivational learning environments.

6.6.2. The Setting

For this study, a simple reduced version of Maroon and Maroon Mobile VR were used. As introduced in Chapter 5, the experiments "Van da Graaff Generator" and "Balloon at Van de Graaff Generator" were the primary learning experiences for the setup.

6.6.3. Study Setup

We designed a qualitative A/B user study with 20 participants. Again, we focused on evaluating aspects supporting motivational environments such as immersion and engagement. Additionally, we wanted to get first insights into the learning experiences and the learning process as well. As it was designed as multi-user experience, the 20 participants were arranged in groups of two. They had to complete three tasks together in both setups.

Participants

In this study, 20 (four female) participants between 22 and 34 (AVG=26.05; SD=3.5) were asked to evaluate the two experiences. Most of the participant were students (15) and five employed. The fields of studies were mixed. The majority of the students were studying fields such as software engineering or electrical engineering. Others study architecture, chemistry, or account management. Their expertise with computer usage is also very mixed (AM=3.6; SD=1.34), as well as their experience with video games (AM=3.4; SD=1.7). Some play video games very often (five), some almost never (five), the arithmetic mean is 2.95 (SD=1.54). The majority of them has no experience with VR, but 13 have already heard of the Google Cardboard or Samsung Gear VR; six have already tried the Gear VR, four the Google Cardboard. 16 have player online multi-user games before. They rate their physics knowledge in average rather low (AM=2.4; S=0.9).

Equipment and Setup

For the computer-based experience, two standard workstations were used. For the Mobile VR version two Samsung Galaxy S6 together with two Samsung Gear VR were provided.

Method

Participants filled-out the pre-questionnaire about demographic information, previous experience with games, virtual reality, multi-user setups, and physics. The study is designed in an A/B format. Half of the users started the study with the VR setup; the other ten started with the computer-based experience. The study tasks were completed in pairs. In a first step, participants were introduced to the system. Then they had to complete three tasks together. After each iteration, they completed a small post-questionnaire with question about their impressions and 20 single-choice questions about their experience with answers as rating on a Likert scale between 1 (fully disagree) and 7 (fully agree) and the GEQ (Brockmyer et al., 2009), rating aspects of immersion and engagement on a Likert scale between 1 (fully disagree) and 5 (fully agree).

After completing both experiences including the two post-questionnaires, a post-questionnaire asking them to compare the two systems was given.

6.6.4. Findings

The setup of this study was very similarly to the setup of analysis 4 to be able to compare results and systems.

Experiencing Immersion and Engagement

As we can see in Figure 6.14, the differences between the two versions with respect to immersion, flow, absorption, and presence are not significantly high. As illustrated in Table 6.7 The experience with in Maroon Mobile VR was rated as a bit higher (AVG=2.6) compared to the experience in the computer-based version (AVG=2.2).

Most elements of the GEQ (see 6.8) are rated very similarly when comparing the computer-based multi-user setup with the mobile VR multi-user setup. Experiences supporting flow such as *"I play without thinking about how to play"* are partly better rated in the computer-based version since users are more used to the controls and the setup. Elements, supporting immersion and absorption such as *"I feel spaced out"* are partly better supported by the VR setup.

Experiencing Learning

They would use the VR version to learn in a more engaging way and find learning applications such as a laboratory experience well suited for learning in VR. Participants also mentioned to rather use computer-based experiences for learning subjects, which do not require visual and graphically-rich components such as mathematics.

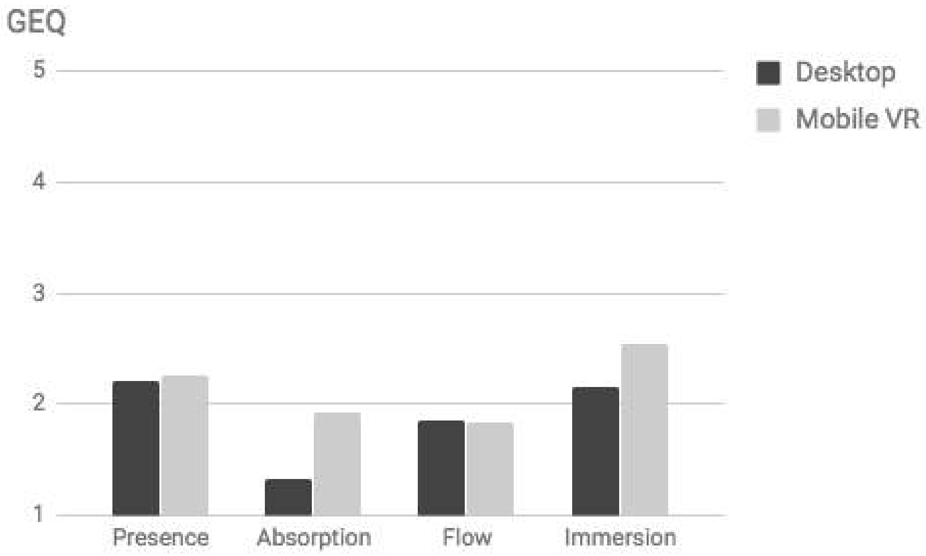


Figure 6.14.: GEQ results comparing average between the multi-users setup in mobile VR and in a computer-based version

The multi-user capability was experienced very positively (see Table 6.10). On a Likert scale between 1 and 7, the average rating for *"I would like to learn with others in a multiplayer VR environment"* was rated with an average of 5.4. Especially the streaming mode was received very well (5.8) and suggested for further use in classrooms.

Usability and User Experience

When asking the participants, which device they would prefer 13 would prefer the VR version. Reasons for that were explained with "more fun", "easier to understand and follow the experiments", "new experience", and "more immersive". On the other hand, 7 participants would prefer the computer-based version of VR. Reasons were mainly the more natural controls, better resolution, and some participants experience dizziness in the mobile setup. As it can be

Table 6.7.: Comparison of GEQ main elements between the multi-user version of Mobile VR and the computer-based setup

	Screen		Mobile VR	
Category	AVG	SD	AVG	SD
Presence	2.2	1.4	2.3	1.2
Absorption	1.3	0.6	1.9	1.2
Flow	1.9	1.0	1.8	1.0
Immersion	2.2	1.1	2.6	1.0

seen in Table 6.9, the learning experience was received a bit better in the VR version.

Limitations

As mentioned earlier, this study is only designed as a first preliminary study of early prototypes presenting the multi-user capabilities. It was designed to get first insights and feedback to advance those capabilities further and evaluate design concepts and ideas such as the streaming mode.

6.6.5. Conclusion and Discussion

Similar conclusions as in the previous studies can be drawn. Virtual reality experiences are described as more motivating, engaging, fun, and immersive. But also, in particular, the mobile setup, more complicated to learn and sometimes too complex for small experiments and learning concepts. In the multi-user setup, especially the streaming mode was received very well as learning structure. Also seeing other in the lab was mentioned as a positive experience when learning. Dizziness was mentioned as an issue in the mobile VR experience.

Table 6.8.: Detailed comparison of GEQ elements between the multi-user version of Maroon Mobile VR and a computer-based setup

		computer-based		Mobile VR	
GEQ Statement	Category	AVG	SD	AVG	SD
I loose track of time	Presence	2.3	1.4	2.4	1.1
Things seem to happen automatically	Presence	2.4	1.5	2.4	1.2
I feel different	Absorption	1.4	0.0	2.1	1.3
I feel scared	Absorption	1.1	0.7	1.4	0.9
The game feels real	Flow	1.7	0.9	2.0	0.9
If someone talks to me, I don't hear them	Flow	1.3	0.6	1.4	0.8
I get wound up	Flow	1.6	0.8	1.6	0.8
Time seems to kind of stand still or stop	Absorption	1.3	0.6	1.8	1.2
I feel spaced out	Absorption	1.40	0.68	2.00	1.26
I can't tell when I'm getting tired	Flow	1.65	0.93	1.85	1.09
Playing feels automatic	Flow	2.25	1.37	2.00	1.08
My thoughts go fast	Presence	2.25	1.52	2.00	1.21
I loose track of where I am	Absorption	1.50	0.83	2.30	1.38
I play without thinking about how to play	Flow	2.65	1.63	2.15	1.14
Playing makes me feel calm	Flow	3.06	1.60	2.50	1.25
I play longer than I mean to	Presence	1.90	1.07	2.25	1.33
I really get into the game	Immersion	2.15	1.14	2.55	1.00
I feel like i just can't stop playing	Flow	1.55	0.76	1.70	0.80
I don't answer when someone talks to me	Flow	1.05	0.22	1.50	1.05

Table 6.9.: Statements to different experiences on a Likert scale between 1 (not at all) and 7 (fully agree), which were asked after the VR and the computer-based experience

	Screen		Mobile VR	
	AVG	SD	AVG	SD
I would like to learn with the Lab	5.0	1.6	5.2	1.7
It is a good idea to use the Lab for learning	5.6	1.1	6.0	1.9
The Lab is a good supplement to regular learning	5.4	1.4	5.5	1.4
I learned something with the Lab	4.4	1.8	4.8	1.8
The Lab makes the content more interesting	5.3	1.3	5.8	1.1
The Lab makes the content easier to understand	5.3	1.7	5.9	1.1
The Lab makes learning more engaging	5.7	1.2	6.0	1.0
The Lab makes learning more fun	4.9	1.8	6.0	0.9
The experience with the Lab inspired me to learn more about physics	4.1	1.8	4.1	1.7
Learning with the Lab was more motivating than ordinary exercises	5.1	1.5	5.8	1.1
It makes course content more interesting to learn about	5.0	1.5	5.7	0.9
I would rather like to learn Physics with the Lab than with traditional methods	4.5	1.7	5.1	1.5
I find regular physics classes boring	5.1	1.8	4.3	2.4
I would like to learn with the Lab at home	4.4	2.11	4.9	1.5
I would like to learn with the Lab in the classroom	5.2	1.4	5.6	1.6

Table 6.10.: Statements to different cooperative learning experiences on a Likert scale between 1 (not at all) and 7 (fully agree)

	AVG	SD
Interacting with other players helps me stay motivated	5.4	1.5
A teacher could use streaming mode for teaching students virtually	5.8	1.6
Mobile VR could be used as a virtual alternative for classrooms	5	1.6
I would learn content through a "virtual teacher" (streaming mode")	5.6	1.2

Observation

Observation 5. Mobile VR setups are described as more motivating, fun, immersive, and engaging compared to computer-based settings. In learning scenarios users like seeing other learners in the virtual space. The streaming mode as part of a teaching situation was described as a very promising social learning tool.

6.7. Summary and Discussion

Table 6.11 gives an overview of the GEQ results of the different studies. We can see that virtual reality technologies are described as more immersive when compared with computer-based versions. Especially a highly interactive version of a room-scale VR setting supports the feeling of immersion and presence. Non-interactive and more guided experiences such as presented with mobile VR can also support high levels of immersion, flow, and presence.

Table 6.11.: Comparison of GEQ main elements between HTC Vive (Maroon Room-scale VR) and Samsung Gear (Maroon Mobile VR) setup

	RS-VR	M-VR	IRS-VR	Screen	Screen MU	M-VR MU
Presence	2.6	2.4	3.0	2.2	2.2	2.3
Absorption	2.4	2.3	2.5	1.3	1.3	1.9
Flow	2.5	2.3	2.4	1.9	1.9	1.8
Immersion	2.9	2.6	3.7	2.2	2.2	2.6

Virtual and remote laboratory have been shown to be valuable tools to support learners in understanding concepts. They provide an experimentation space in a safe, remote, and flexible way. However, the missing realism of the computer-based scenario and lack of hands-on experience is often pointed out as a downside. This can be also described as missing the feeling of immersion and presence. Emerging virtual reality tools providing full-body tracking and even force-feedback when interacting with experiments support this feeling of immersion and engage focused learning.

In the five studies described above, immersion has been shown as central element to motivate learners. All VR experiences have been shown as more engaging and immersive compared to computer-based version. However, the design of the different VR experiences has a strong impact on the experience. In room-scale setups, in particular, natural and realistic interactions with learning objects such as experiment settings are crucial to optimize the experience. In contrast, mobile virtual reality setups only provide limited interaction possibilities. Alternative forms of engagement, such as social interactions, can help in making this experience to a more motivating one. Social tools such as streamed guided learning experiences can be a valuable element to support and engage learners.

In this chapter, we have identified elements such as VR technologies as primary drivers of immersion. Social aspects, explorative design, or goal-based guided tour have been shown as valuable tools to support engagement. In the following section, we want to summarize and discuss those findings in more detail.

7. Discussion

> ”We are at the very beginning of time for the human race. It is not unreasonable that we grapple with problems. But there are tens of thousands of years in the future. Our responsibility is to do what we can, learn what we can, improve the solutions, and pass them on.”
>
> Richard Feynman

This chapters compares, discusses, and summarizes strategies and design aspects for creating motivational environments. These strategies and aspects are based on observations we made while creating MAL and Maroon and its variants. Then, we will discuss some limitations of the approaches introduced in this thesis.

7.1. Design Guidelines for Motivational Environments

Different forms of motivational environments such as Maroon support different forms of engagement and immersion. In this chapter, we build recommendations for the design of motivational environments based on the findings when evaluating MAL and the different versions of Maroon. We will compare design elements of motivational environments supporting immersion against elements supporting engagement to discuss design guidelines for motivational environments. Those guidelines are based on the observations presented throughout this thesis.

The main elements of the conceptual model that we have introduced in Chapter 2 are engagement and immersion. In this thesis, we have presented different implementations of such learning environments supporting different elements supporting engagement and immersion.

7.1.1. Engagement

In Chapter 2, we have introduced a conceptual model for creating a motivational environment. A process for creating motivational environments based on engagement should include the following main elements:

i) **Guidance**: Identify and describe clear goals
ii) **Player Type Design**: Include elements supporting and engaging the player types achievers, explorers, and players looking for social interactions such as collaboration (socializer) or competition (killer).
    a) **Achievers**: Design appropriate and engaging forms of feedback and progress statements including accomplishments, achievements, or points
    b) **Explorers**: Add elements which support discovery, exploration, or experiencing situations
    c) **Socializers and Killers**: Add different forms of social interactions, which could be either cooperative or competitive forms.

In Chapter 4, we have introduced MAL as an example of how to integrate those elements in the classroom. We were able to show that different students are engaged by different elements supporting different player types and styles. Thus, it is crucial to design the engagement elements with flexibility and also allow for freedom of choice. Elements such as competitive rankings are interesting for some students, but not for all. Some are even discouraged by heavily competitive elements. When evaluating MAL, we also found that good group sizes for social activities in learning environments are between 2-3. Students prefer to receive feedback elements such as points or achievements individually and not as a whole group.

In Chapter 6, we have evaluated digital learning environments designed as immersive and engaging experiences. We showed that interactive tasks create a high level of engagement. Interactive tasks designed as virtual hands-on experiences in VR can even create flow. Learning in environments supporting interactive virtual reality design was often described as more engaging when compared to traditional experiences. Engagement and immersion are often mutually dependent.

Based on these observations, we propose the following guidelines for creating ***motivational learning environments*** with a focus on designing with engagement elements:

- ***Flexibility and freedom of choice***. Users should be able to have some extent of freedom in choosing activities. These activities should support different forms of engagement to encourage different player types.
- ***Individual feedback***. Feedback should be received as an individual user and not as a whole group.
- ***Allow failure***. It is important to allow second chances and give room for improvement.
- ***Interactivity***. Interactive task design creates a deeper engagement with the tasks.

7.1.2. Immersion

To create immersive experiences we have defined four major kinds of immersion, which can be created through different design strategies or technological aids.

i) **Spatial immersion or presence:** Technical aids such as virtual reality displays, and natural environment design (such as realistic interactions or immersive sound design) create this sort of immersion.
ii) **Tactical immersion:** Add fast-paced challenges and learning experiences, requiring users to react quickly and automatically.
iii) **Strategic immersion:** Add learning experiences and tasks which challenge users to observe and calculate. This could be, for instance, a hands-on experiment setup, encouraging learners to optimize solutions through observing and calculating.
iv) **Narrative immersion:** Add interesting and engrossing story elements with interesting characters and an interesting environment.

We have demonstrated immersion as a valuable tool to support focused learning experiences. In Chapter 5 and Chapter 6, we have introduced and discussed the virtual motivational learning environment Maroon and different variants of Maroon supporting different forms of immersion. While VR displays have been used mainly to create spatial immersion, we have also used design elements such as hands-on experiments to create strategic immersion or discussed a guided learning tour to create narrative immersion.

Based on our observations we propose the following guidelines with a focus on creating immersive experiences for motivational learning environments. These guidelines create different forms of immersion. First, we describe general guidelines for creating stronger immersive experiences in learning environments, and then we focus on guidelines supporting the use of VR devices.

- ***Interactive experiences***: Interactive task design creates highly immersive and engaging experiences. Interactive experiences also help students to stay focused. When using VR devices supporting body-tracking (such as the HTC Vive), interactive tasks should be designed in a natural way.
- ***Realistic and natural interaction design***: Hands-on learning experiences (e.g., experiments) should be designed to create natural and realistic interactions with the experience.
- ***Strong emotions***: Designing experiences, environments, and stories which create strong emotions can induce a high level of immersion. Strong emotions are also a good way to create immersive experiences in setups with only a limited support of interactivities such as experiences with mobile VR devices.
- ***Guidance***: Another way to create a high level of immersion is to focus on guided experiences, which are designed following the engagement guidelines of guidance (clear goals).

7.2. Possible Applications

In Chapter 4, we have demonstrated the potential of gamification strategies as an engagement element in motivational learning environments in a blended but also virtual context. Small elements engaging different player types are quick and easy to integrate into different learning scenarios. This approach mainly supports learning environments which require hands-on learning experiences, practical assignments, or group tasks. If such tasks are also supported in virtual experiences, such as interactive VR experiences, this approach can also be used to enhance remote learning scenarios.

In Chapter 5 and 6, we have demonstrated how virtual reality technologies can improve immersion in learning applications. It was shown that VR applications as a tool to support the in-class scenario are in particular valuable in enabling students to experience experiments or simulations with a very visual or experimental hands-on character. VR-based motivational learning environments should be used to support fields and subjects which require students to understand the concepts with visual aids. Typical situations include laboratory environments, environments which are not possible or hard to reach and explore (e.g., a historical experience at Machu Picchu, diving in the ocean), or realistic experiences, which are hard, dangerous, or expensive to simulate in real life (e.g., surgery).

We believe that VR has the potential to bring new learning experiences into the classroom and the living room, as we have shown that it supports new and innovative pedagogical concepts for in-class and distant learning. Engagement and immersion are both important factors to motivate students. Many of the design aspects we have presented in this thesis are scalable and quickly and easily applicable in various learning environments.

Maroon, as a virtual motivational learning environment, was designed in a flexible and extensible way. While in this thesis we designed it for learning physics, the main concept of Maroon also supports many other subjects, which require hands-on experience and interactive learning tasks.

7.3. Limitations of Immersion and Engagement in Learning Environments

As we have learned, there are different learner types and player types. Within the various studies, we have also demonstrated that participants had different preferences towards our motivational environments. While many of our strategies and design elements were motivating, for many users some elements might be discouraging. This is the case for social interactions. While some users prefer competitive actions, others would prefer collaboration and would eventually be discouraged by competition. Also, VR technologies are very motivating for many users; however, some have issues with cyber-sickness or simply do not want to wear such glasses. While some were motivated by VR technologies, others felt dizziness and would prefer more traditional methods. Some study participants also pointed out that they prefer reading books to learn new concepts. Those are trade-offs that need to be considered when designing motivational learning environments. Moreover, not all of us like to "play". When introducing new learning concepts, it is crucial to allow alternative paths and tools when using such elements. There should always be alternatives for users who would prefer alternative forms of learning and learning content to make learning experiences as inclusive as possible.

The lack of automatic assessment possibilities is another limitation we face when working with motivational learning environments. In different virtual and blended learning environments, tools to assess automatically need to be designed separately. We are facing similar issues in the context of content creation.

In this thesis, we have only presented a first prototype of the motivational environments and have evaluated those prototypes in limited settings and with a limited number of participants. The focus of our evaluations was to get a better understanding of immersion and engagement as the main drivers of motivational learning environments. To get a better understanding of the environments, the motivators, and the learning behavior, these environments need to be tested in realistic learning setups supporting different subjects.

7.4. Contributions

In Chapter 1, we have summarized three main objectives of this thesis. In the following sections, we discuss the contribution of this thesis towards those objectives and discuss further future improvements to reach these goals with a focus on future research scenarios to improve and extend this research and our conceptual model.

Identification and Analysis of Virtual Learning Environments to engage and actively involve the new Generation of Learners In this thesis, we have presented a conceptual model, which builds on immersion and engagement to create motivational learning environments based on the requirements of the new generation of learners. We have analyzed and evaluated concepts supporting engagement and immersion through two learning environments (MAL and Maroon). Contributions towards this objective are the analysis and discussion of emerging learning tools, such as virtual reality and mobile virtual reality tools, and guidelines to engage learners with game-based learning approaches. This analysis has the potential to improve future educational scenarios. We have shown not only the potential of these tools but also the desire of learners to use the presented tools and methods. However, while we have shown the potential of the tools and methods, the analysis and implementations in this thesis only form the foundation for creating motivational learning environments. In particular, the need for flexible and mobile learning environments still poses an issue, since often assessment strategies supporting new tools are missing. Also, in this thesis, we have identified several elements and strategies supporting motivation through engagement and immersion. Within the scope of this thesis, it was not possible to evaluate all of the identified elements and strategies. A more detailed investigation of different forms of immersion and strategies to support engagement is necessary to demonstrate the potential and strengths of our conceptual model.

Bridge Learning and Gaming Theory through Engagement Strategies We have presented different strategies inspired by game-design theory to support engagement in our conceptual model. Additionally, we have presented the design strategies *"Player-Type-Design"* to create motivational environments supporting the four different player types. In the first evaluation of MAL, we have shown the potential of this strategy. This strategy can be used to design and also evaluate existing systems based on their potential to engage different player types. This theory gives an interesting perspective on designing digital environments supporting different motivators. Bartle's categorization into four player types is a simplified one. In the literature, we can find further categorizations into player types and also further strategies for designing playful environments. Those elements and strategies can be used to improve and extend our conceptual model and design strategies. Summarizing, to improve this model further. We need more evaluations towards clustering and classification of player types in learning environments.

Investigating immersive and engaging environments and technologies for learning With different prototypes of Maroon, we have investigated virtual environments supported by emergent virtual reality devices as a tool to immerse learners. We have used room-scale and mobile virtual reality technologies to analyze the potential of these devices for learning settings and have contributed recommendations for immersion strategies. The use of these devices to support immersive learning has been shown to be a powerful tool to teach learning concepts, which require hands-on experiences and visualizations (such as physics). We have focused our research on these scenarios. Extending on our recommendations and our conceptual model will need further research into different applications and learning fields.

8. Conclusion

”The future is here, it’s just not widely distributed yet.”

William Gibson, 1948

This dissertation introduced a conceptual model to create motivational environments. The main elements to create such environments are design and technology strategies supporting immersion and engagement.

Motivational environments can engage learners and create more interesting and inspiring educational experiences. In this thesis, we have discussed the two most important elements for creating motivational environments: immersion and engagement. Combining elements of game design theory with lecture design is one major element to engage learners. Another form of creating a motivational environment is the support of immersion through emerging technologies. Virtual reality technologies offer new ways of student engagement and immersion by representing visual learning content in a new way. The integration of mobile virtual reality displays, such as that provided by Google Cardboard, also offers new ways of integrating digital-based learning tools into the classroom. The use cases introduced in this dissertation should inspire new ways of teaching and learning, to make not only self-directed remote learning more engaging but also classroom experiences.

Based on this conceptual model, the two motivational environments MAL and Maroon were introduced. Both environments integrate and support different forms of engagement and immersion.

To conclude, the first part of this chapter summarizes the main contributions of this dissertation and the second part proposes directions for further future developments and research.

8.1. Summary

In this thesis, learning theory is compared and enriched with the theory based on game design elements and applied in emerging technologies. Broadly, this thesis makes the following contributions:

The basis of this thesis builds a conceptual model to create motivational environments. We identified immersion and engagement as essential elements to create motivational elements. This conceptual model describes different elements and strategies supporting engagement and various forms of immersion.

MAL was designed to support engagement elements based on our conceptual model. It contributes a pedagogical blended learning model supporting active learning and interactive engagement strategies and combines it with elements inspired from game design theory. This model shows the potential of such playful elements incorporated in a learning environment as a tool to enhance engagement.

The original and award-winning **Maroon System** contributes an extensible virtual learning environment supporting various forms of interactive engagement interactions supporting various emerging virtual reality technologies. **Maroon Mobile VR** demonstrates how mobile head-mounted displays support a cost-effective and mobile solution for immerse learners. In comparison, with **Maroon**

RSVR we demonstrated that room-scale virtual reality experiences support more realistic and immersive learning and training experiences, but support only limited pedagogical approaches due to the cost-intensity and immobility.

8.2. Recent Development and Directions for Future Work

8.2.1. MAL

With MAL, we have shown the potential of using gamification elements, which engage different player styles to make the learning experience more fun and engaging for a broad range of users. In future work, these findings can be used to develop a personalized and adaptive form of a learning environment, supporting and enabling different player and also learning types. As hands-on experiences have been shown as a valuable tool to help learners, future work will also include the integration of various experimental setups and hands-on experiences illustrating different computer science problems.

Future work will additionally focus on different qualitative and quantitative experiments to investigate player types in learner settings. In current and future work, we are working with clustering and classification methods to get a better understanding of different player types in games and learning applications (Rattinger et al., 2016; Pirker, Griesmayr, et al., 2016). In a next step, we will analyze the interaction of learners with different engagement elements in the digital learning environment to identify and map learners and player types and compare it with qualitative data from the course.

MAL is designed for learning settings for a small number of learners. One major challenge for future work also includes the scalability of this approach to support e-learning systems such as MOOCs. Especially for MOOCs, which suffer a high drop-out rate, the introduction of strategies of motivational environments can support, motivate, and retain learners (Gütl et al., 2014).

8.2.2. Maroon

One major next step is the further development of Maroon. In this dissertation, a series of prototypes and case studies have been presented. Future direction focus on the further development of *Maroon* to provide a stable open-source learning environment. This first prototypes and conceptual ideas should be applied to a broader learning context and in the end, have an impact on the education to make learning science more meaningful.

With the more advanced version of Maroon, more experiments to get a deeper understanding of immersion and engagement can be conducted. One direction supported by experiments is the analysis of the different immersion types as suggested by our conceptual model. In this thesis, we have focused on immersion through technological aids. With the current implementation of Maroon, we can design different forms of immersion. Future experiments will focus on designing and evaluating these forms of immersion to gain a deeper understanding of their impact on learning and motivation.

Future work can grow in many directions. The identification of the different player and learning types can be a core element for future developments to create an adaptive and personalized digital learning experience with automatic assessment features.

One major issue is the missing possibility for assessing the learners' behavior in virtual learning environments. This includes the assessment of interaction with interactive learning experiences such as hands-on experiments or the contribution of individuals in group assignments.

The newest developments focus on supporting a dynamic and procedural generation of the virtual lab experience. We are working on a novel technology for procedurally and dynamically generating virtual environments such as laboratories, museums, or other three-dimensional room-based environments. The integration of this approach is currently developed to provide the possibility to more easily integrate new learning experiences and make the environment more dynamic and flexible.

As also mentioned earlier, currently different prototypes supporting multi-user experiences are designed and implemented. However, when developing collaborative environments, we are facing several challenges.

One problem we are facing at present is the social implications of the interaction between users in multi-user VR environments. In many multi-user environments, virtual sexual harassment has been shown to be an issue (Wong, 2016). In VR, such experiences are even more traumatizing, because users feel more immersed and it appears that the harassment is happening to their own body. For Maroon, we used a cartoon-based illustration of other avatars. However, this was also mentioned in a negative way by users who would prefer more realistic environments. In future work, we are interested in developing and researching solutions to avoid harmful behavior in multi-user VR environments. We want to encourage the use of virtual reality environments as inclusive and motivational platforms for *all* learners.

Appendix

Appendix A.

Experiment Questionnaires

A.1. Game Engagement Questionnaire

We used the version as illustrated in Table A.1 of the GEQ (Brockmyer et al., 2009) for the experiments introduced in Chapter 6. The GEQ rating was introduced with a Likert scale between 1 to 5.

A.2. Experience Scale

The following scale (Table A.2) was used to illustrate experiences with the virtual environments on a Likert scale between 1 to 7. The statements of the scale were adapted based on the current experiment.

A.3. Interview Questions

Table A.3 illustrates the interview and conceptual questions.

Table A.1.: GEQ (Brockmyer et al., 2009) used for the evaluations

	Statement	Category
1	I loose track of time	Presence
2	Things seem to happen automatically	Presence
3	I feel different	Absorption
4	I feel scared	Absorption
5	The game feels real	Flow
6	If someone talks to me, I don't hear them	Flow
7	I get wound up	Flow
8	Time seems to kind of stand still or stop	Absorption
9	I feel spaced out	Absorption
10	I can't tell when I'm getting tired	Flow
11	Playing feels automatic	Flow
12	My thoughts go fast	Presence
13	I loose track of where I am	Absorption
14	I play without thinking about how to play	Flow
15	Playing makes me feel calm	Flow
16	I play longer than I mean to	Presence
17	I really get into the game	Immersion
18	I feel like i just can't stop playing	Flow
19	I don't answer when someone talks to me	Flow

Table A.2.: Experience Scale

1.	I would like to learn with the Physics Lab
2.	It is a good idea to use the Physics Lab for learning
3.	The Physics Lab is a good supplement to regular learning
4.	I learned something with the Physics Lab
5.	The Physics Lab makes the content more interesting
6.	The Physics Lab makes the content easier to understand
7.	The Physics Lab makes learning more engaging
8.	The Physics Lab makes learning more fun
9.	The Physics Lab makes learning more interesting
10.	The experience with the Physics Lab inspired me to learn more about physics
11.	Learning with the Physics Lab was more motivating than ordinary exercises
12.	It makes course content more interesting to learn about
13.	I would rather like to learn Physics with the Physics Lab than with traditional methods
14.	I find regular physics classes boring
15.	Seeing the physics simulations with the Virtual Reality glasses was engaging
16.	Seeing the physics simulations with the Virtual Reality glasses was interesting
17.	Seeing the physics simulations with the Virtual Reality glasses was more engaging than without
18.	I would install the Physics Lab on my phone (+ Virtual Reality glasses)
19.	I would like to learn with the Physics Lab at home
20.	I would like to learn with the Physics Lab in the classroom

Table A.3.: Overview of the interview and conceptual questions

Q1. What is the relationship between the magnetic field and the electrical current? On a scale between 1 - 5 (5.. Very sure) how sure are you about your understanding and your answer?
Q2. Which quantities determine the force effects for a live conductor in a magnetic field? On a scale between 1 - 5 (5.. Very sure) how sure are you about your answer?

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