

# Effects of Immersion and Presence on Learning Outcomes in Immersive Educational Virtual Environments for Computer Science Education

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Andreas Dengel  
University of Passau

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First supervisor: Prof. Dr. Jutta Mägdefrau

Second supervisor: Prof. Dr. Tim Bell



*Despite the overwhelming odds,  
tomorrow came.*



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# Abstract

## *Background*

Abstract concepts and ideas from Computer Science Education can benefit from immersive visualizations that can be provided in virtual environments. This thesis explores the effects of the key characteristics of virtual environments, immersion and presence, on learning outcomes in Educational Virtual Environments for learning Computer Science.

## *Theory*

Immersion is a quantifiable description of the technology to immerse the user into the virtual environment; presence describes the subjective feeling of 'being there'. While technological immersion can be seen as a strong predictor for presence, motivational traits, cognition, and the emotional state of the user also influence presence. A possible localization of these technological and person-specific variables in Helmkes' pedagogical supply-use framework is introduced as the Educational Framework for Immersive Learning (EFiL). Presence is emphasized as a central criterion influencing immersive learning processes. The EFiL provides an educational understanding of immersive learning as learning activities initiated by a mediated or medially enriched environment that evokes a sense of presence.

The idea of Computer Science Unplugged is pursued by using Virtual Reality technology in order to provide interactive virtual learning experiences that can be accurately displayed, schematizing, substantiating, or metaphorical. For exploring the effects of virtual environment characteristics on learning, the idea of Computer Science Replugged focuses 'hands-on' activities and combines them with immersive technology. By providing a perception of non-mediation, Computer Science Replugged might enable experiences that can contribute additional possibilities to the real activity or enable new activities for teaching Computer Science.

### *Method*

Three game-based Educational Virtual Environments were developed as treatments: ‘Bill’s Computer Workshop’ introduces the components of a computer; ‘Fluxi’s Cryptic Potions’ uses a metaphor to teach asymmetric encryption; ‘Pengu’s Treasure Hunt’ is an immersive visualization of finite state machines. A first study with 23 middle school students was conducted to test the instruments in terms of effectivity, the devices’ induced levels of presence, and adequacy of the selected learning objectives. The second study with 78 middle school students playing the environments on different devices (laptop, Mobile Virtual Reality, or head-mounted-display) assessed motivational, cognitive, and emotional factors, as well as presence and learning outcomes.

### *Results*

An overall analysis showed that pre-test performance, presence, and the previous scholastic performance in Maths and German predict the learning outcomes in the virtual environments. Presence could be predicted by the student’s positive emotions and by the technological immersion. The level of immersion had no significant effect on learning outcomes. While a good-fitting path analysis model indicated that the assumed relations deriving from the EFiL are largely correct for ‘Bill’s Computer Workshop’ and ‘Fluxi’s Cryptic Potions’, not all results of the overall path analysis were significant for the analyses of the particular environments.

### *Discussion and Limitations*

Presence seems to have a small effect on learning outcomes while being influenced by technological and emotional factors. Even though the level of immersion can be used to predict the level of presence, it is not an appropriate predictor for learning outcomes. For future studies, the questionnaires have to be revised as some of them suffered from poor scale reliabilities. While the second study could provide indications that the localization of presence and immersion in an existing educational supply-use framework seems to be appropriate, many factors had to be blanked out. The thesis contributes to existing research as it adds factors that are crucial for learning processes to the discussion on immersive learning from an educational perspective and assesses these factors in hands-on activities in Educational Virtual Environments for Computer Science Education.



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# List of Abbreviations

AR Augmented Reality

CS Computer Science

CSE Computer Science Education

EFiL Educational Framework for Immersive Learning

EVE Educational Virtual Environment

HMD Head Mounted Display

TPACK Technological Pedagogical Content Knowledge

VE Virtual Environment

VLE Virtual Learning Environment

VR Virtual Reality



# Chapter 1

## Introduction

“What is real? How do you define ‘real’? If you’re talking about what you can feel, what you can smell, what you can taste and see, then ‘real’ is simply electrical signals interpreted by your brain.” Morpheus in *The Matrix* (Wachowski & Wachowski, 1999)

Thoughts about alternative virtual worlds have been around for quite a while in film and literature. Movies like *The Matrix*, *Inception*, *Assassins Creed*, and *Tron* show how the transfer of the human consciousness into virtual parallel worlds could be possible. Hereby, the alternative worlds from these movies have different characteristics:

- In *The Matrix*, humanity is enslaved in a virtual world that resembles today’s everyday life (Wachowski & Wachowski, 1999).
- In *Inception*, dreams are visualized through technology and become accessible for others (Nolan, 2010).
- In *Assassins Creed*, immersive technology can be used to relive our ancestors’ past lives whose information are stored in the genes of each of their descendants (Kurzel, 2016).
- In *Tron*, the user can be transferred physically into a digital environment (Lisberger, 1981).

Despite these differences, all these forms of Virtual Reality (VR) share one similarity: Their respective users feel and act as they would do in the real world. Their behaviors and thought processes seem to resemble the ones found in real life regardless of design, strangeness or consequences that they encounter in the virtual world.

In his idea of a perfect VR, Sutherland (1965) describes an *ultimate display* in a similar manner:

“The ultimate display would, of course, be a room within which the computer can control the existence of matter. A chair displayed in such a room would be good enough to sit in. Handcuffs displayed in such a room would be confining, and a bullet displayed in such a room would be fatal. With appropriate programming, such a display could literally be the Wonderland into which Alice walked” (p. 508).

Even though this thesis will not cover the philosophical discourse of questions about what reality is, the research on VR addresses questions and terms about human perception, especially the perception of reality. Therefore, this section is supposed to give a brief insight into the rudimentary basics of human sensations and combines it with questions on the perception of physical, mediated, and combined realities.

Starting with Plato’s *Allegory of the Cave* 2400 years ago (and most likely also before that), human beings have been wondering about how human perception of reality works and what comes along with its modification or restriction. Human perception of reality in Plato’s *Allegory of the Cave* is (at least at the beginning of the allegory) limited to and caused by sensual perceptions. Descartes poses that our perception of reality may not only be an incomplete picture but could also be a deception caused by a (hypothetical) evil ghost (genius malignus) that simulates the whole reality of the human (Dörner & Steinicke, 2013).

In one of his early works, Kant (1794) even defines the concepts time and space as subjective constructs: Time, which can be considered as pure intuition, relies on the necessity of the human mind to coordinate objects among themselves by a certain law. Relations occurring in sensual channels, regardless of their successive or simultaneous character, involve nothing but a determined position in time. Space is, as well, not objective and real, but subjective and ideal. It arises from the nature of the mind in order to coordinate external sensations. When restricting existences by conditions of space and time, even divine beliefs like that of God’s omnipresence had to be restricted by these conditions.

Similar to Kant, skepticism asks if reality or underlying truths are even possible. For example, Putnam’s (1975) *Brain in a Vat* thought experiment states that human perception could derive from the fact that the brain of an individual “has been removed from the body and placed in a vat of nutrients which keeps the brain alive. The nerve

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endings have been connected to a super-scientific computer which causes the person, whom the brain belongs to, to have the illusion that everything is perfectly normal" (p. 5–6). By releasing electronic impulses that travel from the computer to the nerve endings, the individual perceives people, objects, the sky, etc. The same goes for every movement of the individual in the world as well as every interaction with the world (Putnam, 2002). Philosophical approaches like these have been connected to science-fiction ideas of altering the human perception of reality ever since (e.g., Miller, 2002; Johnson, 2012).

According to Dörner, Jung, Grimm, Broll, and Göbel (2013), human perception can be divided into

- visual perception (seeing),
- auditive perception (hearing),
- olfactory perception (scenting),
- gustatory perception (tasting),
- haptic perception (feeling),
- tactile perception as a part of the haptic perception (feeling with the fingers),
- vestibular perception (sense of balance),
- proprioception (spatial awareness),
- thermoception (perceiving temperatures), and
- nociception (perceiving pain signals).

On the basis of the named perception channels and building upon the thoughts of Plato, Descartes, and Putnam, Dörner and Steinicke (2013) ask whether or not it would be possible to set a user into an apparent actuality<sup>1</sup>, a VR in which the human could not distinguish the virtual world from the real world. This VR would be a perfect illusion of reality.

An essential prerequisite that makes creating alternative realities possible is the *willing suspension of disbelief*. In certain situations, apparent contradictions between the virtual or fictive world and the real world have to be disregarded by the individual deliberately in order to create a *sense of presence* in the alternative reality. Therefore, by making use of this suspension of disbelief, a perfect manipulation of senses is not required for creating convincing virtual environments (VE) that evoke the feeling of being present in the mediated world (Dörner & Steinicke, 2013).

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<sup>1</sup>E.g., Dörner et al. (2013) ask if it would be possible to simulate the sensory stimuli originating from the presence of a tiger through a computer and, by transmitting them into a human brain, convincing the individual of the actual presence of a real tiger

In this context, Licht (2010) states that with today’s technology, users are well aware of the technical frame and therefore know exactly whether they are in actual reality or in virtuality. Nonetheless, the capability of a VR to evoke an *immersive experience*<sup>2</sup> does not depend on the conscious knowledge whether the perceived world is real or not but rather results from the cooperation and acceptance of the viewer. This lies in contrast to science fiction movies like *The Matrix* (Wachowski & Wachowski, 1999), in which humans can no longer distinguish between reality and virtuality as they were born in the virtual world and, therefore, naturally percept the virtuality as their reality.

According to Kosfeld (2003), the configuration of sensual stimuli (visual, auditory, haptic and behavioral) is crucial for developing VR applications that meet Sutherland’s requirements of a realistic visualization and interaction. On the basis of Sutherland’s ideas, Dörner et al. (2013) name the input and output devices as distinctive characteristics of (visual) representations in VR systems. These include for example helmet-like displays that are mounted on the head of the user (Head-Mounted-Displays, HMDs), stereoscopic glasses or data gloves. By means of input and output systems, we can characterize VRs by focusing on their technological aspects. Concurrently, Dörner et al. criticize the danger of emphasizing specific aspects of certain input and output devices. A description based on current technological criteria could soon be outdated and would, therefore, not be timeless.

In contrast to an emphasis on several existing devices, there are more general technical definitions of VR: Bryson (1993) relates VR “to the use of three-dimensional displays and interaction devices to explore real-time computer-generated environments”. Similar to Bryson, Cruz-Neira, Sandin, and DeFanti (1993) describe VRs as three-dimensional, computer-generated environments that are immersive, interactive, multi-sensory, and viewer-centered, together with combinations of technologies that are necessary in order to create these environments.

Ryan (2015) introduces three senses of the virtual: an optical sense, a scholastic sense, and a technological sense. The optical sense refers to the virtuality as an illusion. The scholastic sense regards the virtuality as a possibility for intellectual development while the technological sense refers to the virtuality as an environment mediated by a computer system. All three senses are involved in a VR:

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<sup>2</sup>Licht (2010) uses the term *immersion* as a mental immersion into VR in order to take it as being true. This work uses the term *immersion* differently. For a detailed discussion about a mental immersion in terms of the feeling of ‘being there’, see section 2.2

- VRs consist of computer-generated data (technological sense);
- the immersive dimension of the VR experience depends on the possibility to acknowledge the VR as an autonomous reality (optical sense, as the illusionistic ability, also is related to the quality of the display);
- VR as an interactive system provides a matrix of usage opportunities for the user (scholastic sense).

### Summary 1: Perception of Reality

Humans perceive their reality through sensual stimuli. A virtual reality (VR) is an apparent actuality in which the manipulation of sensory channels, together with a willing suspension of disbelief, evokes a sense of presence in the virtual environment (VE).

Regarding these notes on the human perception of reality, a VE seems to be characterized by a technological side focusing technological features and devices to immerse a user into the environment and a person-specific, perceptual side emphasizing the resulting individual perception that contributes to the experience within a VE. With this separation, together with a pedagogical perspective focusing the use of VEs for education (Educational Virtual Environments, EVEs), it can be asked: What are the effects of technological and person-specific factors on learning outcomes in Educational Virtual Environments?

It seems appropriate to combine ‘first-hand’ experiences, deriving from perceived-as-real environments, with ‘hands-on’ activities to create engaging learning opportunities. Especially when learning about abstract concepts, as it is the case for many Computer Science topics, ‘hands-on’ activities can be beneficial. Such activities, for example provided by the Computer Science Unplugged program, can be a great way to motivate students for learning about various topics, typically even without using computers at all (Bell, Alexander, Freeman, & Grimley, 2009). As virtual environments might show their greatest potential when removing constraints of real experiences in a virtuality (Sutherland, 1965), Computer Science seems to be a good subject to explore the influences of the various factors on learning. By integrating multiple perspectives of the educational sciences, immersive media research, and Computer Science Education, the research question of this interdisciplinary thesis asks:

- What are the effects of technological and person-specific factors on learning outcomes in Educational Virtual Environments for learning Computer Science?

In order to define important terminologies regarding the technological and person-specific aspects, chapter 2 reviews the key characteristics of VEs and explores the terms immersion and presence in depth.

These VE key characteristics are then localized in a theoretical educational supply-use-framework in order to explain Immersive Learning from an educational perspective (development of the EFIL, chapter 3). By investigating the theories behind the factors influencing learning outcomes and presence, a research model for the investigation of scholastic learning in immersive EVEs is proposed.

In chapter 4, the idea of Computer Science Unplugged is extended to the technology-assisted Computer Science Replugged approach. It is argued how VR can contribute to existing hands-on activities and how it can enable new activities for learning computer science.

To answer the research question, two studies with middle school students are presented in chapter 5. The subjective and objective factors and their relations are analyzed by using three environments for various topics of Computer Science Education: *components of a computer*, *asymmetric cryptography*, and *finite state machines*. The results and the limitations of the study are discussed.

The sixth chapter concludes the theoretical and empirical results by regarding them through several lenses. The lense of Computer Science Education discusses immersive technology as an approach for creating new ways to grasp fundamental concepts and ideas of CS. The lense of the Educational Sciences focuses on the possible use of immersive technology in the classroom, together with its affordances and consequences.

An epilogue gives an outlook from these perspectives for Teacher Education. It introduces the concept of Immersive Teaching, combining technological, pedagogical, and content knowledge.



## Chapter 2

# Characteristics of Immersive Virtual Environments

Manipulating sensory channels and utilizing the individual's willing suspension of disbelief (see chapter 1) are the two crucial keys to immerse a user into a virtual world where he/she feels present. As main unique characteristics of virtual worlds in comparison to real experiences, this work distinguishes between the technological side (immersion), which transports the user from the physical reality into the VR by simulating perceptual sensations and suppressing sensations from the physical reality, and the psychological side, which describes the user's feeling of experiencing the VR as his/her actual reality (presence). This chapter introduces these two concepts as a foundation of all immersive virtual experiences.

## 2.1 Immersion: Taking the Plunge into Virtual Worlds

With technology changing fast, it is important to focus on some key concepts on what a VR is and how it can be simulated. This thesis focuses effects of person-specific and technological characteristics on learning in general rather than investigating the effect of particular devices. This section presents various ways of how technology can immerse a user into a VR. Emphasizing the technological side is crucial to explore how VR can affect learning, as technology (regarding hardware and software) is the main objective variable that can be changed by the teacher(s).

### 2.1.1 Characterization and Display of Virtual Environments

The representation of a VR happens through a VR system, which is defined by Dörner and Steinicke (2013) as a computer system that consists of appropriate hardware and software to realize the imagination of a VR. The content of the VR (models of objects,

their arrangement in the room, behavioral descriptions of objects) is referred to as a virtual world. The VE for one or many users is the representation of the virtual world through a VR system.

Milgram et al. (1994) introduced the *Reality-Virtuality (RV) Continuum* (Fig. 2.1). The *Real Environment* (on the left side of the continuum) consists solely of real components for perceiving a certain part of the real world. The perception can happen through the actual physical presence of the observer in the real environment but is also possible through a window or a video display. This means that also filmed reality is assigned to the *Real Environment* pole. The right pole describes environments that are completely virtual. Such an environment only consists of virtual components; its perception by the observer occurs through these virtual representations displayed by technology (for example graphical simulations on a computer display or on VR glasses). The *Mixed Reality (MR)* realm is located between the *Real Environment* and the *VE*. It does not only contain objects from the real world, but also those from the virtual world. Depending on the extent of real or virtual contents in the mixed environment, the representation is assigned to the *Augmented Reality (AR)*, where the *Real Environment* is enriched with virtual contents, or the *Augmented Virtuality (AV)*, where the *VE* is enriched with real world contents.



Figure 2.1. The Reality-Virtuality (RV) Continuum (Milgram et al., 1994, p. 283)

The MR systems are further differentiated by Milgram et al. (1994, see 2.1). First, a separation between the used display-technology is possible: Non-immersive monitor-based concepts can be distinguished from immersive HMD concepts. The next separation is possible between the real or computer-generated environment that is used as a basis for displaying the world. As MR visualizations always contain real components, their perception can be distinguished between see-through and scanned. In a direct viewing, the real world can, for example, be perceived through a glass (see-through). It is also possible to scan the real world and display the scanned environment digitally. Other possibilities to separate MR systems are the reference frame of the user (egocentric or exocentric view) as well as the type of mapping from real and virtual world objects (conformal or non-conformal).

Table 2.1

*Classification of MR-displays (Milgram et al., 1994, p. 286)*

<b>Class of MR System</b>	Real (R) or Computer Generated (CG) world?	Direct (D) or Scanned (S) view of substrate?	Exocentric (EX) or Egocentric (EG) reference?	Conformal Mapping (1:1) or not (1:k)?
1. Monitor-based video, with CG overlays	R	S	EX	1:k
2. HMD-based video, with CG overlays	R	S	EG	1:k
3. HMD-based optical see-through (ST), with CG overlays	R	D	EG	1:1
4. HMD-based video ST, with CG overlays	R	S	EG	1:1
5. Monitor/CG-world, with video overlays	CG	S	EX	1:k
6. HMD/CG-world, with video overlays	CG	S	EG	1:k
7. CG-based world, with real object intervention	CG	D, S	EG	1:1

Milgram et al. (1994) regard the original RV continuum as insufficient to cover the full range of devices. The authors point out that a single perspective distinction does not seem to be appropriate. Therefore, they name three factors for a multidimensional classification as an extension of the RV continuum:

- *Reality*: original factor of the RV continuum, some environments are predominantly (or completely) real, others are predominantly (or completely) virtual
- *Immersion*: virtual and real environments can be displayed with various levels of immersion (the observer does not have to be completely immersed)
- *Directness*: objects from reality can be viewed either directly or through a synthetic electronic process (e.g. on a screen)

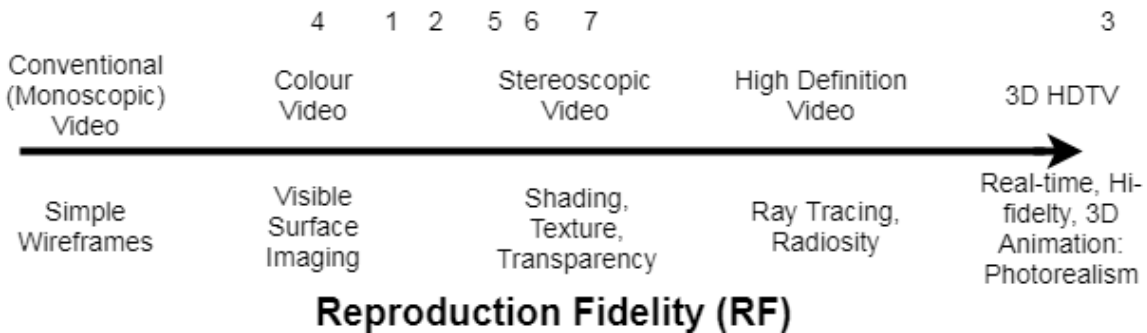
The revised, three-dimensional taxonomy of Milgram et al. (1994) consists of the dimensions *Extent of World Knowledge*, *Reproduction Fidelity*, and *Extent of Presence Metaphor* where the exemplary classifications (1–7) deriving from table 2.1 are assigned to certain levels of the respective dimension.



Note. The numbers relate to the corresponding class of MR system (see Tab. 2.1).

Figure 2.2. Extent of World Knowledge (EWK) (Milgram et al., 1994, p. 288)

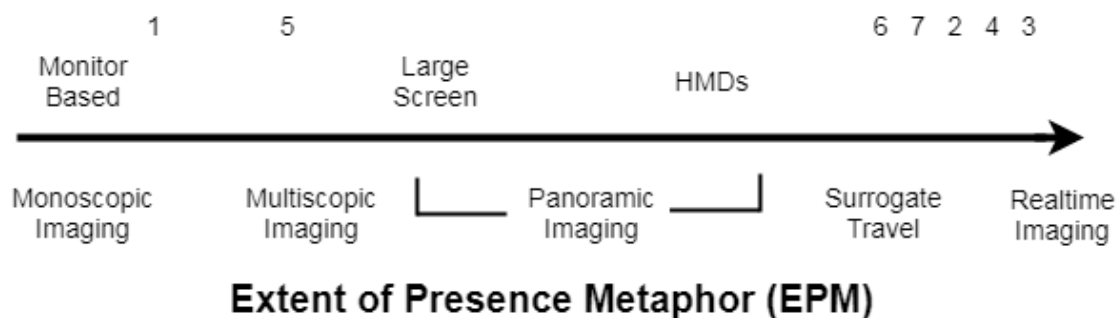
The first dimension, *Extent of World Knowledge*, describes the amount of knowledge respectively the information that the computer has about the displayed world. On the left pole lies a completely unmodelled world of which no information is known, for example through a mere scanning and synthetic representation of the gathered data. Direct see-through displays also belong to this term. On the other side is the completely modeled world of which all information is known as it is the case for example with utterly artificially created virtual worlds. These environments are only created if the computer has all required information about the existing objects and positions, as well as the data about the user (position, the direction of view, interaction with the world, etc.). Between the two extrema lie partially modeled worlds, in which the objects within the world and/or their positions are partly known. Milgram et al. (1994) allocate the display classes deriving from Table 2.1 into the *Extent of World Knowledge* displayed in Figure 2.2.



Note. The numbers relate to the corresponding class of MR system (see Tab. 2.1).

Figure 2.3. Reproduction Fidelity (RF) (Milgram et al., 1994, p. 289)

The second dimension, *Reproduction Fidelity*, refers to the quality of reproduction of the synthesizing display for artificial, virtual objects and for scanned objects from reality that are displayed digitally. Milgram et al. (1994) note that the classification is merely a rough overview, which summarizes factors like display hardware, signaling, and graphics rendering techniques. Each factor could result in its own taxonomy. The right area of the classification is the photorealism, which resembles the level of realism of the actual visual perception of reality. Milgram et al. allocate the displays from Table 2.1 into the classification of the *Reproduction Fidelity* (Fig. 2.3).



Note. The numbers relate to the corresponding class of MR system (see Tab. 2.1).

Figure 2.4. Extent of Presence Metaphor (EPM) (Milgram et al., 1994, p. 290)

The third dimension (Figure 2.4), *Extent of Presence Metaphor*, measures how present the viewer should feel in the environment in terms of his/her sensations differ from reality. The span of MR displays ranges from immersive environments with a strong *Extent of Presence Metaphor* (e.g. displayed through HMDs), to exocentric monitor systems with a weaker level of intended presence. Another factor for the allocation of the display classes along the *Extent of Presence Metaphor*, besides the imaging processes, is the use of ego- or exocentric perspectives<sup>1</sup> (Milgram et al., 1994).

Milgram et al. (1994) gathered the three described dimensions *Extent of World Knowledge* (EWK), *Reproduction Fidelity* (RF), and *Extent of Presence Metaphor* (EPM) and developed a three-dimensional taxonomy for MR-displays (Fig. 2.5). This taxonomy is used in order to classify the VR technology in this thesis. For the purpose of focusing on VR instead of AR/MR, it is useful to simplify the dimensions. As a VR solely consists of virtual components, the VR technology belongs to the

<sup>1</sup>By integrating the perspective, Milgram et al. include not only technological features but also software characteristics in their definition of the *Extent of Presence Metaphor*. Pursuing this idea, this dimension could be used to distinguish not only VR/MR technologies but also their contents as they contribute differently to the sense of presence (see section 2.2.4.1 for a summary of technological and software-related factors influencing presence).

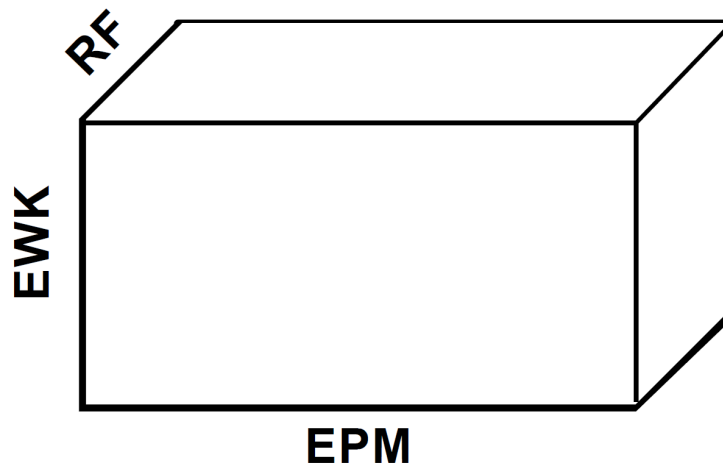


Figure 2.5. A Three-dimensional Taxonomy for the Classification of MR-Displays (Milgram et al., 1994, p. 291)

right extremum of the *Extent of World Knowledge* scale in general. This leaves a two-dimensional taxonomy consisting of the dimensions *Reproduction Fidelity* and *Extent of Presence Metaphor* for the classification of VR devices.

### 2.1.2 Immersion as the Technological Key Characteristic of Virtual Reality

Dörner et al. (2013) compared the characteristics of VRs and conventional 3D computer graphics (Tab. 2.2). 3D computer graphics are seen as purely visual, viewer-independent, non-immersive and not necessarily time-sensitive presentations, which consist of static scenes or precalculated animations whose operation is run by 2D interaction. In contrast, VRs are multimodal, user-dependent, and immersive presentations that are presented in real-time with real-time 3D interaction and simulation. This definition of a VR follows the descriptions from Bryson (1993) and Cruz-Neira (1993), which were presented in chapter 1. When distinguishing VR technology, Dörner et al. use the criteria of immersion developed by Slater and Wilbur (1997) to describe systems like an HMD or a CAVE as immersive VRs, while desktop systems with stereoscopic presentation as non-immersive VRs (Dörner & Steinicke, 2013).

As the immersive presentation of information is seen as a requirement for a VR, this thesis uses immersive VRs as VR in a narrower sense while non-immersive VRs describe VR in a broader sense. This means VR devices supporting head tracking are seen as more immersive than for example conventional computer displays, regardless

Table 2.2

*Characteristics of VR in Comparison to Conventional Computer Graphics (following Dörner & Steinicke, 2013)*

<b>3D computer graphics</b>	<b>Virtual Reality</b>
solely visual presentation	multimodal presentation: visual, auditory, haptical
viewer-independent presentation (exocentric perspective)	viewer-dependent presentation (egocentric perspective)
static scene or precalculated animation	realtime interaction and simulation
2D interaction (mouse, keyboard)	3D interaction (body movement, hand movement, head movement, gestures, voice input)
non-immersive presentation	immersive presentation

of their *Reproduction Fidelity*. But still, within the areas of the immersive and non-immersive VR systems, devices can be distinguished in terms of their display quality. Therefore, this thesis uses the *Extent of Presence Metaphor* as the main scale for the classification of the level of immersion of a device while *Reproduction Fidelity* is used a subscale to determine which device is more immersive when having the same *Extent of Presence Metaphor* level. While Milgram et al. (1994) use the *Reproduction Fidelity* only for the visual presentation of stimuli, a widened approach including all possible sensations seems appropriate. It remains a challenge to compare systems providing different stimuli in terms of their level of immersion, especially when it comes to comparing interaction possibilities and presentation sensations.

### Summary 2: Immersion

A virtual environment (VE) consists solely of virtual components. Besides, other forms of mixed realities and mixed virtualities, as well as the actual reality itself, exist. A VR is a VE that is presented in realtime and that is immersive, 3D-interactive, multi-sensory, and viewer-centered. It is displayed through a VR system that provides features in terms of an *Extent of Presence Metaphor* (intention of making the observer feel present in the VE through the simulation of various stimuli) and *Reproduction Fidelity* (range and quality of the displayed stimuli). VR systems can be compared with regards to their level of immersion by using these dimensions. This makes the level of immersion a (quantifiable/comparable) description of the used technology and software.

## 2.2 Presence: Being There

It has to be noted that a separation between mediated and non-mediated perception in terms of technology has to be handled critically as human senses themselves can be regarded as media: “The perceptual world created by our senses and nervous system is so functional a representation of the physical world that most people live out their lives without ever suspecting that contact with the physical world is mediate” (Loomis, 1992, p. 113). Therefore, Loomis points out the phenomena *externalization* and *distal attribution*, which explain how most of our perceptual experience, though originating in the human’s sensual organs, refer to external objects beyond the limits of these organs (Loomis, 1992). For perceiving these objects and environments as ‘real’, they do not necessarily have to be real. The sense of being in an environment or the perception of objects being in the environment of the individual is described as presence. This section gives a brief insight into presence terminology, its types, its measurement methods, and its influencing factors.

### 2.2.1 Presence Terminology

In most notions seen in existing literature, presence is described as the subjective experience, the psychological quantification of the feeling of *being there* (Nowak & Biocca, 2003; K. M. Lee, 2004; Bailenson & Yee, 2008; Ahn & Bailenson, 2011). Achieving a sense of presence is often seen as an indicator of success regarding the design of medial experiences (Nowak & Biocca, 2003; Meehan, Insko, Whitton, & Brooks, 2002). In terms of VEs, presence is named “the key to defining virtual reality in terms of human experience” (Steuer, 1992, p. 5), an experience deriving from sufficiently high-fidelity displays, a mental attitude of willing acceptance, and a modicum of motor participation (Sheridan, 1992); arguably just an epiphenomenon of a VE (Welch, Blackmon, Liu, Mellers, & Stark, 1996), a design ideal for synthetic environments (Draper, Kaber, & Usher, 1998), and an effect of the participation in a VE (Wilson, 1996).

Slater (2003) separates the presentation of a VE from its content: Presence, as a subjective reaction to a given technical display of a VE solely refers to its presentation, not to its contents. Therefore, good stereo headphones are capable of inducing the impression of being in a concert hall while a possible disinterest in classical music played does not infer with the sense of presence. The feeling of being inside the concert hall would remain despite the lack of interest in the music (Slater, 2003). Therefore, the feeling of presence is described as follows:



“When you are present your perceptual, vestibular, proprioceptive, and autonomic nervous systems are activated in a way similar to that of real life in similar situations. Even though cognitively you know that you are not in the real life situation, you will tend to behave as if you were and have similar thoughts” (Slater, 2003, p. 2)

Nichols, Haldane, and Wilson (2000) follow this approach by focusing on the intuitive behavior resulting from such activation processes: They see presence as “a sense of being there, reflected by engrossment with, and intuitive behavior in, the VE” (p. 472). There is a problem that occurs when trying to define presence: Even in the real world, describing the feeling of being present is tricky and it is even more difficult when it comes to artificial worlds (Nichols et al., 2000). While philosophy and arts express presence through realism and perspective (Nichols et al., 2000), the level of realism in a VE might not necessarily be crucial for developing a sense of presence (Shapiro & McDonald, 1992). In order to ask “What makes people feel involved in the real world, and indeed what do we mean by the ‘real world’?” (Nichols et al., 2000, p. 472), it might also be interesting to know the situations where people feel more detached from the real world, for example after drinking alcohol or when hallucinating (Bentall, 1990).

Steuer (1992) sees presence as the key to defining VR in terms of human perception: “Presence can be thought of as the experience of one’s physical environment; it refers not to one’s surroundings as they exist in the physical world, but to the perception of those surroundings as mediated by both automatic and controlled mental processes” (p. 77). Steuer hereby follows the concept of Gibson (1979) who identifies presence as the feeling of being in an environment. Steuer postulates this for our non-mediated experiences in the natural, physical environment, as well as for mediated experiences, which are presented to a user through a medium. When perception gets mediated through communication technology, the user perceives two separate environments simultaneously: the physical environment and the environments generated and presented through a medium<sup>2</sup> (Steuer, 1992). The concept of telepresence can be seen as the amount to which a user feels present rather in a mediated environment than in the current physical environment: “Telepresence is defined as the experience

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<sup>2</sup>As mentioned in chapter 1, all experience can be regarded as being mediated. Our perceptual channels (as media) let us perceive distant objects/intelligences (distant as they are not directly touching our eyes, ears, or nose) as actual (see Loomis’s (1992) notion of *externalization* and *distal attribution*). Virtually mediated experiences are also perceived through the perceptual channels making us refer to distant virtual objects, even if they are indeed almost touching our perceptual channels (pixels on the HMD right before our eyes, audio signals from the headphones on our ears).

of presence in an environment by means of a communication medium” (Steuer, 1992, p. 78). However, Steuer’s ideas to telepresence do not only refer to VR applications. More examples for evoking presence, according to Steuer (1992), are:

- Reading a letter that comes from a distant friend or colleague can induce the feeling of presence in the environment in which the letter was written and/or it makes the writer appear socially present.
- People using toll-free airline numbers to make reservations for a flight tend to ask the operator about his “real location”. A possible reason for this behavior might lie in feeling uncomfortable with virtual interaction without any contextual clues, which is why one tries to create a background to place the operator’s character into.
- According to users of several online systems like bulletin boards and conferencing systems, each system provides its own distinct ‘sense of place’.
- Live recordings of music give the listener a sense of presence in the room of the recording (e.g. a concert hall).
- Nuclear power plant operators observe and interact with the inside of the reactor by using remotely moveable cameras and remotely controlled mechanical ‘hands’.
- The experience of moving an animated car on the screen is described as ‘driving’ by video game players.

For Witmer and Singer (1998), presence “as the subjective experience of being in one place or environment, even when one is physically situated in another” (p. 225) can be considered as a normal awareness phenomenon. Presence requires directed attention while being based on the interaction between sensory stimulation, several environmental factors (encouraging involvement and enabling immersion) as well as internal tendencies. While an attention shift from the physical environment towards the VE has to take place in order to generate the feeling of presence, a complete displacement of attention is not necessary. Witmer and Singer compare this to real-world experiences where human attention varies between the physical world and the mental world (e.g. memories, daydreams, and planned activities). The mental world also includes previous knowledge and information, for example from books, movies, or VEs. There are arguments for presence being a matter of *broad focus* (in terms of awareness of the entire task environment) or of *selective attention* (narrow focus on selected, meaningful information) (Witmer & Singer, 1998).

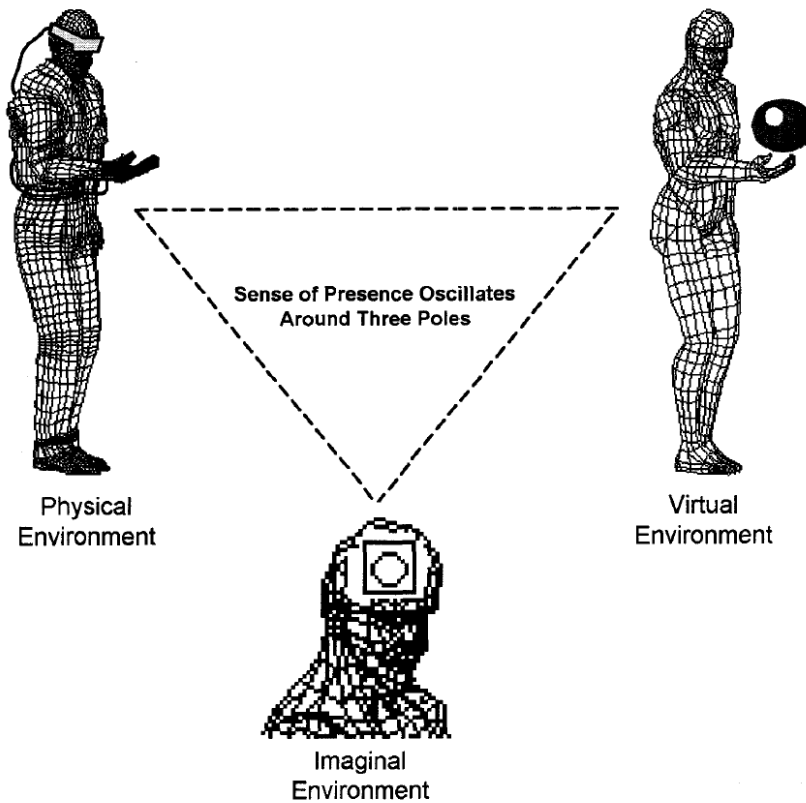


Figure 2.1. Three Poles Of Physical Presence (Biocca, 1997, p. 19)

A similar discussion can be found in the works of Biocca who extends Loomis's idea of presence as a basic state of consciousness (Loomis, 1992) that "is part of the attribution of sensation to some distal stimulus, or more casually, to some environment" (Biocca, 1997, p. 20). In contrast to Witmer and Singer, arguing that presence, as an attention phenomenon, can shift partly from the physical and the mental world, Biocca notes that users can feel physically present only in one of the environments: the *physical*, the *virtual*, or the *imaginal* environment. Therefore, presence is an unstable sense oscillating between these three poles (Fig. 2.1). The *physical environment* leads an individual, in response and attending to cues of the non-mediated environment, to attentively construct a mental model of the surrounding physical space. On the basis of this mental model, the individual plans and guides engagement with the natural world. Similar to this, the mental model of the virtual space<sup>3</sup> is constructed in response to the *VE*, mediated through technology (Biocca,

<sup>3</sup>Kim and Biocca argue that it is possible to readily engage presence in the *virtual environment* when virtual and physical stimuli competing for cognitive accessibility. But the level of presence as it occurs in the physical environment can rarely be maintained (Kim & Biocca, 1997).

1997). The *imaginal environment*, as a third pole, refers to internally generated mental imagery. When withdrawing the focal attention from incoming sensory cues from either the *physical environment* or the *virtual environment*, the user feels present in the *imaginal environment* (Biocca, 1997). It has to be noted that Biocca’s concept of the sense of presence oscillating between the three poles mainly refers to the concept of physical presence (though it might be applicable to other presence types too). For the separation of different types of presence see section 2.2.2

In order to structure and categorize existing approaches of presence definitions, Lombard and Ditton surveyed the literature on presence. What many of the numerous tries to conceptualize presence have in common, is their combination of one or many of the factors *social richness*, *realism in the environment*, *effect of transportation*, *perceptual and psychological immersion*, *user as social actor within the medium*, and *medium as social actor* (Lombard & Ditton, 2000). As a common ground many different conceptualizations were incorporated to define presence as “the perceptual illusion of nonmediation” (Lombard & Ditton, 2000, p. 5).

The aim of this thesis is neither to find a new definition nor to categorize, criticize, or evaluate existing ideas of presence. As the concept of presence is about to be investigated in terms of its predictors, effects, and relations, a simple but established definition that joins multiple perspectives of presence is needed. Further, this work focuses on virtual environments rather than augmented environments (see section 2.1.1), which makes it unnecessary to distinguish between an individual “being in a mediated place” or mediated objects “being in the actual reality”. Thus, the simplest solution might be the best to follow: Presence can be regarded as the subjective feeling of “being there”, in a virtual environment. Still, the feeling of presence can occur in various forms. The next section addresses the different types of presence.

### 2.2.2 Types of Presence

Biocca (1997) distinguishes the presence concepts *physical presence*, *social presence*, and *self-presence*. In terms of physical presence, the default sense of “being there” refers to attributing one’s source of sensation to the physical environment: “We have been present in this environment for so long and it is so natural, that the idea that presence might be a psychological construct is only raised by philosophers and perceptual psychologists” (Biocca, 1997, p. 20). As mentioned in section 2.2.1, *physical presence* seems to oscillate between the *physical*, the *virtual*, and the *imaginal environment*. *Physical presence* is crucial for applications involving spatial cognition (e.g. architectural walkthroughs, battle simulations, engineering design, etc.). In recent

years, especially experiences of compelling VEs raise discussions about how *physical presence* can be achieved (Biocca, 1997).

Biocca notes that communication might essentially be the connection of one intelligence with another, which would make communication the experience of another being. Biocca (1997) asks: “If mediated communication is an inadequate substitute for face-to-face communication, then to what degree does a medium simulate the presence of another? Or to what degree does a user feel the social presence of another” (p. 21). In terms of *social presence*, two practical design problems in the design of media occur (Biocca, 1997):

- *Transporting and displaying patterns of energy to generate the illusion of another:* As the perennial quest of telecommunication, collapsing space by using telecommunication technology and collapsing time by using storage devices makes communication between two distant human beings possible. For example, the light of video or the sound energy of a telephone is being transported and displayed in order to generate the illusion of another through puppets, pictures, avatars, etc.
- *Creating an artificial other:* While the goal of social presence by mimicking the morphology, motion, and communication behaviors of intelligent sentient beings seems simple, its design is complex.<sup>4</sup>

A minimum level of *social presence* can occur when a user feels the presence of another intelligence indicated through a form, behavior, or sensory experience. The level of social presence is dependent on the degree to which a user feels like having access to the intelligence, intentions, and sensory impressions of another. A concept worth mentioning is the idea of *hyperpresence* where a user could feel even greater “access to the intelligence, intentions, and sensory impressions of another” than he/she would in the nonmediated world (Biocca, 1997).

By inhabiting an avatar, a number of changes in *self-presence* are possible as soon as the user’s body enters the virtual world. Biocca (1997) defines self-presence

“as the effect of virtual environment on the perception of one’s body (i.e., body schema or body image), physiological states, emotional states, perceived traits, and identity. To use a phrase, self-presence refers the effect

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<sup>4</sup>Biocca names the Turing test (Turing, 1950), where a machine’s ability to generate human-like responses (text-only) in order to exhibit intelligent behavior is being evaluated by a human being, as the symbol of the challenge of creating *social presence*. While the Turing test requires little embodiment (though still being a difficult task), a convincing, fully articulated being would be even more complicated.

of the sensory environment on mental models of the self, especially when that model of the self is foregrounded or made salient” (p. 22).

It can be assumed that higher levels of cognitive performance and emotional development can derive from increases in *self-presence*. Two issues emerge when a user is embodied as an avatar in a virtual world:

- The mapping of the physical body to the geometry and topology of the virtual body may influence the mental model of the user’s body (his or her body schema or body image).
- There might be a difference in the social meaning (i.e. social role) of the user’s body and the embodiment in the virtual body.

Biocca (1997) adds that issues of class, gender, occupational role, body type, etc. are to be considered when designing virtual avatars. Further, the interaction of the VE with the user’s body schema is an important issue that has numerous implications for the design of virtual worlds. Biocca distinguishes between the *objective body* (the physical, observable, and measurable body of the user), the *virtual body* (the representation of the user’s body inside the VE), and the *body scheme* (mental image of the own body, e.g. the own body’s geometry). The social meaning of the character might also differ between different environments (Biocca, 1997). A mismapping between the actions of the user (motor outflow) and the sensory feedback (sensory inflow) usually leads to some form of intersensory conflict causing simulation sickness (Biocca, 1992).

Lee distinguishes virtual objects into *para-authentic* objects and *artificial* objects. A *para-authentic* object holds some kind of valid connection with a corresponding actual object, regardless of the vividness of its representation. In this case, the virtual experience of a user is not an actual object but a somehow mediated version of it. On the other hand, *artificial* objects do not have any authentic connection to actual objects (lack of actual real-life counterparts), the experienced objects are completely artificial/simulated by technology (K. M. Lee, 2004).

Human experience can be divided into *real experience* (sensory experience of actual objects), *virtual experience* (sensory or non-sensory experience of para-authentic or artificial objects), and *hallucination* (non-sensory experience of imaginary objects). As the *virtual experience* can be regarded as the realm of presence research<sup>5</sup>, Lee follows the idea of presence being a “perceptual illusion of nonmediation” (Lombard

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<sup>5</sup>The discussions about what the realm of presence research is and if it should be limited to virtual experiences are controversial, see section 2.2.1.

& Ditton, 2000, p. 5, see section 2.2.1) and defines presence as “a psychological state in which virtual (para-authentic or artificial) objects are experienced as actual objects in either sensory or nonsensory ways” (K. M. Lee, 2004, p. 37).

On the basis of Biocca’s ideas, Lee (2004) separates the different presence types into *physical presence*, *social presence*, and *self-presence* as well. Whenever actual physical objects are mediated by technology or when physical objects are artificially created by technology, the physical experience becomes virtual. *Physical presence* refers to the user’s experience of physical objects which can be entities and/or environments. *Physical presence*, as “a psychological state in which virtual (para-authentic or artificial) physical objects are experienced as actual physical objects in either sensory or nonsensory ways” (K. M. Lee, 2004, p. 44) occurs whenever the para-authentic or artificial nature of objects/environments is not noticed by the user.

The social experience is the experience of social actors. It becomes virtual (similar to the physical experience) whenever other humans are experienced through media or when human-like intelligence is artificially created by technology. Thus, *social presence*, as “a psychological state in which virtual (para-authentic or artificial) social actors are experienced as actual social actors in either sensory or nonsensory ways” (K. M. Lee, 2004, p. 45), occurs when the para-authentic nature of mediated humans or the artificial nature of simulated nonhuman social actors is not noticed by the user.

Lee defines *self-presence* as “a psychological state in which virtual (para-authentic or artificial) self/selves are experienced as the actual self in either sensory or nonsensory ways” (K. M. Lee, 2004, p. 46). *Self-presence* refers to the experience of one’s own self. This experience can become virtual when the perception of the user’s self is mediated by technology (e.g. para-authentic representation of the user) or when there is an artificial construction of the user’s self in the VE. Similar to Biocca’s notes on interaction (Biocca, 1997), Lee (2004) states that appropriate responses to the inputs of the user are crucial for the feeling of self-presence.

While a distinction of presence types into *physical*, *social*, and *self-presence* seems to be reasonable, the ideas of how these types are to be defined vary between researchers. As noted in section 2.2.1, the concept of presence that a broad part of the literature agrees upon is the idea of “being there”, which mainly emphasizes *physical presence*. Therefore, this thesis will focus on investigating the concept of *physical presence* further as it can be assumed that the findings will be applicable to the other types of presence as well. By focusing on physical presence, it is possible to distinguish the content from its presentation<sup>6</sup> and from the used technology.

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<sup>6</sup>It was argued in section 2.2.1 that the perception of presence ‘in a place’ (*physical presence*)

### 2.2.3 Methods of Measuring Presence

Just like every psychological construct, the measurement of presence as the subjective feeling of “being there” (see section 2.2.1) is difficult and raises a number of issues. Nichols et al. (2000) note that presence “is multifactorial and may be physiologically and psychologically displayed in different ways by different people” (p. 474). Further, even though it is clear that the feeling of presence should be at its highest when an individual participates in regular activities requiring his or her full attention in the actual physical world, presence is difficult to describe or to quantify. In order to select an appropriate instrument for the measurement of presence, this section summarizes popular methods of measurement. Baren and IJsselsteijn gathered and compared current presence measurement approaches in a comprehensive compendium (Baren & IJsselsteijn, 2004), which was used as a basis for the structure of this section.

A basic distinction of presence measurements separates the subjective methods of measurement from the objective corroborative methods of measurement. Subjective measurements (questionnaires, continuous measurements, qualitative instruments, psychophysical measurement, and subjective corroborative measurement) use the individual’s conscious judgment of his/her psychological state or response regarding a given mediated environment. Objective approaches (physiological measurement, neural correlates, behavioral measures, task performance measurement) try to measure the user’s responses to the mediated environment, which are produced automatically and without conscious deliberation while still being correlated with quantifiable properties of the medium/content (IJsselsteijn, 2004). Baren and IJsselstein note that a clear distinction between subjective and objective methods of measurement is not always possible (Baren & IJsselsteijn, 2004). As important criteria for presence measures have been identified (Baren & IJsselsteijn, 2004):

- *Reliability*: consistency and stability over time, delivering comparable results when used under comparable conditions
  - *Inter-rater reliability*: To which degree do different observers agree with each other in their assessment?
  - *Test-retest reliability*: How stable is a measurement over a period of time?
  - *Parallel forms*: How consistent are similar measures?

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is independent of the interest of the user in this place or in its contents. *Social presence* and *self-presence* strongly rely on the programmed social actors and the programmed body interactions as well as other internal factors (issues of class, gender, occupational role, body type, etc.).



- *Internal consistency reliability*: To which extent do the items of a measure address the same underlying trait or characteristic?
- *Validity*: measurement of the intended construct
  - *face validity*: To which extent does the instrument appear to address the intended construct?
  - *content validity*: Is the measure compatible with theories and does it address all relevant dimensions of the construct?
  - *criterion-related and construct validity*: Can the instrument be compared to some other measure or criterion?
- *Sensitivity*: ability of the instrument to distinguish between different levels of presence with a reasonable level of detail
- *Robustness*: applicability to various different media platforms (form, content, context-of-use)
- *Non-intrusiveness*: interference of the method with the measured construct
- *Convenience*: simplicity of learning and administering the measurement method, costs, portability

Self-reports are currently the most popular measurement method of presence. They can range from ratings comparing the real world to the virtual world and ordinal rating scales asking the user about his/her memories of being inside the environment to the analysis of essays written subsequent to the mediated experience (Nichols et al., 2000).

The advantage of continuous assessment methods, where users rate fluctuations in their subjective sense of presence, is their sensitivity to time-variant information. Thus, it is possible to overcome recall problems or anchoring effects. But, even if the instrument requires little effort and attention, this method can interrupt the experience of the VE and it is only possible to rate one aspect of the experience at a time (Nichols et al., 2000). For example, to measure the concept of physical presence, participants can be asked to move a slider in order to indicate their currently perceived level of presence (Ijsselsteijn, Ridder, Hamberg, Bouwhuis, & Freeman, 1998).

Presence questionnaires that measure the user's memory show a broad variety and are the most frequently used instrument to assess presence. While there are studies trying to measure presence with a single item, others have tried to assess presence on the basis of a multidimensional structure (Baren & IJsselsteijn, 2004). Lessiter et al. (2001) argue that presence questionnaires should not ask respondents directly about how present they feel; questions should not address two issues in one

item; response options should be consistent across items; questionnaires should reflect the multidimensional character of presence; questions should not be specific to the specific media system or content properties; general presence measures should be piloted with a range of media systems and contents as well as that the piloting process should include a sufficient number of participants. Baren and IJsselstein (2004) note that presence questionnaires usually have high face validity, are relatively cheap, easy to administer, analyze, and interpret. Further, as the questions are answered after visiting the VE, the questionnaire does not interrupt the experience. As the main disadvantage, Baren and IJsselstein (2004) state that post-experience questionnaires are retrospective, resulting in an incomplete reflection of the experience as they rely on the user's memories. Upon that, questionnaires are sensitive to hints and cues in a research situation biasing the user's responses.

Baren and IJsselstein (2004) state that "qualitative research methods produce information which is not arrived at by any means of quantification, such as statistical procedures" (p. 27). Qualitative methods include content analysis (e.g. written text or thinking aloud protocols referring to the VE experience), interviews (expression of the personal experience), and ethnographic approaches (open-ended questionnaires, unstructured interviews, and observation of naturally occurring behavior). A common use of qualitative methods is exploratory research in order to generate hypotheses. These methods can help to gain a deeper understanding of the users' experiences by providing very rich and detailed information. For qualitative instruments measuring presence, it is difficult to determine the factors *sensitivity*, *reliability*, and *validity* (Baren & IJsselsteijn, 2004).

Subjective psychophysical measures of presence "require an observer to provide a subjective rating of the physical magnitude of a stimulus" (Baren & IJsselsteijn, 2004, p. 34). Examples for psychophysical measures are the free-modulus magnitude estimation (users assigning a value to the degree of presence induced by a stimulus), the paired comparison test (discrimination between stimuli), and cross-modality matching (users translating the intensity of their feeling of presence to a different modality), which can be used to sensitively distinguish different levels of presence (Baren & IJsselsteijn, 2004). With a comparison to the Turing test of artificial intelligence, Sheridan (1992) suggests a presence measurement where people discriminate between real and virtual worlds. Nichols et al. (2000) note that such a measurement of presence, "though sound in theory, is probably impractical for today's technology" (p. 475). Psychophysical measures are relatively cheap, easy to use, and they can

be used unobtrusively even though they are prone to bias, dependent on the experimenter's instructions and on the participants' own interpretation of the instruction (Baren & IJsselsteijn, 2004).

Subjective corroborative measures do not directly provide information about the feeling of presence but they assess mental processes that might be related to presence, like attention, memory, and spatial cognition (IJsselsteijn, 2004). The measurement of various related mental processes can support the *validity* of presence instruments. According to Baren and IJsselstein (2004), examples of subjective corroborative measures are

- *the breaks in presence method*: assessing transitions between the virtual world and the real world,
- *the duration estimation*: investigating the human ability to indicate how much time one needed to complete a task,
- *simulator sickness*: measuring nausea, oculomotor effects, and disorientation,
- *memory characteristics*: assess differences between experiences in memory,
- *attention/awareness*: measuring selective attention on the virtual world,
- *spatial memory*: assessing the amount of spatial information from the VE that is remembered by the user,
- *spatial memory awareness states*: differing the awareness states remembering and knowing), the gravity referenced eye level,
- *gravity-referenced eye level*: investigating users' estimates of spatial orientation by comparing actual and estimated eye levels in a VE, and
- *subjective tilt angle*: assessing the user's subjective coordinate axis to measure the sensation of reality.

Objective corroborative measures “have mainly been used or suggested because they are not influenced by the participant's subjective interpretation” (Baren & IJsselsteijn, 2004, p. 44). Once the participant got used to the equipment (e.g. electrodes) the methods of measurement are relatively unobtrusive as the information is collected automatically. An occurring problem is that the *validity* of the measured construct often remains unclear as the sense of presence is not assessed directly (IJsselsteijn, 2004). Moreover, the measures can be sensitive to other factors than presence as the same physiological responses can be induced by different stimuli (Insko, 2003).

An approach including objective psychophysiological measures, for example, used by Slater, Usoh, and Steed (1994), measures physical reactions, such as shaking legs,

exclamations, and heart rate. Individuals who have a stronger sense of presence in a VE may react strongly to virtual danger situations<sup>7</sup>. Other psychophysiological measures include cardiovascular measures, skin measures, ocular measures, and facial electromyography (Baren & IJsselsteijn, 2004).

Some psychophysiological techniques aim to investigate the brain's processes and its activity. The interpretation of data gathered from such methods is difficult as only little is known about neural processes related to the sense of presence. At the moment, brain imaging equipment is expensive and intrusive. But still, instruments measuring neural correlates seem promising as the collected data cannot be influenced by the user. Examples for neural correlate measurement methods are the electroencephalogram (EEG), where the electrical activity from the scalp is amplified and recorded by using small electrodes, and the functional magnetic resonance imaging (fMRI), which detects changes in the brain's blood flow by using magnetic fields in order to provide images displaying the activity of the different brain areas (Baren & IJsselsteijn, 2004).

Nichols et al. (2000) follow the idea that users feeling present in the mediated environment would treat their surroundings as a place, leading to a similar reaction behavior in the virtual world as if its events were occurring in the real world (Barfield, Zeltzer, Sheridan, & Slater, 1995). This idea underlies the concept of behavioral measures (IJsselsteijn, 2004). Behavioral measures are tricky as they are prone to bias from the experimenter as he/she observes and interprets the behavior. An advantage of these measurement methods is that they are not intrusive as the behavioral changes occur spontaneously (Baren & IJsselsteijn, 2004). This includes measures of how reflexively a user reacts to virtual events in a VE, e.g. ducking to avoid a virtual projectile (Held & Durlach, 1992)) or virtual social encounters producing socially conditioned responses like apologizing or grasping for objects being handed from an avatar (Nichols et al., 2000). Other methods measure the postural responses to the VE, pointing (towards real/virtual objects), and the facial expressions of the participant (Baren & IJsselsteijn, 2004).

Task performance measures can be used as an objective corroborative indicator of presence when there are clear tasks in the VE that should be performed. Examples for such presence measures are the assessment of completion time and error rate, the number of actions required to complete a task, secondary task performance (assuming

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<sup>7</sup>In an experiment, participants were exposed to standing on a visual cliff (Slater & Usoh, 1993). Nichols et al. (2000) argue that a higher sense of presence in such a scenario might derive from the kinetic motion effect, as well as the level in photorealism in the VE. There are studies that disagree with this assumption, see section 2.2.4

a relation between the amount of effort and attention allocated between a primary and a secondary task), as well as the transfer of skills that were learned or practiced in a VE to real-world situations.

Even though objective corroborative measures may provide deeper insights into the concept of presence in the future, its interpretations still remain unclear at the moment and many instruments are intrusive, expensive, and/or simply not appropriate for large studies. It can be assumed that corroborative measures strongly rely on the content as well, responding to emotional arousal as a result of presence rather than presence itself<sup>8</sup> As presence is a subjective feeling, Sheridan (1992) argued that presence should primarily be assessed with subjective measures. In order to avoid intrusive instruments while still providing quantifiable measures for statistical analyses, questionnaires measuring physical presence seem to be an appropriate choice for the aims of this thesis.

#### 2.2.4 Factors Influencing Presence

Presence, as a subjective feeling, is influenced by several subjective and objective factors. Baños et al. (2004) note that it “is determined by a complex variety of characteristics of the medium, the user and the context” (p. 156). This section tries to provide a brief overview of various factors influencing presence with a focus on physical presence. While this section is not supposed to be extensive as there have been great efforts investigating predictors of presence in the last years, this section tries to cover all relevant aspects that might become important for learning processes as well, in especial the basic constructs of the “trilogy of mind” (Hilgard, 1980, p. 107), consisting of cognition, affection (in terms of emotional factors), and conation (in terms of motivational factors). The investigation of these might be beneficial, as it is very likely that presence, being a product of the individual’s brain, “will vary significantly based on individual differences in, for instance, perceptual-motor abilities, mental states, traits, needs, preferences, and experiences” (IJsselsteijn, 2004, p. 146).

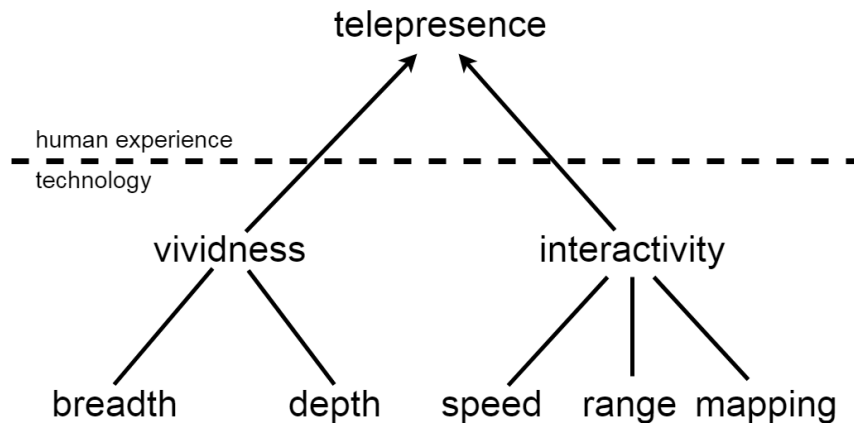


Figure 2.2. Technological Variables of Telepresence (Steuer, 1992, p. 81)

#### 2.2.4.1 Level of Immersion

The level of telepresence is influenced by the objective technological variables *vividness* and *interactivity* (Fig. 2.2). *Vividness* can be seen as “the representational richness of a mediated environment as defined by its formal features” (Steuer, 1992, p. 81). *Vividness* refers to how the technological setting presents information from the environment to the senses. This characteristic of a virtual environment mainly consists of the components *breadth* and *depth*. *Sensory breadth* describes the number of sensory dimensions (perceptual channels) that are presented simultaneously to the user. *Sensory depth* quantifies the resolution of the cues within the presented perceptual channels. *Interactivity*<sup>9</sup> as “the extent to which users can participate in modifying the form and content of a mediated environment in real time” (Steuer, 1992, p. 84) is described by the factors *speed*, *range*, and *mapping*. The *speed of interaction* refers to the response time of the medium in terms of latency regarding interactions of the user (e.g. turning the head or activating a button). The desirable value here would be a real-time response. The number of attributes that can be manipulated in the VE and the quantity of possible interactions is referred to as *range*. *Mapping* takes into

<sup>8</sup>For example, picking up the example of Dörner et al. from section 1, a user feeling present in a virtual zoo might respond stronger to corroborative measures when seeing a virtual tiger in front of him/her while perceiving the same level of physical presence in the VE of the zoo (perhaps, social presence might be increased as the user feels the social presence of the tiger).

<sup>9</sup>Steuer sees *interactivity* separated from terms like *engagement* and *involvement* (which are frequently used by communication researchers) as a stimulus-driven variable. *Interactivity* is determined by the technological structure of the medium.

account the connection between human actions<sup>10</sup> and the resulting actions within the environment (Steuer, 1992). As *vividness* and *interactivity* consist of objective and partly quantifiable technological variables, these criteria can be seen as the characteristics of immersion that influence presence. Immersion is one of the main factors influencing presence in general. Studies comparing different immersive settings (in terms of using different technological devices) and their effects on presence show associations between differences in hard- and software and the feeling of self-reported presence. There are several studies investigating the effect of particular aspects of technological characteristics on presence.

Mikropoulos (2006) examined differences between the users' feelings of personal presence<sup>11</sup> in egocentric and exocentric perspectives for a projection setting and a HMD setting. While the display type does not seem to be crucial for the feeling of presence when providing an exocentric perspective ( $t = 1.35$ ,  $df = 59$ ,  $p > .05$ ), using a projection based presentation versus an HMD based presentation seems to be an important factor when providing an egocentric perspective ( $t = -3.55$ ,  $df = 58$ ,  $p < .05$ ). The highest mean value of personal presence ( $M = 3.85$ ,  $SD = 0.12$ ) was found in an HMD setting with egocentric perspective.

Lin et al. (2002) investigated the effect of field of view (FOV) on presence in VEs by comparing four FOVs (+/-30°, +/-50°, +/-70°, and +/-90°). Presence (and other variables like enjoyment and simulation sickness) were measured in a VE named *Crayoland* (simulated with a CAVE driving simulator) where the participants drove through a cartoon world with a cabin, pond, flowerbeds, and a forest. Using a within-subject design, presence could be modeled as a function of FOV (Fig. 2.3). An ANOVA could show an effect of FOV on presence [ $F(3, 27) = 11.91$ , adjusted  $dfs = (2.04, 18.40)$ ,  $p < .001$ , observed power = .99]. Results indicate that presence enhances with an increasing field of view even though there was only few difference between the 140° and the 180° FOVs. Lin et al. (2002) argue that these similarities for high FOV values derive from the human eyes' characteristics as "rod and cone

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<sup>10</sup>Steuer notes that the mappings of certain interaction can be arbitrary and unrelated to the function performed: "For instance, wiggling one's left toe might increase the loudness of sound from the television speaker." (Steuer, 1992, p. 87). Mapping is generally increased by adapting interactions in a way that they resemble natural human actions as the human perceptual system is optimized for interactions with environments in the real world.

<sup>11</sup>Mikropoulos investigated personal presence and social presence with a self-developed questionnaire using a five-point Likert scale. Mikropoulos follows Heeter's (1992) taxonomy with personal presence referring to a similar theoretical construct as the term physical presence, which was suggested to be investigated further (see section 2.2.2).

receptors are distributed very differently in the retina, and different receptors mediate different visual perceptions. In terms of acuity, the all-cone fovea in the center of the retina permits high visual acuity, the rod-rich peripheral retina has lower visual acuity since the rods' convergence decreases their ability to resolve details" (p. 167). The authors note that visual acuity might contribute to presence and that presence could be associated with the central visual field. Further, as the human eyes have an individual FOV of  $150^\circ$  each horizontally with a binocular overlap of  $120^\circ$ . Thus, FOVs exceeding 120 do not improve stereo perception, which is why the effect on presence was small (Lin et al., 2002).

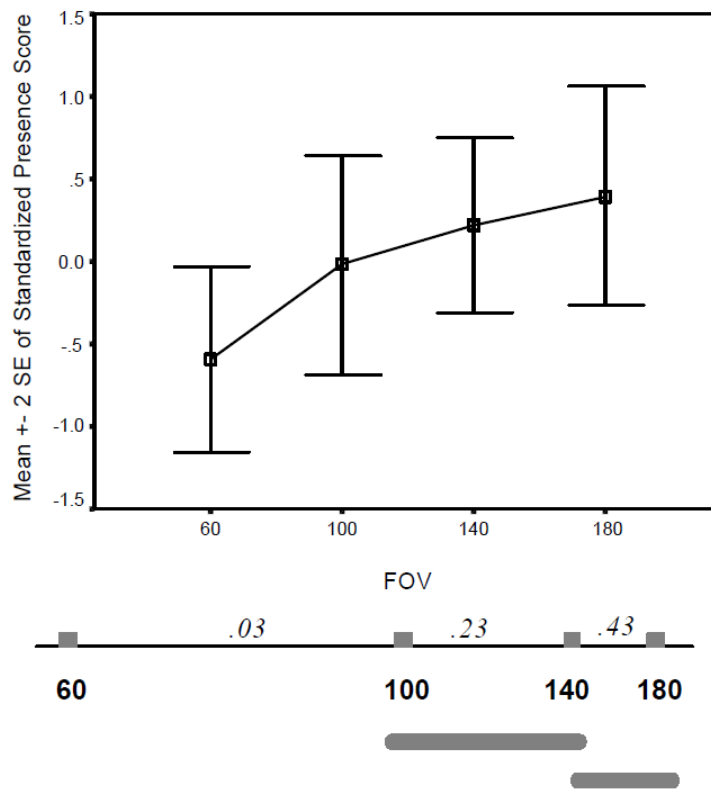


Figure 2.3. Presence as a Function of Field of View (Lin et al., 2002, p. 167)

In a study with 232 participants, Lee, Wong, and Fung (2010) investigated how VR features like representational fidelity and immediacy of control as well as usability (consisting of perceived usefulness and perceived ease of use) affect presence. Representational fidelity includes the degree of realism that is provided by the 3D images and the content of the scene, the degree of realism that is provided by tem-



poral changes to the images (motion of the objects), as well as the degree of realistic behavior or a behavior that is consistent with the ideas being modeled (Dalgarno, Hedberg, & Harper, 2002). The used VR-based dissection simulator V-Frog<sup>TM</sup> provided a virtual learning environment (VLE) where students could cut, pull, probe, and examine a virtual specimen similar to a real frog. In the research model of Lee et al. the factors representational fidelity and immediacy of control were treated as exogenous variables while usability was treated as a predictor for presence while being influenced by the VR features as well. The results showed positive effects of the VR features (representational fidelity and immediacy of control) on presence ( $\beta = .42$ ,  $p < .001$ ) and on usability ( $\beta = .77$ ,  $p < .001$ ). The effect of usability on presence was not significant. Lee et al. (2010) argue that “the positive relationship between VR features and presence indicates that the better the VR features in terms of realism and control factors, the higher level of presence the users experienced” (p. 1442).

Chow (2012) investigated how a participant’s perceived ease of use affects presence<sup>12</sup>. Perceived ease of use was treated as an exogenous variable, referring to questions like “It is easy to operate RSI[Rapid Sequence Intubation] in Second Life and get it to do what I want it to do” (M. Chow, 2012, p. 84). Thus, the concept of perceived ease of use could be interpreted as a variable assessing the level of mapping perceived by the user. Findings showed a significant positive effect ( $\beta = .22$ ,  $p < .01$ ) of perceived ease of use on presence.

#### 2.2.4.2 Motivation

VR can be considered as potentially offering “extraordinary opportunities for enhancing both motivation and learning across a range of subject areas, student developmental levels, and educational settings” (Dede, Jacobson, & Richards, 2017, p. 1f.). Motivation, as a central criterion for every learning environment, is likely to influence presence as well. In order to motivate players and learners, Pirker, Gütl, and Löffler (2018) suggest the Player Type Design for designing engaging virtual learning experiences on the basis of Bartle’s player type distinction (Bartle, 1996).

In a study with 64 university students, Yeonhee (2018) investigated the relations between the level of immersion, perceived interactivity, and intrinsic motivation by using a virtual school environment for Korean language learning. Results show that

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<sup>12</sup>In the questionnaire, the participants were asked questions like “[...], how much did you feel as if you were walking when your own avatar walked?” (M. Chow, 2012, p. 84). Therefore, the presence concept used by Chow is can be referred to as self-presence.

intrinsic motivation<sup>13</sup> and perceived interactivity as a core component of presence were moderately correlated ( $r = .46, p < .01$ ). Similar effects for other internal motivational constructs (i.e. identification) are to be expected. A negative association between the least autonomous constructs of extrinsic motivation, external regulation and introjection, and presence could be assumed as well.

The study from Lee et al. (2010) presented before also investigated intrinsic motivation by using the Intrinsic Motivation Inventory (IMI) by McAuley, Duncan, and Tammen (1989). The questionnaire assessed the four sub-dimensions interest-enjoyment, perceived competence, effort-importance, and tension-pressure. An overall scale was used as an intrinsic motivation<sup>14</sup> scale (18 items with  $\alpha = .74, \alpha = .82$  after deleting three items). VR features ( $\beta = .22, p < .01$ ) and usability ( $\beta = .71, p < .001$ ) were found to be significant antecedents to motivation. Even though the effect of motivation on presence was not calculated in the study, the model implied a correlation of .49 between motivation and presence (for the whole model and the model fits, see section 3.3). Thus, the relationship between motivation and presence could be assumed.

Chow (2012) notes that attitude towards the use of a virtual world has a positive effect on (self-)presence. In particular, attitude was assessed as the user's positive or negative attitude towards using Second Life for teaching Rapid Sequence Intubation ( $N = 206$ ). Results showed that attitude had a significant positive effect ( $\beta = .44, p < .001$ ) on presence. Presence, as a matter of focus, occurs when we direct our attention to selected information in an environment that is meaningful and of particular interest to us:

“Experiencing presence in virtual world requires us to focus on one meaningful coherent set of stimuli to the exclusion of unrelated stimuli in the physical environment. If we find a virtual world novel and interesting, our attention is more easily attracted by it. With such positive attitude, we are more willing to suspend our disbelief and allocate attentional resources to the mediated environment” (M. Chow, 2012, p. 86).

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<sup>13</sup>Intrinsic motivation was treated as a state variable occurring and being measured after the VR experience. Therefore, intrinsic motivation was not seen as a predictor for perceived interactivity. The main objective of the study was to investigate if perceived interactivity plays a mediating role in the relationship between the medium (level of immersion) and the intrinsic motivation.

<sup>14</sup>It is important to note that Lee, Wong, and Fung assessed intrinsic motivation as a state variable that varies depending on the situation and context of learning. Therefore, motivation was not assessed prior to the VR experience but in a posttest.

With this link to the user's suspension of disbelief (see chapter 1), it is possible to argue why motivation might contribute to presence. Motivational traits directed towards the content of the VE seem to influence various presence types and can, therefore, be regarded as a person-specific predictor of presence in general.

### 2.2.4.3 Cognitive Skills

Cognitive skills can also be regarded as a determinant for presence: Constructing the representation of one's own bodily actions as possible actions in the virtual world while suppressing incompatible sensory input are the two cognitive processes involved for feeling present in the mediated world (Slater & Usoh, 1993). The idea that users suppress incompatible sensory inputs willingly to accept a VE can be referred to as a "(suspension of dis-)belief that they are in a world other than where their real bodies are located" (Slater & Usoh, 1993, p. 221). Such an understanding of cognitive activities also corresponds with Biocca's theory of presence being a labile psychological construct oscillating between physical, imaginal, and VEs (Biocca, 1997).

"When one tries to explain how this effect [presence] occurs psychologically, it becomes clear that the answer requires a model of the cognitive processes leading to presence, and that the causation of presence by interactivity may offer insights into the psychology of the sense of presence." (Regenbrecht & Schubert, 2002, p. 426)

According to Schubert, Friedmann, and Regenbrecht (2001), the construction of a spatial-functional mental model of a VE induces a sense of presence. While current theoretical models see the sense of presence as the outcome of a direct function of immersion, the authors argue that it would be misleading to assume a one-to-one relationship between both variables: "One must take into account the cognitive processes leading from stimuli perception to presence. Cognitive processes mediate the impact of immersion on the development of presence" (Schubert et al., 2001, p. 267). Thus, the stimuli from the VE are the raw material for the user's mind, which is responsible for constructing a mental picture of a surrounding world (Schubert et al., 2001). Even though the authors note that a mental picture of pixels on a display would be more valid (Schubert et al., 2001), the sense of physical reality seems to be "a consequence of internal processing rather than being something that is developed

only from the immediate sensory information we receive” (Ellis, 1991, p. 323)<sup>15</sup>. The process of constructing a mental model of a VE can be compared to mental processes like conscious recollection and language comprehension as “it is necessary to mentally represent a situation that is different from the one immediately present” (Schubert et al., 2001, p. 268).

Schubert et al. (2001) conducted two studies asking participants about their latest experiences in VEs. In an exploratory factor ( $N = 246$ ,  $KMO = .83$ ) analyzes, the first-level factors spatial presence, quality of immersion, involvement, drama, interface awareness, exploration of VE, predictability and interaction, and realness could be extracted. Second order factors combined the components realness, spatial presence, and involvement (being joined by drama and quality of immersion when forcing a two-factor solution), as well as the components interface awareness, exploration of VE, and predictability and interaction. A second study ( $N = 296$ ,  $KMO = .92$ ) could confirm the factors spatial presence, exploration of VE, realness, predictability and interaction, and involvement. The authors argue that especially by confirming the content and the division of the factors spatial presence and involvement, the basic prediction that the attentional and spatial constructive component leading to presence was experienced due to cognitive processes could be verified.

Lee et al. (study described in section 2.2.4.1) assessed spatial ability and learning styles and investigated their moderating effect on the relationship between presence and learning outcomes (E. A.-L. Lee et al., 2010). The students were categorized into the learning styles accommodator or assimilator using the Kolb Learning Style Inventory (Kolb & Kolb, 2005). Further, the participants were categorized in high and low spatial groups based on the spatial ability test from Barrett and Willams (2003, reprinted 2004). Neither spatial ability nor learning style showed a moderation effect on the relation between presence and learning outcomes. Similar to these factors, Lee et al. assessed cognitive benefits<sup>16</sup> referring to better memorization, understanding, application, and overall view of lessons learned. Even though the relationship between cognitive benefits was not reported, usability showed a positive association to cognitive benefits ( $\beta = .75$ ,  $p < .001$ ) while VR features were not correlated with cognitive benefits ( $\beta = .10$ ,  $p > .05$ ), assuming a mediating effect

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<sup>15</sup>Ellis also takes into account that previous knowledge influences the perception and construction of VEs as many aspects of perceived stimuli are often presented in incomplete, noisy form. Therefore, an accurate perception has to involve prior knowledge about the possible structure of the world. (Ellis, 1991)

<sup>16</sup>In this study, cognitive benefits refer to the development of conceptual understanding during experiencing the VE. Therefore, it was not treated as a predictor variable but as a dependent variable.

of usability (E. A.-L. Lee et al., 2010). When following the argumentation from Schubert, Friedmann, and Regenbrecht (see above), the effect between usability and cognitive benefits could be explained by 1.) being mediated by presence and 2.) not being a causal but a mutual one.

Regenbrecht and Schubert state that the number of possible interactions is related to the number of possibilities in terms of a better cognitive meshing, which, in turn, leads to an increase in presence. In a study with 56 participants using a between-subjects design, the possibilities of interacting with a given VE (a floor of an office building) were manipulated in order to determine the effect of possible interactions on presence. The interaction possibilities were free movement versus prerecorded interaction sequences and static environment versus animated characters entering and exiting doors in the VE. After the VR experience, the participants filled out a questionnaire assessing spatial presence, involvement, and realness. The results showed a main effect of self-movement on spatial presence [ $F(1, 48) = 5.81, p = .020$ ] and on realness [ $F(1, 48) = 4.21, p = .046$ ]; a borderline significance for animations on realness [ $F(1, 48) = 2.94, p = .093$ ] was also found. In a follow-up study, 26 participants experienced the same VE as described above (with animations and free locomotion). This time, one group was told that they could interact with the characters (even though they could not, thus changing the users' mental representation of possible interaction with virtual characters) while the other group was told that the characters would not respond to interactions (Regenbrecht & Schubert, 2002). Regenbrecht and Schubert (2002) interpreted an effect of illusory interaction on spatial presence [ $t(24) = 1.19, p = .038$ ] in terms that "presence is a subjective experience, an outcome of cognitive processes like perception and categorization of environmental features in terms of possible actions" (p. 432). Thus, cognition seems to work as a mediating bridge between immersion and presence<sup>17</sup>. Moderating effects between immersion and presence seem to derive from the users' expectations of the environment, their anticipations, goals, and experiences. The mental construction of the environment is influenced by these variables (Regenbrecht & Schubert, 2002).

In terms of previous knowledge, Lombard and Ditton (1997) note that a medium might induce presence easier if the user is not familiar with the nature of the medium in terms of knowledge about how it works:

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<sup>17</sup>Especially the second study separated the cognitive aspect from the immersion aspect: Users with the mental image of a possible interaction experienced higher presence than users without this mental image, even though no interaction was possible in both cases.

“An engineer can not help but notice flaws in a virtual environment or the image in a high definition television system because she/he knows or wants to know what is responsible for the flaw; this knowledge reminds her/him that the experience is mediated. The situation is analogous to a magician who knows how a trick is performed and is therefore unimpressed with the illusion” (“Knowledge of and prior experience with the medium”, para. 1).

On the other hand, being unfamiliar with the medium in terms of how it is used (the nature of the experience) might discourage a sense of presence because of the uncomfortable interaction. More experience with the interaction might enhance presence. Continued experience with a medium might either increase the feeling of presence (in terms of “being there again”) or decrease it through a habituation effect (Lombard & Ditton, 1997).

It is yet unclear how cognitive factors contribute to presence exactly. But due to the close connection between perceptual and other cognitive processes (which might show mutual relationships), it can be assumed that the cognitive abilities, as well as previous experiences and knowledge, influence the user’s sense of presence. Future research has to investigate which cognitive factors predict presence and which can be seen as cognitive correlates.

#### **2.2.4.4 Emotional State**

While IJsselstein et al. (2004) argue that “presence is not about interesting or emotionally captivating content” (p. 145) as even boring VEs can induce a high sense of presence (similar to Slater’s notion on presence, see section 2.2.1), a number of authors have stressed that emotions play an important role in VEs as part of the sense-making process<sup>18</sup> (IJsselsteijn, 2004). The user’s mood before and during media use influences presence as well (Lombard & Ditton, 1997). Hoorn, Konijn and Vand de Veer (2003) note that VR needs to induce emotionally loaded experiences in order to be true-to-life and to be “accompanied by the feeling that ‘something is really going on’ – touching upon basic concerns, motives, or goals of the user”(p. 158). Huang and Alessi (1999) even state that “any theory of presence must take emotional factors into account” (p. 151). On the basis of the theory of Lazarus (1989) that emotions work through a set of interdependent systems (processes for cognitive appraisal,

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<sup>18</sup>It has to be noted that IJsselstein focuses on emotional responses to the environment in terms of internal feedback mechanisms rather than emotions as antecedents for presence. Further, IJsselstein recommends a separated view of the factors emotional involvement and experiencing a media environment as a place (presence)

physical interaction between person and environment, coping, emotional response), it can be assumed that “emotions affect all behaviors, all cognitions, and all conscious and unconscious interactions between the individual and the environment” (Huang & Alessi, 1999, p. 151). Thus, emotions have an impact on presence and ignoring emotions when assessing presence would also mean ignoring an essential part of human experience. Also, reporting biases like participants trying to please an experimenter, feelings about the benefits of a certain technology or fears about the used technology would be ignored as well. Huang and Alessi (1999) state that, by investigating behavioral, cognitive, and emotional aspects of presence further, it is possible to adapt virtual environments with regards to the user’s mental status.

As the physiological measurement methods of presence show, emotional variables that are connected to the purpose of the virtual experience, like anxiety and fear for phobia treatments, also influence the user’s presence. Following this idea, it can be assumed that positive emotions enhance presence in a pleasant environment. On the other hand, presence can be regarded as a crucial factor for triggering emotions in virtual and mixed realities (Price & Anderson, 2007). Witmer and Singer classified separation anxiety/disorientation as a sensory factor of presence. The amount of disorientation or anxiety when returning from the VE to the real world may increase as the presence experienced in the VE increases. In their Immersive Tendency Questionnaire, the authors added an item assessing emotional involvement (happiness, anger, sadness) (Witmer & Singer, 1998).

Baños et al. (2004) investigated the effect of emotional VEs on presence. In a study with 80 university students, the participants walked through one of five virtual parks, each one designed to trigger another emotion (sadness, joy, relaxation, anxiety, neutral/control group) during the experience. After the VR experience, the participants filled out an adapted version of the *Visual Analogue Scale* (Gross & Levenson, 1995), assessing the emotions sadness, joy, anxiety, and relaxation, the *ITC-Sense of Presence Inventory* (Lessiter et al., 2001), as well as the *Reality Judgment and Presence Questionnaire* (R. M. Baños et al., 2000). The analyses of the ‘sad’, ‘happy’ and ‘relaxation’ emotion environments showed that the VEs induced the mood that was anticipated in the representations in the predicted directions. No differences were found for the neutral condition; the “anxiety” environment induced anxiety mood in the predicted direction but did not reach statistical significance. Further, ANOVAs between the emotional group and the neutral group in terms of the different presence measures could show differences regarding the *Reality Judgment and Presence Questionnaire* for the quality/realism measures ( $F(1, 78) = 5.29$ ,

$p < .024$ ), the reality/judgment measures ( $F(1, 78) = 4.16, p < .045$ ), the positive presence measures ( $F(1, 78) = 3.51, p < .065$ ) and the emotional engagement measures ( $F(1, 78) = 20.23, p < .001$ ) with the emotional group showing higher scores and for the emotional indifference measures ( $F(1, 78) = 5.51, p < .021$ ) with the neutral group showing higher scores. The differences in negative presence and in the interaction/navigation scale were not statistically significant. Regarding the *ITC-Sense of Presence Inventory*, the emotional group scored higher in the scales for engagement ( $F(1, 78) = 4.06, p < .047$ ) and ecological validity ( $F(1, 78) = 4.73, p < .033$ ); the other scales did not reach statistical significance (R. Baños et al., 2004). Baños et al. (2004) argue that “emotional environments seemed more natural, believable and real to subjects than the neutral environment” (p. 159). The authors conclude that emotions might have the potential to enhance presence: “Therefore, it could even be possible to consider emotions as an indicator of the degree of presence” (R. Baños et al., 2004, p. 159).

As emotions are not a stable but a state variable that changes dynamically, it seems difficult to determine the direction of the effects between the user’s emotional state and presence. Still, the connection between the two variables makes a further investigation of emotional factors as predictor variables for presence interesting.

## 2.2.5 Explaining Presence

As the discussions above show, multiple subjective and objective variables seem to influence the sense of presence in VEs. To enhance the understanding of presence, this section tries to capture approaches including multiple variables to predict presence.

By following Biocca’s initial idea of presence oscillating between physical, virtual, and imaginal environments (see section 2.2.1), Kim and Biocca (1997) argue that

“it is hypothesized that there is a competition between stimuli from the physical environment and the VE for cognitive accessibility. The experience of telepresence is influenced by the mix of stimuli from the physical and virtual environments and by user traits and states” (“A Proposed Model of Telepresence”, para. 1).

They separate the stimulus side (physical environment/VE) from the person-specific side including the user’s states and traits influencing presence and the cognitive correlates of presence (Fig. 2.4).

IJsselstein (2004) states that a theory of presence needs “an iterative process of refinement of measurement and theory, gradually homing in on a more explicit



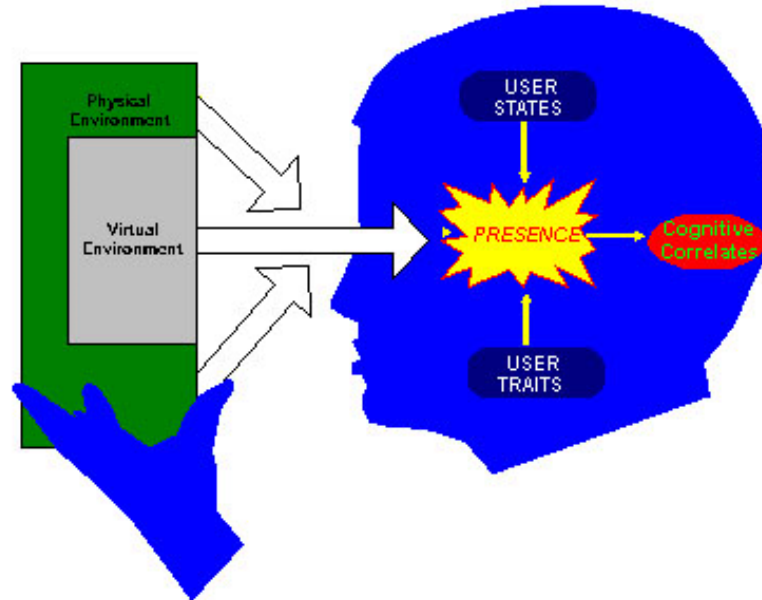


Figure 2.4. Kim and Biocca's General Model of Causes and Correlates of Presence (Kim & Biocca, 1997)

presence theory that includes procedures for analyzing, predicting and explaining the concept of presence” (p. 150). He points out, in a very similar manner as Kim and Biocca, that the underlying construct of presence perception is a continuous perceptual-motor loop reflecting an ongoing process of action-based perception in real-time, meaning that perception changes dynamically while moving through and interacting with the world, as shown in figure 2.5. (Inter-)action includes hand, eye, head and body movements while perception is understood as a highly activity-dependent process that involves embodiment and integrates various sensory data. The perception process is shaped by cognitive and emotional processes. IJsselsteijn et al. (2004) categorize factors determining presence into

- the *extent and fidelity of sensory information* as “technological factor referring to the amount of useful and salient sensory information presented in a consistent manner to the appropriate senses of the user” (IJsselsteijn, Ridder, Freeman, & Avons, 2000, p. 521),
- the *match between sensors and the display*, referring to sensory-motor contingencies like real-time visual and auditory updates while using head tracking,
- *content factors* including objects, actors, and events in the VE (e.g. interactions,

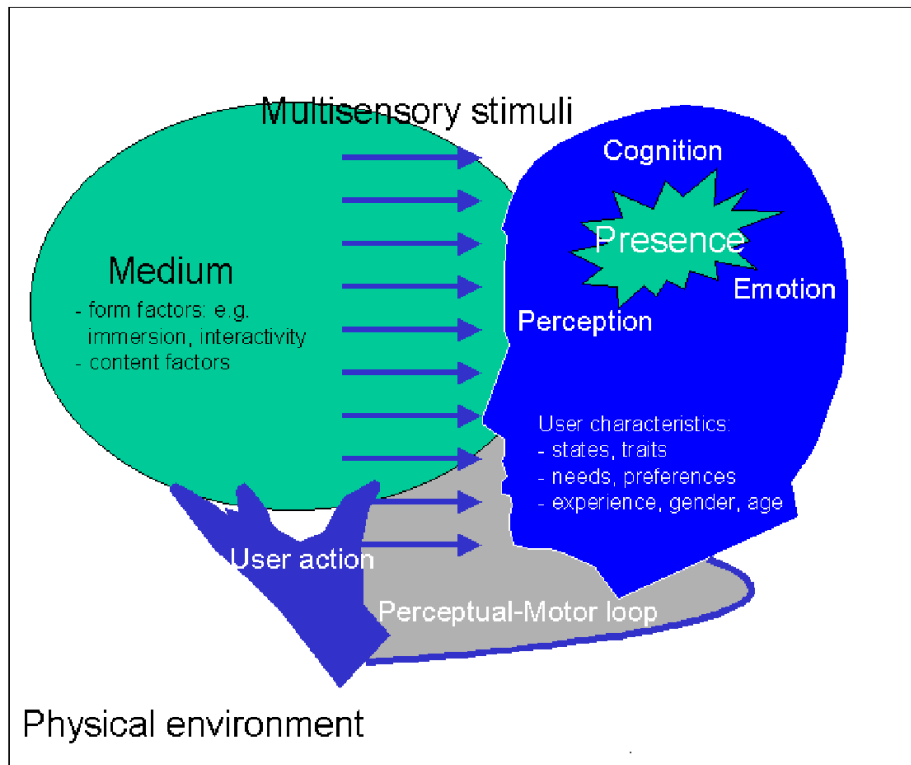


Figure 2.5. IJsselsteijn's Schematic Overview of Presence Experience (IJsselsteijn, 2004, p. 151)

the user's representation, the autonomy of the environment, social elements, the nature of the potential task or activity, as well as the meaningfulness of the content), and

- *user characteristics* including the user's perceptual, cognitive and motor abilities, prior experience, expectations, and a willingness to suspend disbelief, allocation of attentional resources, affective factors, age, and sex (IJsselsteijn et al., 2000).

A structural equation model combining the exogenous variables *perceived ease of use* and *attitude* towards the use of the technology demonstrated evidence of a good model fit ( $X^2/df$  ratio = 1.92; NFI = .97; NNFI = .98; CFI = .98; RMSEA = .07). By including these variables, Chow's study (see section 2.2.4.1) showed a variance explanation for presence of  $R^2 = .32$  (see Fig. 2.6). In the model, *attitude* showed a stronger predictive effect on presence than *perceived ease of use* (M. Chow, 2012). While the variance explanation is high for a two-factor model, it still indicates that there are several other factors influencing presence.

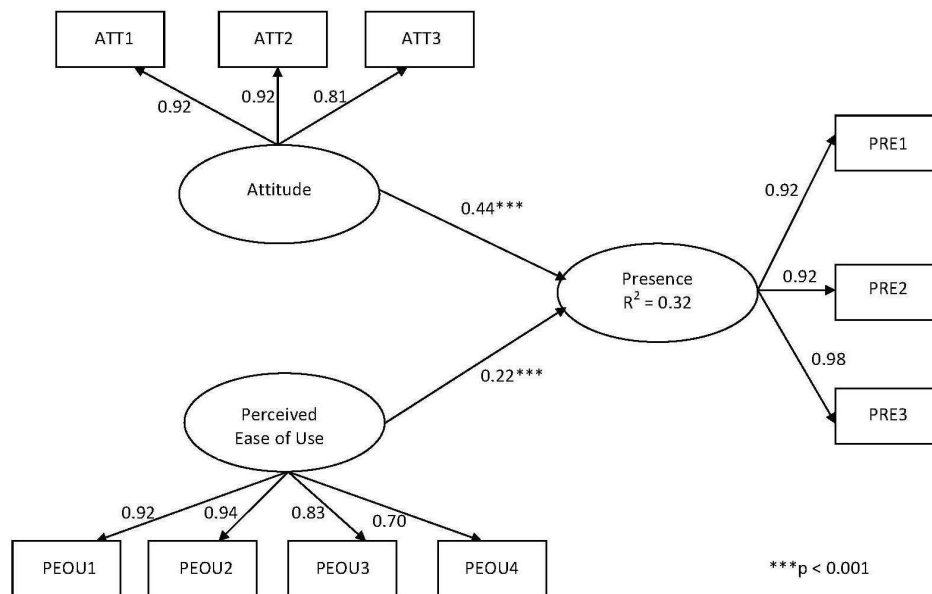


Figure 2.6. Model of Variables Predicting Presence (M. Chow, 2012, p. 86)

In the study of Lee et al. (2010, see section 2.2.4.1), the variance explanation for presence showed a value of  $R^2 = .42$ . As the structural model involved more factors (for the whole model, see chapter 3), model fits for the explanation of presence through VR features and usability were not reported. VR features seemed to be an antecedent to presence while usability was not (E. A.-L. Lee et al., 2010).

By extending Steuer's model of objective technological variables influencing (tele-) presence with the person-specific subjective variables, the conceptual model displayed in figure 2.7 can be used as a theoretical basis for educational research including presence. It can be assumed that the perception of physical, social, and self-presence is influenced by objective technological variables given through immersive hard- and software. Stimulus-driven characteristics of the used immersive material (i.e. vividness and interactivity) determine the level of immersion. Presence interacts with subjective variables like motivational, emotional, and cognitive factors. The resulting conceptual model for objective and subjective factors influencing presence is not thought of as being extensive (Dengel & Mägdefrau, 2019). It is important to add that more factors can influence presence or can be influenced by presence. This thesis focuses on the named factors as they have been identified to be crucial variables in terms of Immersive Learning as well (Dengel & Mägdefrau, 2018).

It has to be noted that there are other factors that are closely related to both constructs, like engagement, involvement, and interactivity, are important characteristics

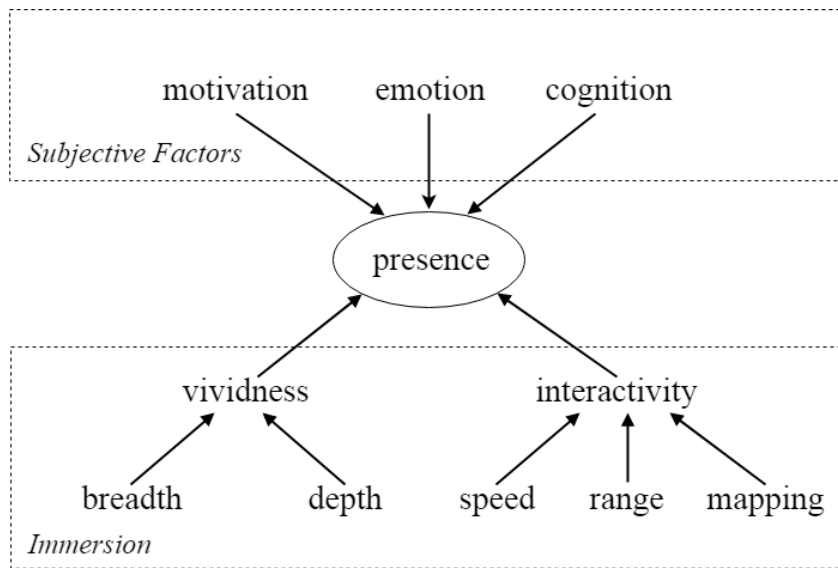


Figure 2.7. A Conceptual Model for Objective and Subjective Factors Influencing Presence (Dengel & Mägdefrau, 2019, p. 187)

for virtual experiences as well. These factors are not only important for describing VEs in general, but they are also crucial for explaining learning processes as well. While it is acknowledged that engagement, involvement, and interactivity influence learning processes in virtual environments, they are not unique to VEs but can also be found in real activities as well<sup>19</sup>. While their relevance is stressed here, this thesis focuses on immersion and presence as they are unique to virtual learning experiences in order to explore their effects on learning outcomes and their importance for the Immersive Learning process. For an overview of how these other factors contribute to learning in VEs, see Pirker, 2017.

<sup>19</sup>Presence can be assessed for real activities too (Usuh, Catena, Arman, & Slater, 2000), but still poses a unique feature of EVEs (Mikropoulos & Bellou, op. 2006)

**Summary 3: Presence**

Presence is a central subjective criterion of VR and can be described as the feeling of “being there” in terms of the perception of non-mediation. It seems to be merely an attention phenomenon and can oscillate between the physical, the virtual, and the imaginal world. As a *perceptual illusion of nonmediation*, various presence types can be distinguished into *physical presence*, *social presence*, and *self presence*. In order to assess presence in a non-intrusive, affordable, and quantifiable way, the use of post-test questionnaires seems to be the method of choice. Presence is influenced by the objective technological factor immersion as well as by several user characteristics like motivational, cognitive, and emotional factors.

## 2.3 A Three-Dimensional Taxonomy for Virtual Environments

In section 2.1, it has been acknowledged that the RV continuum as well as its extension to the three-dimensional classification of displays (Milgram et al., 1994) provide solid frameworks for categorizing the technical affordances of VR technologies. As this thesis aims towards investigating the use of VR for educational purposes, it might be beneficial to take into account the user’s perspective, by integrating the psychological factor presence<sup>20</sup> and the interactive capabilities of the used devices.

Zeltzer (1992), again from a technological perspective, identified three key components of a VE that go beyond the computing platform, the graphics engine and associated peripherals: simulated computational models of objects/processes, possibilities to modify the states of these models during the simulation, and communication channels through which the participants can experience/perceive the simulated events and processes through sensory modalities. By investigating these key components further, Zeltzer presents the *AIP-cube*, consisting of the factors *autonomy*, *interaction*, and *presence* as a “qualitative tool for describing, categorizing, comparing, and contrasting virtual environments, as well as more conventional computer animation and graphics simulation systems” (Zeltzer, 1992, p. 127). *Autonomy* describes the level to which a computational model is capable of acting and reacting to simulated events and stimuli. Hereby, a passive geometric data structure with no associated procedures would be categorized as the least autonomous model while a virtual actor capable of

<sup>20</sup>Milgram et al. did include the *Extent of Presence Metaphor* dimension in their framework. Still, it did only address sensational differences between the reality and the virtuality from a technological perspective, independently from the VE’s content.

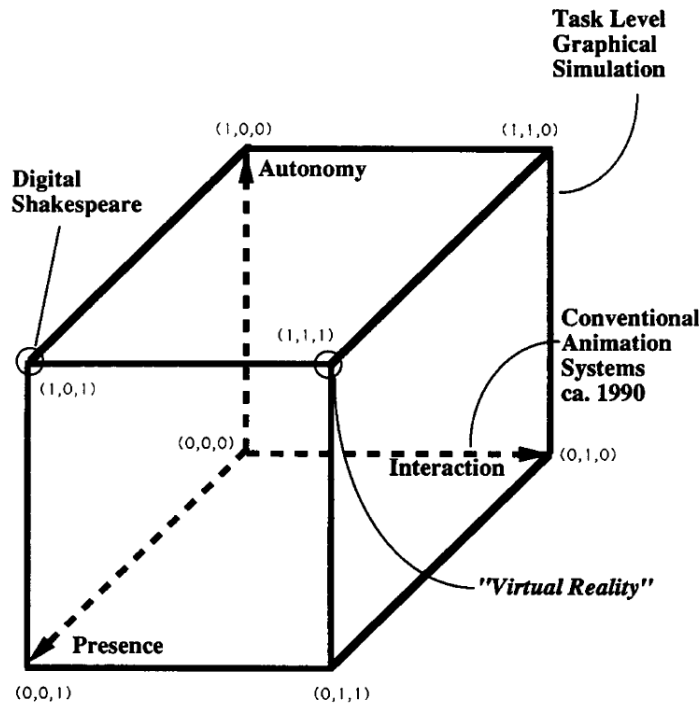


Figure 2.1. The AIP-cube (Zeltzer, 1992, p. 129)

reactive planning and knowledge-based behaviors would be contrasted as the other extreme. *Interaction* is a qualitative measure for the degree to which the model parameters can be accessed at runtime with the two extrema no interaction and, on the other side, comprehensive, realtime access to all model parameters. Zeltzer describes *presence* as the sense of being in/of the world that emerges from a bath of sensations delivered through immersion in terms of a very high bandwidth stream of sensory input. By combining the three axes *autonomy*, *interaction*, and *presence*, the deriving *AIP-Cube* defines a coordinate system (Fig. 2.1). Zeltzer (1992) states:

“At the origin  $(0,0,0)$  we have essentially the situation as obtained in the early 1960s—models with no autonomy, and systems with no interaction and no presence (i.e., batch processing of simple graphical models, with the results, portrayed on a pen plotter or perhaps output to a film recorder). In contrast, the corner  $(1,1,1)$  is our ‘grail’: fully autonomous agents and objects that act and react according to the state of the simulation, and that are equally responsive to the actions of the human participant(s). In addition, the sensory stimulation provided to the participant(s) in the virtual environment is indistinguishable from what would be expected in a physical setting” (p. 129).

It has to be noted that Zeltzer, in order to provide a qualitative measure for VEs, modeled the *presence* axis as a measure of the level of matching between the input and output channels of the machine and the human participant(s) (Zeltzer, 1992). Therefore, it does not describe the feeling of presence actually emerging within the user's mind but the capabilities of the VE to induce presence. As this axis addresses the environment as well as the used technology, it is different from the *Extent of Presence Metaphor* concept from Milgram et al. (1994) presented in section 2.1. It might be far-fetched to assume that the initial idea of the *presence* axis also included the affectional and motivational channels between the software and the user as these might moderate his or her feeling of presence. But still, Zeltzer's model provides a solid basis for not only comparing the used technology but the contents as well. Thus, the *AIP-cube* might be a good start for exploring the opportunities and affordances of using VR in education by bringing together the technological capabilities with the psychological response of the user's perception in terms of presence. Zeltzer's model and the conceptual model for objective and subjective factors influencing presence by Dengel and Mägdefrau (see section 2.2.5), both provide valuable insights into the technological perspective (including their psychological responses and correlates) on VR and will be used as basic frameworks for this thesis.





## Chapter 3

# Theoretical Groundwork: The Educational Framework for Immersive Learning (EFiL)

After concluding the technological perspective on VR, this chapter aims to connect this technological knowledge with established pedagogical theories and research. A combination of pedagogical and technological perspectives on Immersive Learning is used to provide a framework for the developmental and empirical work of the thesis.

In general, technology can contribute to education in different ways: Puentedura (2006) presents the Substitution, Augmentation, Modification, and Redefinition (SAMR) model as a four-level approach for the selection, use, and evaluation of technology in K-12 settings. Intended as a tool to describe and categorize K-12 teachers' uses of classroom technology, the model separates the levels *Substitution* and *Augmentation*, which enhance the learning processes as well as *Redefinition* and *Modification*, which work in a transformational manner. On the *Substitution* level, which represents the lowest level of *Enhancement*, technology acts as a direct tool substitute and does not provide any functional change compared to the real task (e.g. reading Shakespeare texts in online versions). Technology as *Augmentation* also acts as a direct tool substitute, but provides functional improvement (e.g. dictionaries, study guides, history sites linked to online text). Regarding *Modification*, technology allows a significant task redesign (textual, visual, and audio tools for constructing shared knowledge). In a task *Redefinition*, as the highest level of *Transformation*, the technology supports the creation of new tasks that were previously inconceivable (e.g. visualization tools of narrative and structural aspects of text) (Puentedura, 2006). The model has been criticized for not acknowledging aspects of the context and, therefore, its poor connection to research and teaching practice. Further, its

rigid structure "dismisses the complexity of teaching with technology by defining and organizing teachers' uses of technology in predefined ways" (Hamilton, Rosenberg, & Akcaoglu, 2016, p. 439). Still, the SAMR model provides a useful theoretical overview of how current and future technology can be used in the classroom. By doing so, it might be applicable to explain the use of immersive technology in education as well.

Research regarding the use of virtual and mixed reality technology in education has been around for a while now: Bricken (1990) named VR a paradigm shift in education in the early 90s. Several technical aspects of VR might change education (in terms of technology-enhanced teaching and learning) as we know it: Symbol processing becomes reality generation; viewing a monitor becomes wearing a computer; symbolic representation becomes experiential; the observer becomes a participant; an interface becomes an inclusion; physical experiences are now programmable; visual perception becomes multimodal in VR; a metaphor becomes a virtuality. Even though Bricken (1990) states that the generation of VR applications for education is easy ("Just substitute the virtual for the actual, then get rid of the constraints of the actual", p. 1), he is well aware of the fact that different factors might influence the learning process in an educational VR by separating the concepts *Programmable Participation* (creating/programming environments for a specific curriculum in which students can participate), *Natural Semantics* (creating natural VR input possibilities), *Constructivism* (explaining abstraction through interaction), *Cognitive Presence* (bringing the learner's perspective within the same context as the learning object) and *Multiple Participants* (social interaction in virtual worlds) (Bricken, 1990).

Due to the lack of VR applications at the time, Bricken's discussion remains at a theoretical level. But it becomes clear that learning experience in an EVE, which immerses the user into a virtual or mixed reality, is influenced by many different person-specific (subjective) and technological (objective) factors. As an EVE pursues one or more educational objectives (e.g. by using pedagogical metaphors) and provides experiences that users would otherwise not be able to experience in the physical world (Mikropoulos, 2006), it is helpful to investigate these subjective and objective factors. By doing so, it might be possible to explain how each factor contributes to the EVE's learning objectives and to the individual experiences.

In order to provide a solid basis for discussions and research from a pedagogical perspective in terms of Immersive Learning, a subsumption and classification of these factors is needed. First, this chapter takes a look into existing theoretical approaches to explain learning outcomes in immersive EVEs. It aims to provide a theoretical

localization of the factors that are crucial to the educational success (learning outcomes/performance) in immersive EVEs and that were disclosed through empirical research in a pedagogical framework for explaining scholastic learning in EVEs: the Educational Framework for Immersive Learning (EFiL). By taking a closer look at the theories behind the EFiL, a research model for explaining basic relationships between the factors is developed.

### 3.1 Learning in Educational Virtual Environments

“[V]irtual reality (VR) might be seen as the latest white knight in the arsenal of educational technologies. [...] Simulating a world in which the learner moves toward full participation should prove a powerful environment for understanding, and also help with the transfer of concepts to new contexts.” (Hedberg & Alexander, 1994, p. 214)

There has been extensive research about learning processes involving technology using varying terms like technology-enhanced learning, multimedia learning, etc. Although this thesis can only give a brief insight into this wide realm of research, this chapter tries to cover some of the main research findings in order to adapt them for Immersive Learning processes.

Through their research on the effectiveness of VR environments for educational purposes, Whitelock, Brna, and Holland (1996) found that the use of such environments can improve both performance and conceptual understanding on a specific range of tasks. VR systems can promote conceptual learning when students become engaged in sense-making activities. It seems to be necessary to understand which elements of a VR encourage students to become engaged in tasks in order to explain learning activities in EVEs.

In section 2.3, we proposed the AIP-cube (Zeltzer, 1992) as a basic framework for categorizing the technological features of VEs and their psychological effects on presence by distinguishing the dimensions *autonomy*, *interaction*, and *presence*. Whitelock et al. (1996) add an educational perspective to the framework as they note that the best balance of factors in order to enhance effective conceptual learning may not be the same constellation of factors for typical applications promoting task performance or for the acquisition of sensory-motor skills. Therefore, they extend Zeltzer’s model for conceptualising EVEs by separating the three properties *representational fidelity*, *immediacy of control*, and *presence*.

The *representational fidelity* of an EVE consists of further subdivisions:

- *Technical Fidelity*: technological variable, refers to realistic renderings in terms of colours, textures, motion, etc.,
- *Representational Familiarity*: degree to which the EVE is familiar to the user, and
- *Representational Reality*: level of possibility of the simulated EVE in reality (Whitelock et al., 1996).

The *immediacy of control* factor of an EVE relates to the medium's control channel. Perfect immediacy is illustrated through controls that are close to real-world movements and, therefore, feel natural for the user (Whitelock et al., 1996). For example, a command line input would show a low level of immediacy while a finger-tracked controller supports a high level of immediacy.

The *presence* factor in the framework from Whitelock et al. (1996) is considered to be a subjectively reported phenomenon<sup>1</sup>, but also as an objective measure. Whitelock et al. (1996) note that “[n]o agreed precise objective measures exist, but taking a simple view, we may go from a 2D Window on the World system with low objective presence to a fully immersive system with haptic features, a head-mounted display and 3D audio”, p. 6. Thus, their concept of *objective presence* is similar to the concept of immersion presented in section 2.1.

The model for the relation between VEs and conceptual learning was supposed to be a framework for investigating how *representational fidelity*, *immediacy of control*, and *presence* encourage high levels of task performance as well as how these factors foster a clear understanding of the EVEs conceptual content (Whitelock et al., 1996). The main hypotheses deriving from this framework are:

- High *presence* and high *immediacy of control* lead to better implicit learning.
- Low *immediacy of control* values are more likely to be associated with EVEs designed for explicit learning.
- Representational infidelities in terms of technical failings have a smaller effect on conceptual understanding than appropriately designed infidelities (Whitelock et al., 1996).

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<sup>1</sup>This perspective of Whitelock et al. differs significantly from Zeltzer's original model (see section 2.3). While the original model understood *presence* solely as the ability of the VE to induce presence. It also differs from the three-dimensional taxonomy of Milgram et al. presented in section 2.1.1, who see the *Extent of Presence Metaphor* as the ability of the technology to induce presence.

The main contribution of this framework for understanding Immersive Learning might be: 1) the idea of taking into account the person-specific feature presence rather than just focusing on the features of the technology and the environment, together with 2) the idea that different concepts of learning/different learning objectives might each have different requirements to the technology and the EVE.

Hedberg and Alexander (1994) took on a similar approach as described by White-lock et al.: By defining a continuum between interactive multimedia and VR, they distinguish the educational technology's factors *degree of immersion*, *fidelity of representation of information*, and *degree of learner participation*. They assume that the main operating dimension between interactive multimedia and VR might be "the disappearance of the traditional structured interface between the user and the computer" (Hedberg & Alexander, 1994, p. 215), rather than being only caused by the technological immersion or interactivity.

In terms of the factor *immersion*, Hedberg and Alexander (1994) distinguish between *physical immersion*, *psychological immersion*, and *motivational immersion*<sup>2</sup>. While *physical immersion* (e.g. data gloves, goggles, etc.) might be of great use when it comes to developing physical skills and dexterity, as well as for understanding relationships between cognitive models and their manipulations, *psychological immersion* refers to the "conceptual congruence between user actions and their understanding of the concepts embodied in the learning context" (Hedberg & Alexander, 1994, 217). *Motivational immersion* pays attention to challenging and involving learning environments that address the intrinsic motivation of the learner (Hedberg & Alexander, 1994).

The factor *fidelity of representation* has to be regarded critically: Hedberg and Alexander (1994) note that simple environments might be just as effective as complex environments and, in some cases, even more effective as it might be easier for a novice to focus on the important chunks of information. The interaction of *representation fidelity* with *immersion* has to be considered in order to determine the complexity of sensory input that is necessary to enhance learning outcomes.

*Active participation* by the learner in the learning context is also relevant, especially when discussed together with the interaction within the environment. In VR (where the interface disappears into the context), the learner always has to take an active role in the interaction (Hedberg & Alexander, 1994).

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<sup>2</sup>Here, again, it becomes clear that terminologies are not always used consistently. While White-lock, Brna, and Holland use the term *presence* to describe technical features to immerse the user as well as the emerging sense of being in the environment, Hedberg and Alexander use the term *immersion* in a similar manner.

With the inclusion of the psychological and motivational dimensions of immersion (in terms of what is described as presence in this thesis, see section 2.2), Hedberg and Alexander's (1994) framework integrates the learner even more, especially through claiming the user's active participation as an essential attribute of educational VRs. Beyond seeing the user as an individual, their model also asks for collaboration with peers, fostering conversations and integrating aspects of apprenticeship in a virtual community of practice. They further suggest investigating the interrelationships between the factors defining educational VRs (immersion, fidelity, and learner participation) in order to explore the potential of VR to offer superior learning experiences.

In their model of learning in 3-D VLEs, Dalgarno and Lee investigate these relationships by establishing learning affordances<sup>3</sup> of 3-D VEs. They see a big discrepancy between the educational sciences and the virtual world/games development research as they call current efforts in the field of developing 3-D VLEs "largely hit-and-miss, driven by intuition and 'common-sense' extrapolations rather than being solidly underpinned by research-informed models and frameworks" (Dalgarno & Lee, 2010, p. 20). By subsuming the models from Whitelock et al. and Hedberg and Alexander<sup>4</sup> and by following Slater's (2003) approach of seeing presence as subjective feeling of 'being there' and immersion as a quantifiable description of technology (see section 2.2), Dalgarno and Lee (2010) separate the objective characteristics of 3-D VLEs (in terms of immersion) from the subjective characteristics of the learner's experience (in terms of presence) that result from these VLE characteristics (Fig. 3.1).

In this context, immersion is understood as properties of a system or environment that are objective and measurable, relying on the technical capabilities of the used technology to render sensory stimuli. The immersion factor *representational fidelity* consists of the characteristics realistic display of environment, smooth display of view changes and object motion, consistency of object behavior, user representation, spatial audio, and kinaesthetic and tactile force feedback, whereas the factor *learner interaction* summarizes characteristics regarding embodied actions including view control, navigation, and object manipulation, embodied verbal and non-verbal communication, control of environment attributes and behavior, construction of objects and scripting of object behaviors.

Presence, in Dalgarno and Lee's (2010) approach, is context-dependent and emerges as the individual's subjective psychological response to the EVE. Similar to the con-

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<sup>3</sup>According to Gibson (1979), an affordance can be understood as a complementary offer between an environment or an object and an observer (in this case, the learner).

<sup>4</sup>Dalgarno and Lee (2010), too, note that Hedberg and Alexander use the term immersion similar to Whitelock et al.'s use of the term presence.

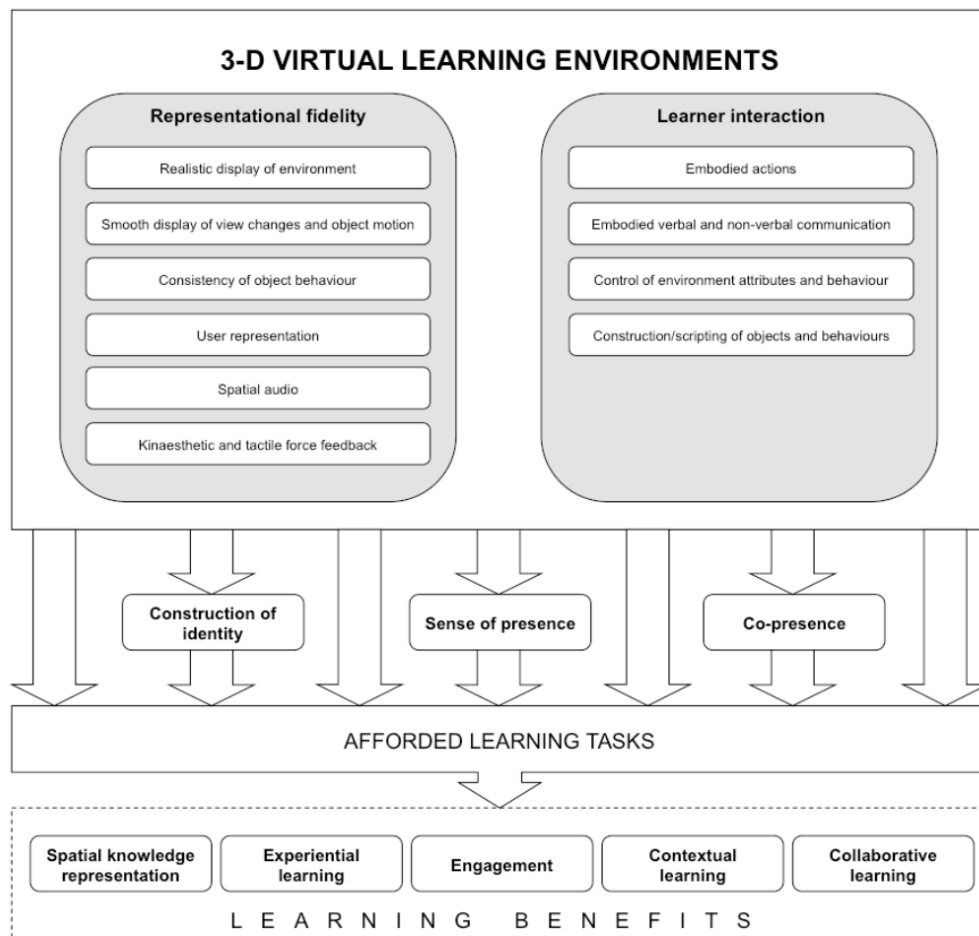


Figure 3.1. Elaborated Model of Learning in 3-D VLEs (Dalgarno & Lee, 2010, p. 19)

cepts of Biocca (1997) and Lee (2004), each distinguishing physical presence, social presence, and self-presence (both concepts were presented in section 2.2), Dalgarno and Lee separate the perception of ‘being there’ in terms of physical presence (naming it *sense of presence*) from the perception of ‘being there together’ (*co-presence*) and the process of identity construction in the VLE (*construction of identity*). They note that the *construction of identity* is a product of the aspects presence (physical and social), representation (visual appearance of the user’s avatar), and embodiment (inclusion of physical actions along with the corresponding social positioning of these actions).

Dalgarno and Lee (2010) argue that “it is essentially the fidelity of the representation along with the types of interactivity that are available within the environment that will lead to a high degree of immersion and consequently a strong sense of presence”, p.12. Thus, *representational fidelity* and *learner interaction* are unique

characteristics of 3D VLEs, whereas the characteristics of the learner's experience (*sense of presence, co-presence, and construction of identity*) are results from these characteristics (Dalgarno & Lee, 2010). These characteristics (of the VLE and of the learner's experience) lead to five affordances/learning benefits:

- *Spatial Knowledge Representation*: "3-D VLEs can be used to facilitate learning tasks that lead to the development of enhanced spatial knowledge representation of the explored domain." (Dalgarno & Lee, 2010, p. 15),
- *Experiential Learning*: "3-D VLEs can be used to facilitate experiential learning tasks that would be impractical or impossible to undertake in the real world." (Dalgarno & Lee, 2010, p. 16),
- *Engagement*: "3-D VLEs can be used to facilitate learning tasks that lead to increased intrinsic motivation and engagement." (Dalgarno & Lee, 2010, p. 17),
- *Contextual Learning*: "3-D VLEs can be used to facilitate learning tasks that lead to improved transfer of knowledge and skills to real situations through contextualisation of learning" (Dalgarno & Lee, 2010, p. 17), and
- *Collaborative Learning*: "3-D VLEs can be used to facilitate tasks that lead to richer and/or more effective collaborative learning than is possible with 2-D alternatives" (Dalgarno & Lee, 2010, p. 18).

According to Dalgarno and Lee (2010), their model can be used as a basic framework for investigating the relationships between the characteristics of the VLE, the characteristics of the learner's experience, and the learning benefits further. For example, one can hypothesize that a learning process for factual information within a 3-D VLE might lead to greater transfer to the corresponding real environment than within a 2-D VLE. The underlying assumption would be that the greater fidelity of a 3-D VLE in comparison to a 2-D VLE can lead to a greater sense of presence, and consequently, to a greater transfer. By addressing such research questions, "sound instructional design and pedagogy will prevail over the mere novelty of the technology" (Dalgarno & Lee, 2010, p. 20). Though the model primarily refers to so-called 'desktop VEs' that can be explored using standard personal computer (PC) hardware, the authors note that the discussion may also apply to immersive VEs.

Fowler (2015) criticizes that interpretations of Dalgarno and Lee's model might suggest that higher levels of representational fidelity and learner interaction will always lead to better learning. He argues that there are optimum levels for the VLE characteristics and that going beyond these levels might even decrease the learning



benefits. Also, for describing the learning experience as a whole, it might not be sufficient to just describe the technological affordances. A broader view has to include pedagogical requirements as well. According to Fowler (2015), a construct named *pedagogical immersion* emerges “from a complex interaction of different pedagogical variables, in other words, the pedagogical state that arises from learning within an immersive system” (p. 416). Therefore, the concept of immersion would bridge technological, psychological, and pedagogical experiences of learning in VLEs (Fowler, 2015). For extending the framework described by Dalgarno and Lee, Fowler uses the results from his former collaboration with Mayes (2011) that simplify the complexity of the psychologic process of learning by distinguishing the three fundamental stages *conceptualisation*, *construction*, and *dialogue*:

“First, a learner will encounter some kind of explanation or description that provides the opportunity for a new concept to be created. [...] Second, learners must, in order to deepen their understanding, start to explore, manipulate or ask questions, and this means they must perform some actions on, or with, the new concept in a way that will provide feedback. [...] Third, to acknowledge that all learning is in some way situated in a wider social context, [...] the learner may test their emerging understanding through some kind of interaction or discussion with others” (Fowler, 2015, p. 416).

In Fowler’s (2011) argumentation, the term immersion is used technologically, psychologically, and pedagogically. That is why he suggests the use of the terms *empathy* (the ability to identify and empathise with the concept), *reification* (the ability to make the concept more concrete), and *identification* (having a deep enough understanding of a concept that allows the learner to engage in thoughtful and structured arguments and discussions in order to identify with the subject matter). Fowler suggests to define specific learning objectives and learning activities. He, therefore, relates to Bloom’s (1968) taxonomy<sup>5</sup>. Figure 3.2 shows Fowler’s (2011) extension of Dalgarno and Lee’s model with the pedagogical input derived from Fowler and Mayes’ (2011) framework.

Fowler emphasizes the learner and his/her individual characteristics as an essential part of the learning process. Therefore, he does not only separate the learner’s

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<sup>5</sup>See section 3.3 for a summary of the taxonomy.

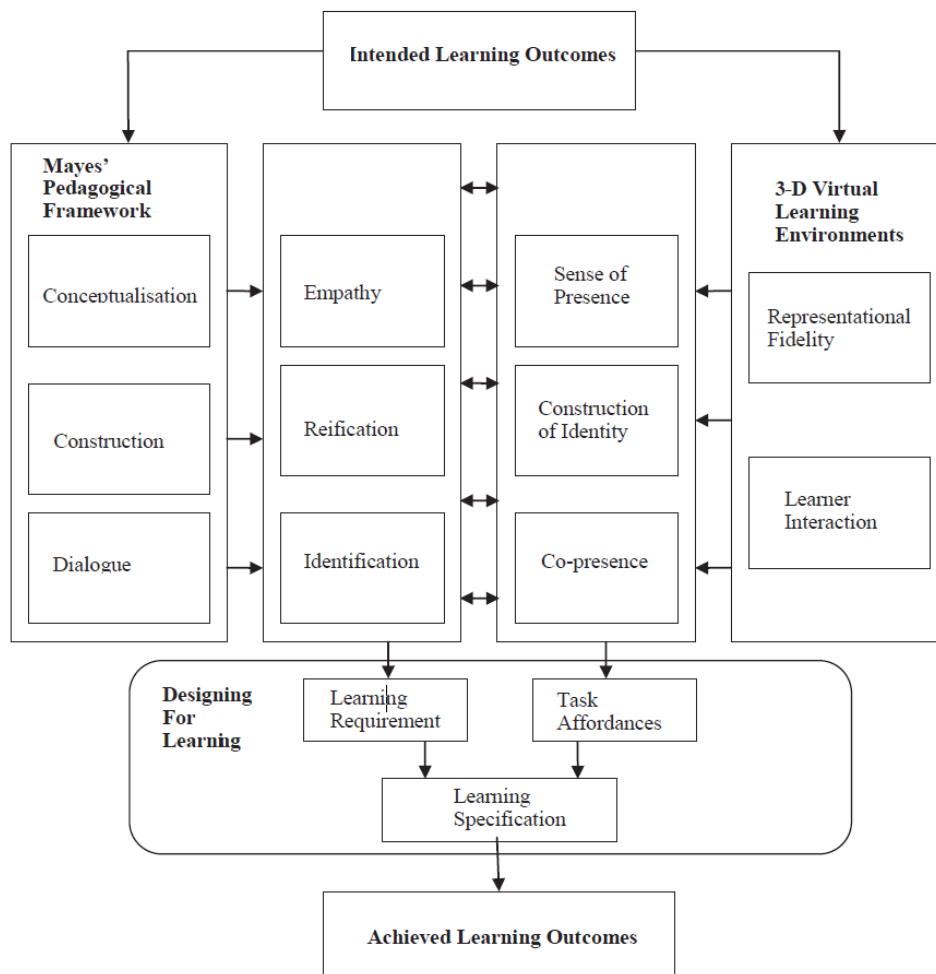


Figure 3.2. Fowler's Model of Learning in 3-D VLEs (Fowler, 2015, p. 418)

subjective response to the EVE, but also their internal learning processes, which correspond with their sense of presence. Also, Fowler emphasizes the importance of separating the intended learning outcomes from the learning requirements/activities and the achieved learning outcomes. This is crucial for understanding the process of Immersive Learning as different learners might achieve different learning outcomes in the same EVE, depending on their sense of presence as well as on their internal learning processes.

When defining learning outcomes in terms of intentional learning, a learner should establish “cognitive processes that have learning as a goal rather than an incidental outcome” (Bereiter & Scardamalia, 1989, p. 363). Even though all experience may have learning as an incidental outcome, cognitive activity related to intentional learning strives to fulfill defined learning goals (Bereiter & Scardamalia, 1989)

Slater names five reasons why VR may contribute to education in terms of intentional learning:

- *Transforming the Abstract to the Concrete*: “VR can transform abstractions into concrete perceptions and experiences” (Slater, 2017, p. 23);
- *Doing Rather Than Observing*: VR supports doing things actively rather than only observing through virtual ‘hands-on training’ (i.e. when it comes to problematic or dangerous activities);
- *Explore Manipulations of Reality*: In VRs, it is possible to change the parameters of reality (it is e.g. possible to model and experience theories of relativity);
- *Doing the Infeasible or Practically Impossible Becomes Practical*: Activities that may be infeasible in reality can be carried out by using VR technology (e.g. places unable to visit, which are important for learning geography, geology, or archeology, can be visited virtually using VR);
- *Go Beyond Reality to Positive Advantage*: “It is possible also to go quite beyond what is possible in reality in unexpected and radical ways” (Slater, 2017, p. 24).

With regards to Fowler’s (2015) framework, Slater emphasizes that it might be beneficial to foster the pedagogical aspects of VR. VR applications should address the pedagogical aspects “(i) how the VR experience advances explanation; (ii) deepening understanding, for example through exploration; (iii) taking account of the wider social context involved in learning” (Slater, 2017, p. 24). All named reasons, just as Fowler’s framework, rely essentially on the presence inducing aspects of VR (Slater, 2017). Thus, the sense of presence seems to play a crucial role in the success of all intentional learning purposes in EVEs.

In contrast to intentional learning, implicit learning is an unconscious process that yields abstract knowledge: “Implicit knowledge results from the induction of an abstract representation of the structure that the stimulus environment displays and this knowledge is acquired in the absence of conscious, reflective strategies to learn” (Reber, 1989, p. 219). With reference to the ‘Proteus Effect’<sup>6</sup>, Slater (2017) points out that in case of an embodiment with first-person-perspective and visuomotor synchrony (regardless of how much the avatar looks like our real body), the brain assumes that the virtual body is our own body. Such a change of body can come along with several

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<sup>6</sup>The ‘Proteus Effect’, as coined by Yee and Bailenson (2007), assumes that the behavior of an individual adapts to their digital self-representation. Yee and Bailenson conducted a study where participants were assigned to more or less attractive avatars in immersive VEs and another study where participants were assigned to shorter or taller avatars. The studies’ results show that self-representations have a strong impact on a user’s behavior in the immersive VEs.

attitudinal, behavioral, physiological, and cognitive changes. These non-conscious, complex ‘implicit’ changes (which are also not supposed to be the result of hypothesis testing or based on episodic memory) can also lead to implicit learning: A virtual avatar corresponding with the learning goal might enhance learning even above what can be contributed via intentional learning. Some examples would be: Learning how to be an orchestra conductor while being embodied as Leonard Bernstein, learning to sing an opera as Luciano Pavarotti, or learning ballet as the famous ballerina Natalia Osipova.

#### Summary 4: Learning in Educational Virtual Environments

Learning in EVEs can be regarded as an interactive process between the objective characteristics (immersion) of the technology/the supplied VE and the person-specific characteristics of the learner, including his or her sense of presence induced by the supplied VE. With regards to the learning objectives, the unique characteristics and affordances of EVEs can be used to initiate and enhance intentional or implicit learning processes.

## 3.2 Utilizing Supply-Use Frameworks for Immersive Learning

The idea of separating more distal, objective characteristics from person-specific characteristics of the learner when describing Immersive Learning processes has been pursued by Dengel and Mägdefrau (2018): The Educational Framework for Immersive Learning (EFiL) takes advantage of the fact that research in education has already made great advances in terms of explaining scholastic learning processes and learning outcomes. As the ‘new’ factors that characterize VEs, immersion and presence (as described in chapter 2), derive from either intrasubjective characteristics and perceptual processes (presence) or from distal influences like the decisions from a teaching person regarding the instructional medium (immersion), Dengel and Mägdefrau decided to localize these factors inside a supply-use-framework. This part of the thesis describes supply-use-frameworks as theoretical frameworks for explaining teaching and learning processes and outcomes and then presents the EFiL. A discussion about the limitations of the framework concludes the section.

### 3.2.1 Supply-Use-Models for the Explanation of Scholastic Learning

Supply-use frameworks follow the idea of gathering several factors that influence learning processes and outcomes together with the endeavor of exploring relations between these factors. Weinert (1989) states that scholastic learning cannot be explained by the observation of isolated variables as there are many context dependencies between educational characteristics. Isolated characteristics of teaching and learning do not contribute to a universal understanding/a general explanation of scholastic learning. Though investigations of isolated variables are necessary, stable relations between and predictive effects of criteria of successful learning and teaching cannot be explained through simplified process-product models. In order to enhance the empirical results of educational research, Weinert suggests the integration of multiple factors in the theoretical frameworks. Subjective expectations, perceptions, interpretations, cause explanations, and situative meanings mediate the observable characteristics of education from a person-centered approach (regarding students as well as teachers). Specific characteristics of education and specified criteria of effects depend on several context variables, meaning that these factors vary depending on psychological, social and pedagogical conditions. The requirements of the learner and the effectiveness of teaching characteristics are dependent on combinational and compensational effects as well. Weinert states that connecting learning styles and teaching characteristics can contribute to predicting and explaining student performances<sup>7</sup>.

A pedagogical-psychological perspective on scholastic learning is described by Shuell (2001) in a similar manner as Weinert: “Teachers and students work together in the rich psychological soup of a classroom, a soup comprised of cognitive, social, cultural, affective, emotional, motivational, and curricular factors” (p. 726). In recent years, pedagogical research has followed Weinert’s ideas and has replaced simple cause-and-effect relationships for the explanation of performance and learning outcomes with more comprehensive frameworks for scholastic teaching and learning, which integrate multiple educational actors and influences, as well as person-specific psychological factors. While we acknowledge that there are several frameworks describing the design of educational systems from a governmental and general perspective (e.g. Fend, 2008), this thesis focuses on individual learning processes in the classroom. Therefore, the factors that are inherent to or in direct relation to the

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<sup>7</sup>It has to be noted that Weinert does not suggest a certain constellation of characteristics to determine a ‘perfect’ setting for teaching and learning. Weinert rather supposes that constellations leading to successful outcomes and performances vary strongly.

learner and those that can be influenced by or inherent to the teacher are of particular interest for the explanation of learning activities in Immersive Learning research.

Supply-use-models for the explanation of scholastic learning describe the relations between such factors by separating three domains: supply structures, use of learning opportunities, and learning outcomes. The supply structures (teaching processes including instructional materials/media, teacher competencies, teacher characteristics, the context of the classroom) specify the learning opportunities; the use of these learning opportunities specifies the individual learning activities influenced by the individual requirements and the learning environment. Learning activities are separated into such external learning activities (in terms of visible behavior) and internal learning activities (regarding mental processes). Internal learning activities are thought of as decisive factors leading to learning outcomes. The internal learning activities (cognitive and meta-cognitive) are influenced by motivational-affective processes. The multi-criterial learning outcomes consisting of cognitive learning outcomes and non-cognitive aspects like attitudes and interests towards a subject or generic competencies can be explained through those internal learning activities (Seidel, 2015).

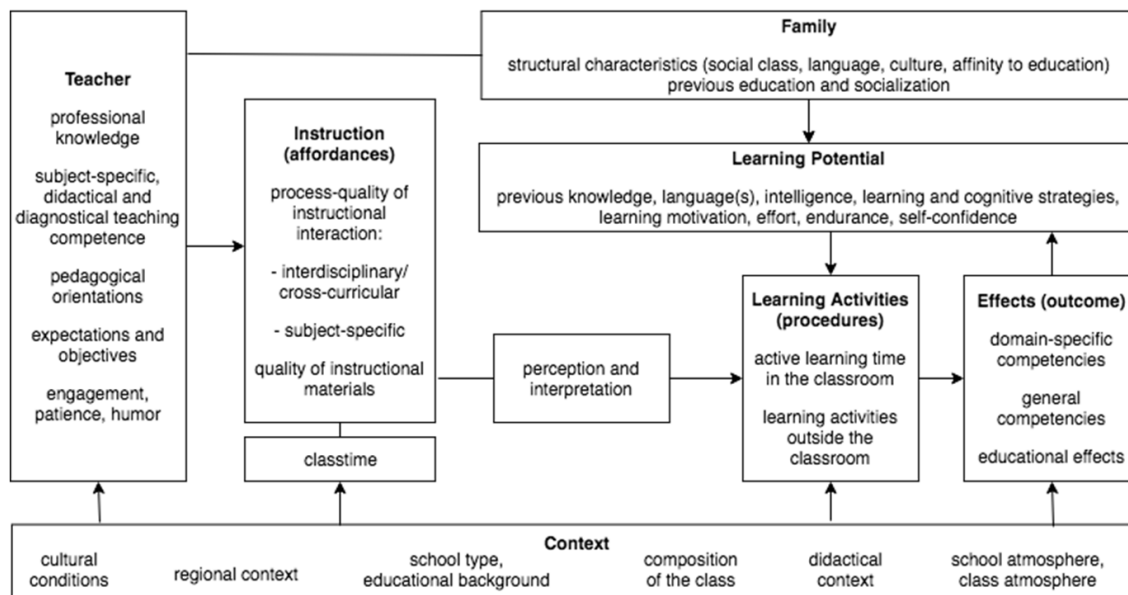


Figure 3.1. Helmke's Supply-use-model (Translated from German in Dengel & Mägdefrau, 2018, p. 612)

A popular supply-use-model has been developed by Helmke and Weinert (1997) and later refined by Helmke (2014) pursuing the approaches from Fend (1981) and

Weinert (1989). Helmke's (2014) framework (Fig. 3.1) provides an integrative approach for several criteria of teaching quality into a comprehensive model for the explanation of educational mechanisms and objectives. It consists of the characteristics of the teacher, the context(s), the instruction, the family of the learner, the individual learning potential, the mediation processes, the learning activities of the learner, and the effects. The supply of learning opportunities is described from a constructivist view of teaching and learning: There is no direct and inevitable way from the instructional supply to intended and non-intended learning effects as learning requires the active use by the learner. The perception and interpretation of the instructional supply, together with the interpretation of the expectations of the teacher influence the student's learning activities. Active use is influenced by the context(s) and the learning potential. Cognitive, motivational and volitional conditions influencing learning processes contribute to the factor learning potential. Previous knowledge, learning strategies, intelligence, performance anxiety, learning motivation, learning emotion, and the student's self-concept towards competencies are named as central influences of the learning potential. The learning potential and its factors are influenced by the student's family conditions and by effects caused by previous learning activities. The teacher<sup>8</sup>, the instruction, the learning activities, and the resulting effects are influenced by different contexts. The content of the instructional material as a central part of the instructional supply factor may vary in terms of its didactical quality and its stimulating effects (Helmke, 2014).

The integration of multiple determinants in a theoretical model can be beneficial for understanding learning processes and outcomes. Helmke's (2014) model is an appropriate framework for explaining scholastic learning from a person-centered perspective. Explanations for Immersive Learning can benefit from localizing the factors influencing learning processes in (immersive) EVEs, learning activities, and learning outcomes in supply-use-models as well. The next section describes the EFIL as localization of such factors in Helmke's supply-use-framework.

### 3.2.2 A Supply-Use-Model for the Explanation of Learning Outcomes in Educational Virtual Environments

Dengel and Mägdefrau (2018) point out that immersion and presence play a crucial role in the process of Immersive Learning together with person-specific motivational, cognitive, and emotional factors. They emphasize the causal relationship between

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<sup>8</sup>Helmke (2014) notes that the teacher can be another student as well. The framework thinks of the teacher as a provider of learning opportunities, which are described as the instructional supply.

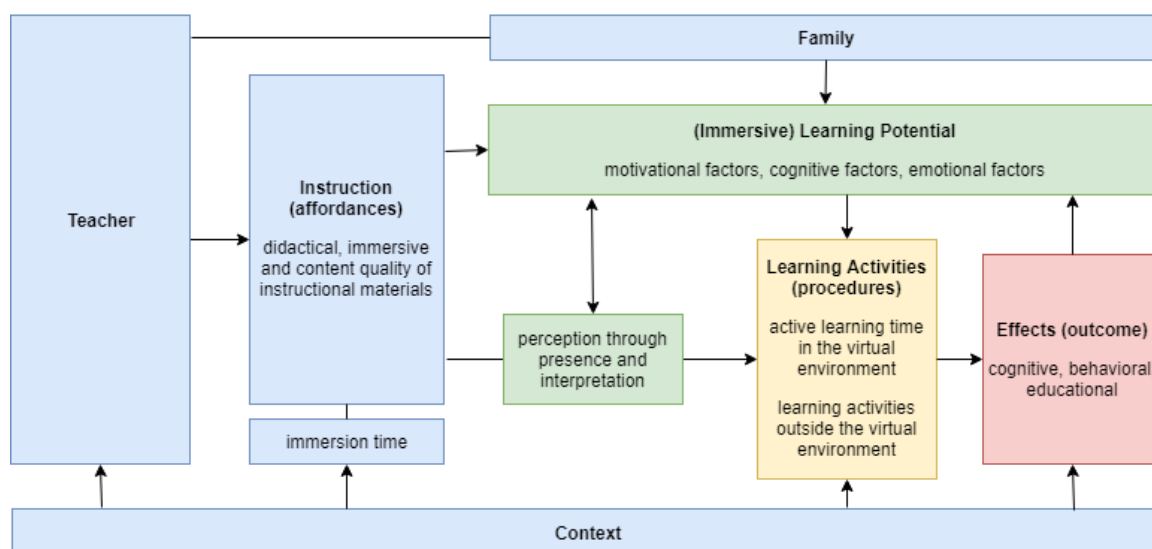
the level of immersion and presence, as well as the relationship between the level of immersion and (situational) motivational factors. An appropriate design of an immersive EVE can contribute to the effect of cognitive factors on learning activities. In addition, associations between individual motivational factors, emotional factors, and presence are pointed out, together with an association between individual cognitive factors and presence. Helmke's framework postulated effects of the motivational, cognitive, and emotional factors on learning outcomes, which could be verified in the several Immersive Learning studies. Thus, an educational framework for Immersive Learning (EFiL) derives from localizing the factors immersion and presence, which influence learning activities in Immersive Learning environments.

The EFiL (Fig. 3.2) follows Slater's definition of immersion (described in detail in section 2.1) as a quantifiable description of technology suppressing stimuli deriving the actual physical reality while simulating virtual stimuli of an artificial environment (including the technological hardware, like HMDs, laptops, books, etc., used to display educational content but also the software as educational content itself). Thus, immersion becomes part of the instructional supply providing learning material characterized by didactical, immersive, and content qualities. This Immersive Learning opportunity is provided by a teacher as an instructional medium with certain educational objectives, embedded in a certain setting. The EVE does not necessarily have to be programmed by him- or herself. The supplied content, as well as the available immersion time, are influenced by conditions deriving from several contexts (Dengel & Mägdefrau, 2018).

Presence, describing the subjective feeling of 'being there' (seen section 2.2), is a crucial factor of perception and interpretation in the EFiL. Dengel and Mägdefrau (2018) point out that the immersive content and the provided technology do not invoke learning activities directly; the learner has to perceive and interpret it first. The feeling of actually being in the immersive EVE, and hence, having a higher sense of presence, can contribute to learning activities and, therefore, to the learning outcomes/effects. The EFiL acknowledges that the feeling of presence can be influenced through the factors immersion, motivation, cognition, and emotion.

Motivational factors influence learning activities and presence as a person-specific characteristic of the learner. Thus, localizing motivation inside the (immersive) learning potential resembles Helmke's (2014) initial suggestion to see learning motivation as part of the learning potential. Following Vallerand's (2016) hierarchical model, the EFiL separates extrinsic motivation, intrinsic motivation, and amotivation, each





*Figure 3.2.* The Educational Framework for Immersive Learning (EFiL): A Localization of the Influencing Factors in Helmke's Supply-use-model, adapted from Dengel & Mägdefrau, 2018, p. 613 (blue: supply and contexts, green: person-specific characteristics, yellow: use, red: effects)

occurring as global, contextual or situational motivation. Global and contextual motivation, likewise as the academic motivation towards learning in general/learning in a specific subject, are stable individual characteristics. Changes regarding these types of motivation are only possible in the long term. Situational motivation refers to current activity of the learner (Vallerand et al., 2016); the provided immersive EVE, together with other situational characteristics of the individual (e.g. emotional factors) could influence situational motivation (Dengel & Mägdefrau, 2018).

The intra-individual cognitive characteristics and skills influencing learning activities are summarized as the factor cognition. Intelligence, learning strategies, learning types and the ability of reflective thinking are included in this factor. Cognition is localized in the (immersive) learning potential. This follows the original localization in Helmke's (2014) framework, where intelligence, previous knowledge, learning strategies, and self-concept towards competencies as cognitive determinants were assigned to the learning potential. The didactical and methodical design of the Immersive Learning content can influence the activation of cognitive factors. As the cognitive processes are closely related to perception processes, the cognitive characteristics might also contribute to the sense of presence (Dengel & Mägdefrau, 2018).

Dengel and Mägdefrau (2018) argue that the emotional factors contribute to the learning activities and to the feeling of presence. Academic emotions like positive

activating emotions (enjoyment, hope, pride), positive deactivating emotions (relief), negative activating emotions (anger, anxiety, shame), and negative deactivating emotions (hopelessness, boredom) towards the learning content are of particular importance as they might influence learning activities and presence (e.g. enjoyment and fear, see section 2.2.4.4). The emotional state of the learner can also be influenced by the content quality of the immersive material.

The intended and non-intended cognitive, behavioral and educational results deriving from the learning activities are considered to be the learning outcomes. The active learning time in the VE and time spent with learning activities outside the VE referring to the VE's content define the learning activities. Cognitive learning outcomes can involve different learning objectives like knowledge, comprehension, application, analysis, synthesis, and evaluation.

Dengel and Mägdefrau conclude the EFiL by giving a definition for Immersive Learning:

“[I]mmersive learning is defined as learning activities initiated by a mediated or medially enriched environment that evokes a sense of presence. Immersive Learning activities are determined through the (immersive) learning potential, the context of the learner, the perception of the didactical, immersive and content quality of the instructional materials at a certain level of presence and the interpretation of these materials. The factors influencing Immersive Learning are related among each other and (especially in scholastic environments) affected by the family and the teacher of the learner.” (Dengel & Mägdefrau, 2018, p. 614)

### 3.2.3 Discussion of the Framework

Localizing the subjective and objective factors that influence learning processes in EVEs in a more general supply-use-model provides new insights into possible relational, moderating, and predictive effects. By utilizing an established pedagogical framework to explain Immersive Learning processes, the EFiL presents a sound theoretical model ready to be used to formulate and test hypotheses. Many assumptions deriving from the EFiL resemble the findings from research presented in previous chapters of this thesis. It should be noted that the EFiL is a localization of factors determining Immersive Learning in an appropriate educational framework. Neither is it an adaption of Helmke's existing model (meaning that the rest of the model, like

the teacher and family characteristics, etc. still keep their importance), nor is it an object theory that can be evaluated easily (Dengel & Mägdefrau, 2018).

Dengel and Mägdefrau (2018) emphasize that research goes beyond the theories displayed in the EFiL and so does the Helmke framework. While the localization of the determining factors for Immersive Learning shows the adequacy of Helmke's (2014) supply-use-model for its application in terms of Immersive Learning processes, other educational perspectives on Immersive Learning are possible. A similar idea is pursued regarding the use of the theories: "Even though the theories underlying the EFiL have been pursued, adapted and revised by several researchers, they still pose the fundamentals of the research fields included in the framework and therefore built a solid basis for argumentation" (Dengel & Mägdefrau, 2018, p. 614).

More factors could influence presence and the (immersive) instructional medium, in terms of its hardware and software characteristics, could influence other intra-individual factors related to learning processes. Therefore, according to Dengel and Mägdefrau (2018), the framework is not supposed to be a final theory but rather a work-in-progress project open for contributions from Immersive Learning research.

In this thesis, the EFiL is used as a theoretical framework for developing a basic understanding about how the key characteristics of a VE, presence and immersion, contribute to learning outcomes. While the EFiL provides a general perspective on the relations between objective and subjective factors in terms of the overall theories, the following section gives a brief insight into the theoretical background of these factors in order to generate assumptions of the relationships among specific theoretical constructs and learning outcomes.

#### Summary 5: The Educational Framework for Immersive Learning

Immersive Learning describes learning activities that are initiated by mediated or medially enriched environments evoking presence. The activities for learning in educational virtual environments are influenced by numerous factors like the motivational traits of the learner, his/her cognitive abilities, his/her emotional state, and various contextual variables. The learner perceives (including his/her sense of presence) and interpretes the instructional materials (including the EVE and the technology used to display it) that are supplied by a teacher. The Educational Framework for Immersive Learning localizes the VE characteristics presence and immersion in Helmke's supply-use framework. The EFiL is a framework for the explanation of scholastic learning in EVEs rather than an object theory with explicit variables. To derive a research model from the EFiL, theoretical insights in the underlying theories are needed.

### 3.3 Factors Influencing Learning Outcomes in Educational Virtual Environments

The EFiL includes several general factors that were found to influence learning processes in EVEs. This part presents an insight into the theories disclosed to these influencing factors and how particular constructs of these theories are related to learning outcomes by subsuming theoretical and empirical approaches. This section tries to suggest a research model for the empirical part of this thesis on the basis of theoretical constructs and empirical findings.

First, it can be beneficial to discuss the desired result of an Immersive Learning process, the learning outcome. Many studies regarding EVEs seem to lack an understanding about what should be learned in terms of clear learning objectives/competencies, and whether the outcome should be e.g. memorizing the VE and its virtual objects, transferring concepts from metaphorical visualizations to a mental model or acquiring new skills/fostering competencies. A problem in the measurement of learning outcomes derives from the implicit construction of knowledge that happens inside of the learner's mind. As knowledge cannot be measured directly, common measurements of learning outcome observe the student's actions and performance that result from his/her learning activities (Alavi & Leidner, 2001).

Bloom (1968) proposed a classification of learning objectives separating the three domains

- *cognitive objectives*: recalling/recognizing knowledge and developing intellectual abilities/skills,
- *affective objectives*: changes in interest, attitudes, and values as well as the adequate adjustment and the development of appreciations, and
- *psychomotor outcomes*: objectives concerning the manipulative or motor-skill area.

Bloom (1968) presents a taxonomy for the *cognitive domain*, which currently poses the most relevant domain for Immersive Learning in terms of classroom settings. *Knowledge, comprehension, application, analysis, synthesis, and evaluation* were introduced as the six major classes of the *cognitive domain* (Fig. 3.1). While the objective *knowledge* primarily stresses the psychological processes of remembering, it may also involve relating and judging. The largest general class of intellectual abilities and skills related to the educational context is thought to be *comprehension*. *Comprehension* includes “those objectives, behaviors, or responses which represent an

understanding of the literal message contained in a communication” (Bloom, 1968, p. 89). For the *application* of knowledge for a presented problem, a solution process is required: The problem can either (1) immediately have familiar aspects guiding particular actions in which case it is sufficient for the student to restructure the elements of the problem so that the resemblance to the familiar model is completed, or (2) the problem is unfamiliar as it occurs, in which case the student would search for elements that are familiar to other problems so that a restructuring process can transfer the problem to a familiar context. After classifying the problem as familiar in type, an abstraction (e.g. a theory, a principle, an idea or a method) has to be selected that is suitable to the problem type. Using this abstraction process leads to the solution of the problem. The class *analysis* emphasizes the process of breaking down a given material into its constituent elements. Afterwards, relationships between the parts and the way in which they are organized have to be detected by the learner. The learner can also direct the *analysis* objective towards techniques and devices used to convey the meaning of a communication/establish its conclusion (Bloom, 1968). *Synthesis* is defined “as the putting together of elements and parts so as to form a whole” (Bloom, 1968, p. 162). When a new pattern or a new structure has to be constituted, the learner combines elements, parts, etc. from these patterns/structures. The category of *synthesis* includes learners’ most creative behaviors. *Evaluation*, as the last class from Bloom’s taxonomy, describes “the making of judgments about the value, for some purpose, of ideas, works, solutions, methods, material, etc. It involves the use of criteria as well as standards for appraising the extent to which particulars are accurate, effective, economical, or satisfying” (Bloom, 1968, p. 185).

While the presented taxonomy has been discussed widely and was revised later by Anderson and Krathwohl (2001), the basic categories of the taxonomy for the cognitive domain provide a simple method for describing the intentional learning outcomes of EVEs in terms of Immersive Learning processes. By using Bloom’s taxonomy for EVEs, learning objectives can be distinguished and explained which is why it was included in the EFiL (Dengel & Mägdefrau, 2018). This thesis focuses on cognitive objectives as these are the most common learning objectives in Computer Science Education. But it has to be noted that learning in immersive VEs is not limited to the cognitive domain: Some origins of VR usage derive from psychological research, using immersive media as treatments for various disorders (Rizzo et al., 2008; Wiederhold & Wiederhold, 2005). Slater (2017; 1998) conducted research focusing behavioral change under the aspects of implicit learning and embodiment. Moreover, psychomotor objectives can be found in industrial applications (Oliveira, Cao,

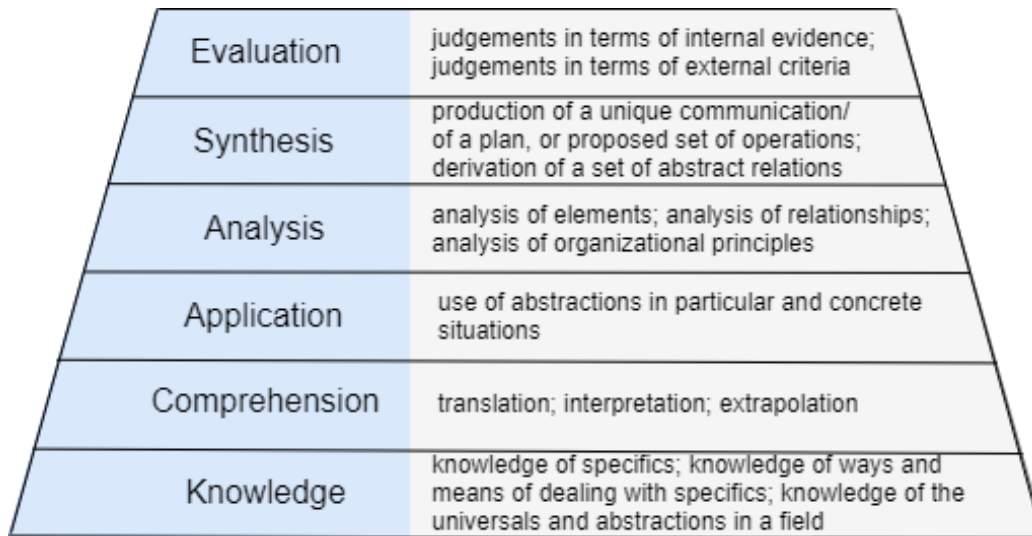


Figure 3.1. Taxonomy of Cognitive Learning Objectives (Bloom, 1968), Visualized

Hermida, & Martín-Rodríguez, 2007) and applications for physical activity training (Hoang, Reinoso, Vetere, & Tanin, 2016; Tan Chua et al., 2003). While this chapter explores the factors that influence cognitive learning outcomes, many of these factors might be applicable for other learning domains as well.

### 3.3.1 Presence

The effect of presence on learning outcomes has been investigated in several studies showing heterogeneous results. Bailey et al. (2012) investigated the effect of presence on cued and free recall. In a study with 33 college students, the participants were exposed to an immersive VE promoting pro-environmental messages related to water-saving principles. After the VR experience, the students had to fill out a physical presence questionnaire, a free recall test measuring how many of the fifteen environment principles were remembered correctly, and a cued recall sheet where the fifteen principles were given and the correct corresponding example that had been read to them previously had to be written down. While a weak negative effect of presence on free recall was not significant, a strong negative correlation ( $r = -.48, p < .01$ ) between presence and cued recall was found. Bailey et al. argue that attention-grabbing capabilities of immersive VRs might drain mental resources. Doing so, limited cognitive capacities could be the reason why a higher sense of presence might hinder learning activities. Another explanation could lie in physiological arousal deriving from the mediated experience as immersive VRs have the capability of providing sensory experiences inducing emotions. Excessive positive or negative feelings, which would

enhance a sense of presence, could interfere with memory. Individual differences concerning cognitive retrieval proficiency, cognitive control, and information processing but also personality and past experiences might be linked to presence and memory. Certain capabilities might be the reason why a person experiences a higher sense of presence while remembering information differently. The argumentation of Bailey et al. complements the results from section 2.2.4, where the factors emotion, motivation, and cognition were found to be antecedents to presence. While some manifestations of these factors might contribute to presence, they might weaken learning activities.

The study of Lin et al. (2002) reported a positive effect of presence on memory recall ( $r = 0.48$ ,  $p < .01$ ). Together with the results presented in section 3.3.5, positive relations were found in this study between memory recall and immersion, immersion and presence as well as between memory recall and presence. Lin et al. argue that in order to clarify the underlying model, more research is still needed.

Roy and Schlemminger (2014) could verify a better improvement in terms of language competence correlating with a higher sense of presence. 60 french students from a 10th grade were distributed into four groups of equal size and homogeneous competence level in German after filling out an initial language test (point of measurement T1). In the provided VE, the participants were asked to follow the German orders from a virtual supervisor. Their task in the virtual internship was to set up and decorate the sales area of a store. The groups were provided with a combination of different settings regarding immersion and interaction (low/high immersion, low/high interaction). A low level of immersion was realized using a presentation of the virtual store on a non-stereoscopic screen in a distance of 150 cm; a high level of immersion included the use of an HMD. Low interaction was realized through pressing buttons on a remote control in order to select and move objects in the virtual world; high interaction used infrared cameras in order to track the position of the remote control, visualizing an optical beam that could be used to select and place objects. After completing the task in the EVE, the participants filled out a presence questionnaire (T2), followed by a listening comprehension test (T3), similar to the initial language test. The listening comprehension test was, in a modified version, repeated two weeks after the VR experience (T4). T-Tests could not show significant differences regarding the presence scores between the two immersive settings and between the two interactive settings. Roy and Schlemminger found positive correlations that were significant or approaching significance between the presence scores and the language competence shown in the listening comprehension tests at T1 ( $r = .25$ ,  $p = .08$ ), T2 ( $r = .27$ ,  $p = .05$ ), and T4 ( $r = .36$ ,  $p < .01$ ). These results indicate that the strength of the

relationship between presence and learning activities might increase over time. Roy and Schlemminger state that the EVE induces a stronger cognitive and sensual inclusion of the user through presence, which might enhance cognitive activities related to listening comprehension. This might be a sound explanation for the results for T3 and T4, but the positive association between the results at T1 and presence (though not significant) cannot be explained. As the study did not investigate the predictive effects of presence on learning but rather correlations, this perspective indicates that the feeling of presence is strongly connected to cognitive activities, as shown in chapter 2.2.4.3, but without specifying its direction. This could indicate that students with higher cognitive capabilities might tend to feel more present as well, for example, due to a better ability to create a mental spatial model of the VE (see chapter 2.2.4.3 for this discussion). Another possible explanation would be that being familiar with the learning content (in terms of a better pre-test score) induces a higher sense of presence. This would make presence merely a side effect of the learning process as the learning activities are fostered not by presence but by the previous knowledge. Also, a connection between a more self-regulated form of motivation for the learning content and, thus, a higher tendency to try and solve the listening comprehension tasks, might introduce motivation as a mediator for learning activities and degrade presence to a side effect of self-regulated forms of motivation.

Presence was one of the main factors predicting learning outcomes ( $\beta = .20$ ,  $p < .001$ ) in the study of Lee et al. (2010) mentioned in section 2.2.4.1. Most divergences ( $R^2 = .97$ ) in learning outcomes, consisting of performance achievement, perceived learning effectiveness, and satisfaction could be explained through the subjective measures motivation, cognitive benefits, control & active learning, reflective thinking, and presence. The authors emphasize the predictive role of presence for learning outcomes with presence being predicted by VR features rather than usability: This indicates that immersive VR features (realism and control factors) lead to a higher level of presence. Higher presence, in turn, leads to better learning outcomes.

In conclusion, presence seems to be related to learning outcomes. Most existing studies analyze this relation in terms of a correlative association rather than a predictive effect. More factors seem to influence presence and learning outcomes. Therefore, one of the central questions for research in terms of Immersive Learning should ask whether the relation between presence and learning outcomes is merely a side effect of other factors influencing learning processes or if presence can predict learning outcomes as an individual, perceptual factor. To test this, the research model will include an assumed direct, predictive effect of presence on learning outcomes.



### 3.3.2 Cognitive Factors

Cognitive factors are probably the most important person-specific variables in learning processes. Hattie<sup>9</sup> (2008) names cognitive factors like Piagetian programs ( $d = 1.28$ ), prior achievement ( $d = .67$ ), concentration/persistence/engagement ( $d = .48$ ) as highly 'working' predictors of scholastic learning exceeding Hattie's hinge point<sup>10</sup> of  $d = .40$ , which is suggested to indicate working factors that make a visible difference to student learning. Piagetian programs are related to the student's development in terms of his/her Piagetian stage<sup>11</sup> and the resulting different capabilities and constraints to think. The student's school readiness (school-entry academic, attention, and socioemotional skills) predicts his/her achievement during the first years of school, measured in terms of school reading and math achievement (Duncan et al., 2007); high school achievements (in terms of the undergraduate grade point average) predict the success of a college/university degree (regarding the Graduate Record Examinations) (Kuncel, Hezlett, & Ones, 2001); performances in school significantly predict the success (income, job satisfaction, effectiveness ratings) in the adult life (Samson, Graue, Weinstein, & Walberg, 1984), and grades predict the performance in the professional life (Roth, BeVier, Switzer, & Schippmann, 1996). Even though concentration, persistence, and engagement seem to be a crucial key for scholastic success, Hattie (2008) notes that these factors do not guarantee a change in students' knowledge. Still, engaging in curricular activities (active participation in the classroom, etc.) seem to have a strong effect on performance (Kumar, 1991). Hattie and Hansford (1982) found a mean correlation of  $r = .51$  between intelligence and scholastic performance (with an effect size of  $d = 1.19$ )<sup>12</sup>.

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<sup>9</sup>John Hattie conducted a meta-analysis including many studies and other meta-analyses in order to determine the effect sizes of various factors on scholastic learning.

<sup>10</sup>An effect size of  $d = .40$  is also the average effect that can be expected from a year's schooling. Though the lower-grade students tend to show a higher gain while upper-grade students tend to show lower gains,  $d = .40$  can be regarded as growth per year on average (Hattie, 2008).

<sup>11</sup>Jean Piaget suggested several stages and substages for the development of cognitive functions: the *sensorimotor stage* (basic interaction with the world through perception-action cycles, first 18 months), the *preoperational stage* (semiotic function underlying children's ability to engage in activities like deferred imitation, pretend play, drawing, psychological functions based on mental images, and language, 2–7 years), the *concrete operational stage* (coordinated operations that are integrated into logical systems, emerging around 6–7 years), and the *formal operational stage* (ability of hypothetical-deductive thinking, emerging during adolescence) (Mueller & ten Eycke, 2015). More recent neo-Piagetian approaches build upon the ideas of Piaget, but define the complexity of the stages in accordance with the child's information processing system characteristics instead of focusing on logical properties (Morra, Gobbo, Marini, & Sheese, 2012).

<sup>12</sup>This effect was coined the "Matthäus-effect". The results indicate that gifted students benefit more from learning opportunities than students with lower intelligence (Hattie, 2008).

It can be assumed that such cognitive factors influence learning processes and outcomes in immersive and non-immersive VEs as well. The study Lee et al. (2010), see section 2.2.4.1, shows that learning outcomes can be predicted by cognitive factors such as cognitive benefits ( $\beta = .14$ ,  $p < .01$ ), control & active learning ( $\beta = .33$ ,  $p < .001$ ), and reflective thinking ( $\beta = .36$ ,  $p < .001$ ) (E. A.-L. Lee et al., 2010).

Such cognitive benefits refer to better memorization, to a better understanding, and to a better application. They contribute to an overall view of learning contents in VR (Antonietti, Rasi, Imperio, & Sacco, 2000). These factors can be addressed through VR through interactive and dynamic visualizations by enabling students to adapt to a presentation's pace and sequence to their own cognitive needs and skills. This, in turn, could lead to better comprehension and assimilation of the contents learned (Schwan & Riempp, 2004).

The psychological state control & active learning is experienced as a consequence of the individual focusing his/her attention to a coherent set of activities and stimuli, which are somehow related (Schuemie, van der Straaten, Krijn, & van der Mast, 2001). In terms of computer-based instructional delivery systems, Williams (1996) names the capability of the systems to deliver individualized lessons as a huge advantage. This can evoke learner control as the learner is able to control the 'flow' or 'path' of the provided learning materials. This also leads to the active involvement of the learner in the learning process resulting in higher feelings towards of the learner's competency and self-determination (see chapter 3.3.3), as well as a higher interest in learning (Lepper, 1985).

According to Dewey (1997), reflective thinking can be defined as the "active, persistent, and careful consideration of any belief or supposed form of knowledge in the light of the ground that supports it and the conclusions to which it tends" (p. 9). This process of thought is needed for resolving cognitive discrepancies evoking from the new perspectives that the learner is confronted with his/her previous knowledge/previous perspectives (Dewey, 1997). It is possible to see this form of puzzlement as a catalyst for meaning-making: "By reflecting on the puzzling experience, learners integrate new experiences with their prior knowledge, or they establish goals for what they need to learn in order to make sense out of what they observe" (Jonassen, Peck, & Wilson, 1999, p. 9). For learning objectives that are closely aligned to tasks in the following assessment, reflective thinking is a predictor of learning outcomes (Phan, 2007).

Cognitive factors are crucial for all learning processes and activities. Immersive Learning seems to benefit from cognitive factors in multiple ways: (1) They enhance presence (see chapter 2.2.4.3) and (2) learning outcomes. Moreover, (3) cognitive

factors can be affected by providing EVEs that support instructional decisions and active learning. The research model integrates cognitive abilities as predictors of presence and of learning outcomes. This means that the selected cognitive factors do include previous performances in order to measure overall cognitive abilities<sup>13</sup> rather than current cognitive processes. The effect of immersion on cognitive processes will not be modeled in the research model due to difficulties in measuring them while being in a VE.

### 3.3.3 Motivational Factors

Motivation is one of the most important predictors of scholastic learning: Hattie's (2008) meta-analysis assigned motivation an average effect size of  $d = .48$ , exceeding Hattie's 'hinge-point' of  $d = .40$ . For an appropriate localization in the learning process, a theory of motivation that can be related to Immersive Learning is required.

There are many different theories of motivation, for example, achievement theories (Dweck, 1986), expectancy-value theories (Eccles et al., 1983), self-determination theories (Deci & Ryan, 1985), volitional theories (Heckhausen & Gollwitzer, 1987), etc. As most studies in terms of Immersive Learning dealing with motivational constructs tend to refer to Deci & Ryan's self-determination theory (see e.g. E. A.-L. Lee et al., 2010; Pirker, 2017), it seems appropriate to introduce this theory briefly.

Starting from a simple idea, motivation can be seen as the underlying "why" of behavior. Following this concept, Deci and Ryan developed the self-determination theory (SDT). The SDT sums up five sub-theories:

- *Basic Needs Theory*: The fulfillment of physiological and psychological needs conduces toward health and well-being while a lack of satisfaction contributes to pathology and ill-being. In order to experience an ongoing sense of integrity and well-being, the basic needs for competence, autonomy, and relatedness must be satisfied (R. Ryan & Deci, 2000).
- *Organismic Integration Theory*: Extrinsic motivation depends on the level to which the motivation emanates from the self. This also depends on the experienced level of self-regulation of the behavior. Through internalizing regulations (assimilating them to the self), people experience greater autonomy in their behavior (R. Ryan & Deci, 2000).

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<sup>13</sup>Of course, an adequate way to measure cognitive abilities would be to measure all the different components like intelligence, learning strategies, etc. on their own. As this is a very elaborate approach for assessing a variable displaying cognitive abilities (and as this factor is not the focus of this thesis), this simplified method is chosen.

- *Cognitive Evaluation Theory*: Intrinsic motivation can be affected by any event that affects people's feelings and perceptions of self-determination or of competence. Any event has a controlling aspect (relating to people's experience of self-determination) and an informational aspect (implying or assuring competence/incompetence). The event is then either informational, controlling, or noncontingent in terms of being not reliably or predictably attainable (R. M. Ryan, Vallerand, & Deci, 1984).
- *Causality Orientations Theory*: An internal perceived locus of causality refers to the orientation of a person towards the environment, which can be autonomous, controlled, and impersonal. While autonomous orientations result from the satisfaction of the basic needs, strongly controlled orientations are linked to internal and external contingencies, which regulate the behavior. Impersonal orientations result from lacking satisfaction of the three basic needs (Deci & Ryan, 1985).
- *Goal Contents Theory*: Basic needs can either be extrinsic goals (e.g. wealth, reputation) or intrinsic goals (e.g. personal growth). Though the way specific goals add to well-being can vary across cultures, the relation between the satisfaction of the basic need and well-being is invariant (R. Ryan & Deci, 2000).

With regards to the organismic integration theory, behavior can be intrinsically motivated, extrinsically motivated, or amotivated (Deci & Ryan, 1985). According to Ryan and Deci (2000), intrinsic motivation might reflect the positive potential of human nature better than any other phenomenon. It "refers to the fact of doing an activity for itself, and the pleasure and satisfaction derived from participation" (Vallerand et al., 2016, p. 1004). Vallerand et al. (2016) propose a tripartite taxonomy that separates the construct of intrinsic motivation into

- *intrinsic motivation to know*: gaining pleasure and satisfaction through learning, exploring, or trying to understand something new,
- *intrinsic motivation toward accomplishments*: gaining pleasure and satisfaction through attempting to accomplish or create something, and
- *intrinsic motivation to experience stimulation*: gaining pleasure and satisfaction through experiencing stimulating sensations.

Extrinsic motivation "refers to the performance of an activity in order to attain some separable outcome" (R. Ryan & Deci, 2000, p. 71). Ryan and Deci (2000) state that extrinsic motivation contrasts intrinsic motivation but does not necessarily include only invariantly non-autonomous behaviors. The self-determination continuum

describes three types of extrinsic motivation: external regulated behavior, where external means like rewards and constraints motivate the person; introjected regulation, where internalization of past external contingencies are internalized by the person; and identified behavior, where extrinsic motives are perceived as chosen by oneself. In the motivational state of amotivation, the individual does not perceive contingencies between outcomes and actions (Vallerand et al., 2016).

Motivation can occur in the form of global, contextual and situational motivation. Global and contextual motivation (e.g. in terms of an academic motivation towards learning in general/in a particular subject), can be considered as being relatively stable characteristics of the learner, which can only be changed over time. In contrast, situational motivation refers to the learner's current activity (Vallerand et al., 2016). Hence, it can be influenced e.g. through the supplied hardware/software or through other situational characteristics of the learner and of the learning environment.

Bartle (1996) investigated different player types in multi-user dungeon (MUD) games. Among questions on liking and disliking certain aspects of these games, it is the underlying why of playing MUDs that separates different player types. In a four-field taxonomy, Bartle distinguishes between

- *Achievers*: Achievers try to accomplish game-related goals (gaining levels, collecting treasures, killing monsters built into the VE).
- *Explorers*: Their primary goal is to find out as much as possible about the VE; this includes mapping the game's topology (the MUD's breadth) and experimenting with its physics (the MUD's depth).
- *Socializers*: These players use the game's communication tools and embrace the role-playing character of the game through interaction with fellow players.
- *Killers*: Killers try to impose themselves on others, e.g. through attacking other players and causing distress.

On the one side, the sources of players' interests can emphasize either other players or the world. On the other side, they can emphasize either acting with somebody/something or interacting with somebody/something. Figure 3.2 shows the allocations of these interests to the different player types. Bartle (1996) notes that these types cross over and, depending on their mood and current playing style, players can drift between all four, but many players have one primary style/one main reason why they play a game.

In terms of Immersive Learning environments, Pirker identified player motivation as a central criterion for designing VLEs (Pirker, 2017). On the basis of Bartle's

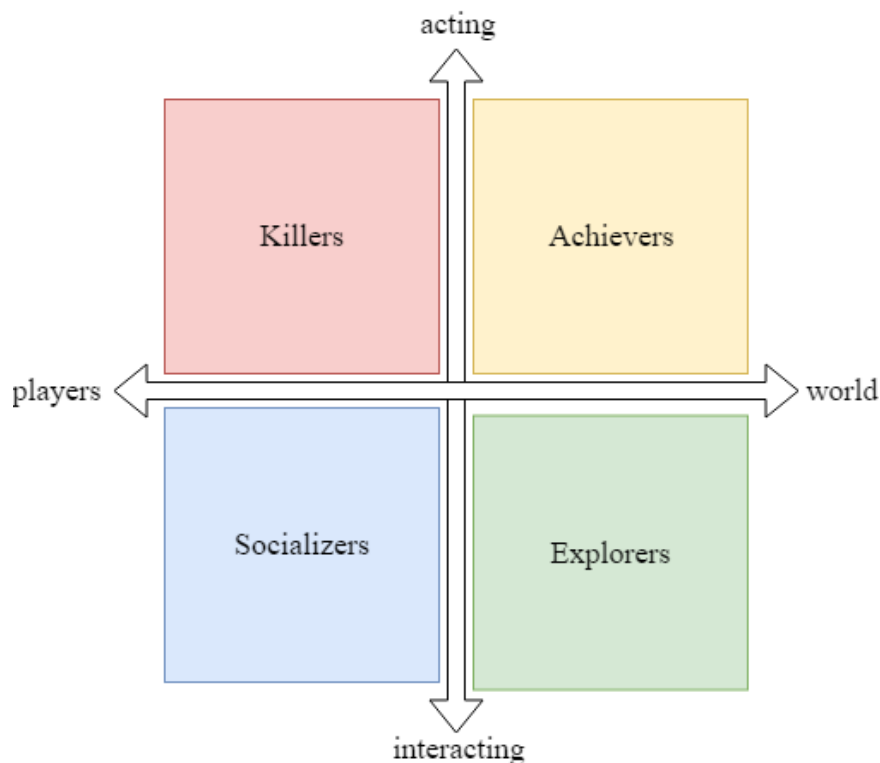


Figure 3.2. Bartle’s Distinction of Player Types (Bartle, 1996, p. 6)

player type distinction, the Player Type Design was suggested in order to meet extrinsic and intrinsic motivational objectives regarding different types of players and learners. Engagement and immersion<sup>14</sup> were included in a conceptual model for creating motivational environments as central factors influencing learning processes in EVEs. Qualitative and quantitative evaluations of the Maroon Room-Scale VR and Maroon Mobile VR software, two versions of an immersive physics laboratory, could show that technological settings with a higher level of immersion are capable of meeting motivational objectives better than settings with a lower level of immersion do. More immersive settings may enhance presence and learning outcomes as well (Pirker, 2017).

Using interactive and immersive EVEs can affect intrinsic motivation and attention, as stressed by Dede: “Discovering new capabilities to shape one’s environment is highly motivating and sharply focuses attention” (Dede, 1995, p. 51). The study from Lee et al. (2010, see section 2.2.4.1) indicates that motivation might be a relevant factor ( $r = .16, p < .01$ ) that influences learning outcomes in EVEs. Motivation

<sup>14</sup>Pirker sees immersion as a subjective criterion that includes presence.

could be explained ( $R^2 = .79$ ) through VR features<sup>15</sup> ( $\beta = .22, p < .05$ ) and perceived usability ( $\beta = .71, p < .001$ ).

Motivation seems to influence Immersive Learning processes in two ways: Motivation can influence learning activities through intrinsic motivation, several forms of extrinsic motivation and amotivation towards the learning content. As motivation leads to behaviors related to learning processes, it can be assumed that contextual motivation towards learning is related to previous scholastic performance as well as to learning outcomes. That is why highly self-regulated motivational constructs like intrinsic motivation and identified motivation can be positively related to scholastic performance and learning outcomes while less self-regulated motivations like external regulation and introjected motivation might be related negatively to scholastic performance and learning outcomes. Secondly, the particular design of the EVE can meet different motivational objectives of the player/learner that, in turn, affect presence. Both occurrences of motivation (global/contextual motivation related to scholastic performance and situational motivation related to the current activity) would be interesting to investigate further. In order to include the most stable person-specific characteristics, the contextual motivation to learn the specific content of the EVE will be included in the research model.

### 3.3.4 Emotional Factors

Educational research on learning activities primarily focused on cognitive, motivational, and behavioral constructs for many years while neglecting the crucial role of emotions in learning processes. In recent years, investigations on how learning outcomes are influenced by academic emotions have been fostered (Pekrun & Linnenbrink-Garcia, 2012). According to the control-value theory of emotions, which assumes a connection between the learner's emotions and his/her achievement motives, activities, and outcomes, the individual achievement emotions<sup>16</sup> of a learner have the potential to shape the key learning processes (Pekrun et al., 2002). An achievement emotion describes an emotion that is directly tied to achievement activities or achievement outcomes. Achievement emotions, in general, can be grouped

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<sup>15</sup>Note that Lee et al. did not control for a mediating effect of presence. Such an effect could be assumed as explained in chapter 2.2.4.2.

<sup>16</sup>Pekrun, Goetz, Titz, and Perry (2002) also coined the term 'academic emotions'. In this thesis, the terms academic emotions and achievement emotions are used interchangeably (meaning that academic emotions relate to outcomes or activities rather than including emotions experienced in academic social contexts like the classroom, which are unrelated to the contents of the learning process).

according to their *object focus*, which can lie either on an outcome or on an activity, according to their *valence* in terms of being pleasant (positive emotions) or unpleasant (negative emotions), and according to their degree of *activation*, which can be either activating or deactivating. Following these distinctions, Pekrun et al. (2014) introduced a three-dimensional taxonomy of achievement emotions (Tab. 3.1). While *positive academic emotions* like enjoyment and pride tend to have positive effects on learning achievement (Villavicencio & Bernardo, 2013), *negative academic emotions* (e.g. boredom) lead to lower levels of learning outcomes (Pekrun et al., 2014). Different emotions contribute to learning processes differently (not all positive emotions enhance learning processes and not all negative emotions hamper learning processes) as they can be either *activating* or *deactivating*. Regarding this, Pekrun (2000) classified academic emotions into *positive activating emotions* (enjoyment, hope, pride), *positive deactivating emotions* (relief), *negative activating emotions* (anger, anxiety, shame), and *negative deactivating emotions* (hopelessness, boredom).

Table 3.1

*Three-Dimensional Taxonomy of Achievement Emotions (Pekrun et al., 2007, p. 16)*

Object Focus	Positive <sup>a</sup>		Negative <sup>b</sup>	
	Activating	Deactivating	Activating	Deactivating
<i>Activity Focus</i>	Enjoyment	Relaxation	Anger Frustration	Boredom
<i>Outcome Focus</i>	Joy Hope Pride Gratitude	Contentment Relief	Anxiety Shame Anger	Sadness Disappointment Hopelessness

<sup>a</sup>Positive, pleasant emotion; <sup>b</sup>Negative, unpleasant emotion.

On the basis of this taxonomy, Pekrun et al. (2007) developed the control-value theory of emotions (Fig. 3.3), which focuses on the arousal of achievement emotions. The theory assumes that appraisals of current activities, past outcomes and approximated future outcomes have a great influence on the arousal of achievement emotions (even though more distal individual antecedents as well as determinants like classroom interaction, social environments, and socio-historical context affect these



appraisals as well). In particular, specific achievement emotions are induced by the feeling of being in or out of control (*control appraisal*) of achievement activities and outcomes that show subjective importance (*value appraisal*) to the individual. The achievement emotions resulting from these appraisal processes can be distinguished into

- *prospective outcome emotions*: emotions related to expected positively valued success or expected negatively valued failure,
- *retrospective outcome emotions*: emotions following successes and failures of subjective importance, which are perceived as subjectively controlled, and
- *activity emotions*: emotions related to perceived controllability and value of an activity.

These emotions can be influenced by genetic dispositions and physiologically bound temperament. According to Pekrun et al. (2007), they do not directly affect achievement as the effect is mediated through *cognitive resources*, *motivation to learn*, *learning strategies*, and *self-regulation of learning*. The resulting achievement is influenced by intelligence and competencies. In turn, the processes of learning, as well as the achievement outcomes, act back on the individual's emotions, appraisals, and on the environment inside and outside of the classroom. Doing so, implications, antecedents, emotions, and the effects deriving from emotions are thought to be related in a process of reciprocal causation over time. The control-value theory supposes that the design of learning and social environments influences the quality of the instruction; appraisal-oriented regulation through cognitive treatment influence the *control* and *value* appraisals; emotion-oriented regulation through emotion-oriented treatment can contribute to relevant achievement emotions; cognitive factors can be influenced by problem-oriented regulation and competence training.

It has to be noted that an approach from Ganotice Jr, Datu, and King (2016) argues that combinations of emotions may lead to distinct outcomes than only investigating singular emotions. Therefore, they extend the variable-centered approaches described above and propose a person-centered approach in order to investigate relations between academic emotion profiles (constellations of emotions) and academic outcomes. The academic emotions were used to investigate the effects of different academic emotion profiles on students' learning outcomes in Maths (in terms of the previous grades) and on their engagement (university intention, school valuing, the intention to leave school, and affection towards school). Intercorrelations between most of the factors and their variables were found. A cluster analysis could show that

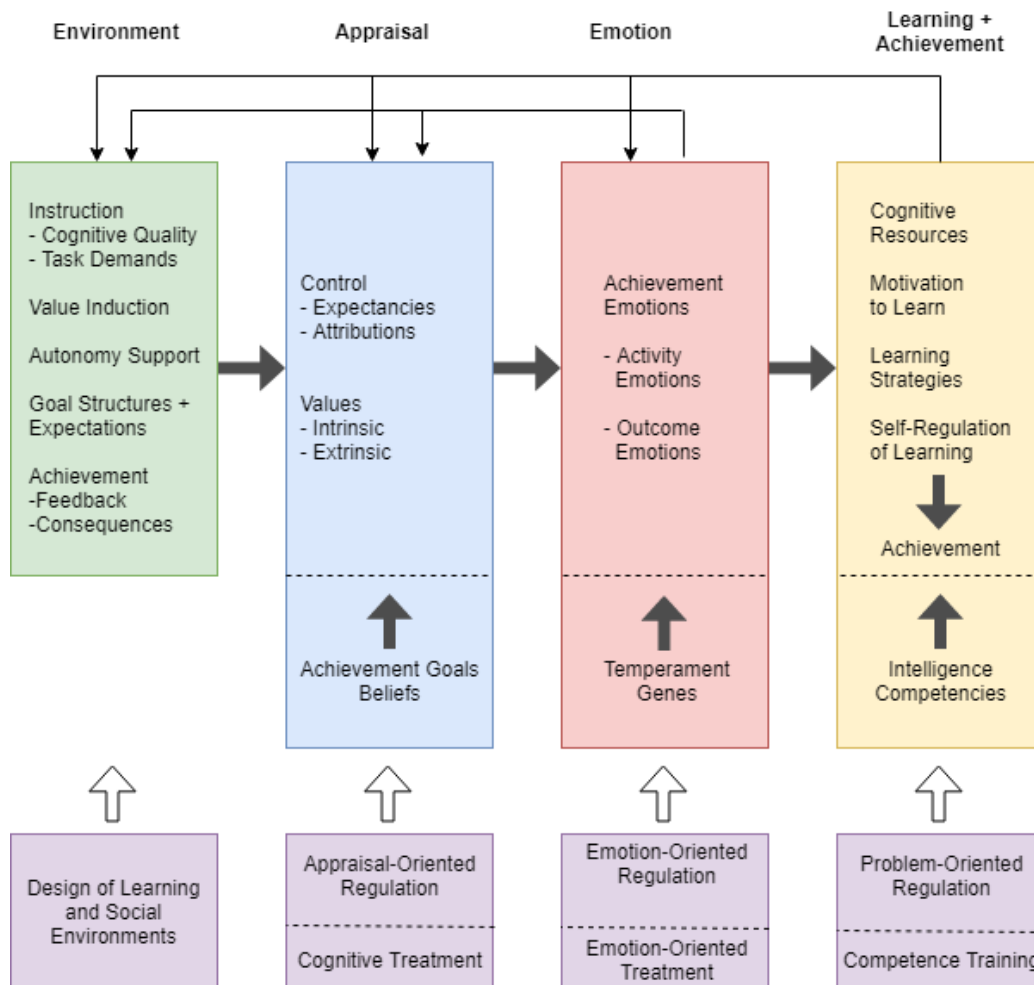


Figure 3.3. The Control-Value Theory (Pekrun et al., 2007, p. 17)

students with a high level of positive academic emotions and a low level of negative academic emotions at the same time showed the best educational outcomes. Ganotice Jr, Datu, and King investigated different types of motivation and their associations with academic emotions. A composite score of intrinsic motivation and identified motivation as autonomous motivation was found to be associated with the emotional state.

In terms of technology-assisted learning, the emotions tranquility and invigoration were found to affect learning in virtual simulation training. Fraser et al. (2012) found that increased invigoration and reduced tranquility are related to increased cognitive load, which led to worse learning performance. As stated in section 2.2.4.4, an early study of Lin et al. (2002) did not verify a positive relation between presence and enjoyment. The study's results showed a positive, non-significant relation between enjoyment and memory. Other investigations from emotional psychology in-

investigating emotions in immersive VEs depict strong associations between the factors emotion and presence, e.g. anxiety and fear (Diemer, Alpers, Peperkorn, Shibana, & Mühlberger, 2015). While the control-value theory states that emotions regulate cognitive resources (which relate to presence, see section 2.2.4.3), presence, in turn, can be regarded as a moderator that influences the activation of emotions through the use of VEs (Parsons & Rizzo, 2008; Price & Anderson, 2007). This might have an indirect effect on learning outcomes through other related cognitive processes.

For the integration in the research model, this means: Emotions primarily derive from current and former learning processes, control appraisals (expectancies and attributions), and control values (intrinsic and extrinsic). They do not have a direct effect on learning outcomes; the effect is mediated through presence (see section 2.2). Through influencing the cognitive resources available to construct the spatial mental model of the mediated environment, an individual's *prospective emotions* and *activity emotions* increase or decrease presence. Emotions (*prospective* and *activity emotions*), therefore, are modeled to be predicted by the previous scholastic performance and by motivation (in terms of perceived self-regulation/control) while predicting presence on their own.

### 3.3.5 Immersion

Immersion, as a quantifiable description of the provided technology (see section 2.1), influences learning from two perspectives: First, it is the use of the technology itself together with its educational content and second, it is the level of immersion that might contribute to learning benefits. Though this work is focused on comparing different immersive settings, such a study would be of poor use if there was no benefit in using (immersive) technology in scholastic settings at all. Hence, both perspectives are relevant to this section.

Hattie (2008) names some technology-related influences on scholastic learning with different effect sizes: computer-assisted instruction ( $d = .37$ ), simulation games<sup>17</sup> ( $d = .33$ ), and visual/audio-visual methods ( $d = .22$ ). Popular studies like Mayer (2009) emphasize the effectiveness of using visual/audio-visual methods as well. Wan and Fang (2006) emphasize the importance of technological features for the learning process.

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<sup>17</sup>Hattie refers to real-life simulation games rather than computer-based simulation games. As the didactical use of technology-assisted simulations does not change compared to real-life simulations, Hattie's results are considered to be important here as well.

When trying to investigate the effect of different levels of immersion on learning activities and learning outcomes, most studies compare several technological settings, like a desktop computer and an HMD, the use of different perspectives, display resolutions, software-related factors, etc. When referring to Steuer's (1992) framework (see chapter 2.2.4.1) for such a comparison in relation to learning outcomes, it is important to maintain as many factors as possible and, if possible, only change one immersion factor. Thus, it can be determined which of the immersive factors are important for the learning process and which are not. Until today, there is still a lack of methods to distinguish (or even numerically quantify) the level of immersion of a technological device.

Several researchers investigated which aspects of immersion influence learning: When comparing desktop computer settings with HMD settings, most studies show that a more immersive setting (HMD) has a positive effect on students' learning outcomes. Mania and Chalmers (2001) state that simulation fidelity as the extent to which the relevant interactions within an EVE are indistinguishable from the learner's interaction in a real environment (in terms of Steuer's mapping factor) might be the crucial part of immersion that influences training and learning effects. In their study, they compared a real world-setting with three virtual world-settings (3D desktop, 3D HMD, and audio-only) using a between-subjects design. In the study, a 15-minute seminar on a nonscience topic was presented to four independent groups of 18 participants, each being provided with one of the four settings. The participants were tested (among other variables) on their memory recall regarding the seminar contents and memory awareness state (in terms of episodic memory related to the spatial features of the environment). For both, the memory recall and the memory awareness state, a confidence score including the items *remember*, *know*, *familiar*, and *guess* was assessed as well. The results of the effects of the conditions ( $F(3, 71) = 6.59$ ,  $p < .05$ ) indicated that the real world-setting lead to the best memory recall scores, followed by the desktop setting, the audio-only setting, and the HMD setting, which lead to the lowest memory recall scores. For the real seminar, memory scores were significantly higher compared to the HMD condition ( $p < .001$ ) and to the audio-only condition ( $p < .05$ ). Similar results were shown for the participants' confidence scores related to the correctness of the answer. For the spatial recall task and the related confidence levels, an ANOVA analysis revealed an insignificant difference comparing the conditions real, desktop, and HMD (the spatial awareness test was not conducted for the audio-only group). Although the correctness of the spatial memory recall was lowest for the HMD setting, the related confidence level was highest here with the

*remember* item that indicates the highest level of confidence, followed by the desktop setting. When comparing the *remember* awareness state with the three settings, a significant difference between the HMD, the desktop setting, and the real world-setting was found ( $F(2, 53) = 4.40, p < .05$ ). The probability of the *remember* responses being correct was higher in the HMD condition than in the real world-setting ( $p < .05$ ). Mania and Chalmers argue that the *remember* awareness state, which occurs when images relating to past events or spaces come to a person's mind during the process of recall, is linked with the episodic memory and, therefore, is linked with how participants remember the environment. Mental images and subsequent memory responses associated with the HMD condition could be more vivid or realistic, hence might have an effect on spatial perception retained in time.

It has to be noted that the used HMD (a Hewlett Packard prototype) was a non-stereo, non-headtracked HMD, which was controlled by using a mouse. Thus, the system can not really be considered to be immersive in the terms of this thesis. Still, the insights from Mania and Chalmer's study are interesting for the design of immersive EVE, as they indicate that HMDs might be beneficial for enhancing implicit learning processes through the learner's episodic memory.

In Mikropoulos' (2006) study presented in chapter 2.2.4.1, the existence of an avatar as a user's representation, the use of an ego-centric perspective, and the use of an HMD facilitate completing learning tasks in EVEs compared to providing a wall-projection and an exo-centric perspective. Mikropoulos concludes this from observations, the software's log files, and from the participants' answers; he sees a strong connection between the level of immersion, presence, task performance, and learning outcomes (but without providing empirical evidence).

Lin et al. (2002, see chapter 2.2.4.1 for the description of the study) found that different fields of view (ranging from  $60^\circ$  to  $180^\circ$ ) contribute to memory. By comparing the results from memory questions about the environment in the different settings, an ANOVA could show significant differences ( $F(3, 27) = 3.73, p < .05$ ). The characteristic *field of view* contributes to the immersion's *depth*. Hence, variables contributing to the *depth* factor of immersion (for a discussion of this factor, see section 2.1) seem to enhance at least implicit learning processes.

Lee et al. (2010, study presented in chapter 2.2.4.1) investigated the effect of immersion with a similar understanding of Steuers' mapping factor, but used subjective judgement for assessing the effect of the genuineness of the interaction on learning outcome. The results showed positive effects of the latent variables usability (consisting of perceived ease of use and perceived usefulness) and VR features (consisting

of representational fidelity and immediacy of control)<sup>18</sup> on presence, motivation, cognitive benefits, control & active, and reflective thinking, which were the determining variables for learning outcomes. In this case, immersion does not have a direct effect on learning outcomes: The authors argue that leveraging VR features can enhance the interaction experience of the learner and his/her learning experience. This, in turn, influences the individual learning outcomes. In particular, representational fidelity (in terms of scene realism) and immediacy of control play a significant role in influencing the experience of interaction and learning in order to enhance learning outcomes. In a structural equation model including all subjective and objective factors of the study, VR features including were found to be strong antecedents to presence ( $\beta = .42$ ,  $p < .001$ ), motivation ( $\beta = .22$ ,  $p < .05$ ), cognitive benefits ( $\beta = .10$ ,  $p > .05$ , not significant), control & active learning ( $\beta = .35$ ,  $p < .001$ ), reflective thinking ( $\beta = .12$ ,  $p > .05$ , not significant), and usability ( $\beta = .77$ ,  $p < .001$ ). Usability, on the other side, predicted presence ( $\beta = .19$ ,  $p > .05$ , not significant), motivation ( $\beta = .71$ ,  $p < .001$ ), cognitive benefits ( $\beta = .75$ ,  $p < .001$ ), control & active learning ( $\beta = .55$ ,  $p < .001$ ), and reflective thinking ( $\beta = .70$ ,  $p < .001$ ).

While these studies show that immersion has a strong influence on learning activities, there are indicators that this effect might not be a predictive one. The effect of immersion on learning outcomes seems to be mediated through person-specific variables (e.g. in Lee et al.'s study: presence, motivation, cognitive benefits, control & active learning, and reflective thinking). As motivation is modeled as a stable, context-dependent variable and cognitive benefits are displayed through previous scholastic performance, the research model includes a predictive effect of immersion on presence.

### 3.4 A Research Model for Central Variables Within the Educational Framework for Immersive Learning

Even though all theoretical assumptions presented in this chapter cover only basic aspects of the underlying theories, it is possible to draw first conclusions for modeling variables: The research model for the empirical part of this thesis derives from the assumptions of the EFIL and its underlying theories (Fig. 3.1). The model displays the factors *immersion*, *contextual motivation*, *cognitive abilities*, *achievement*

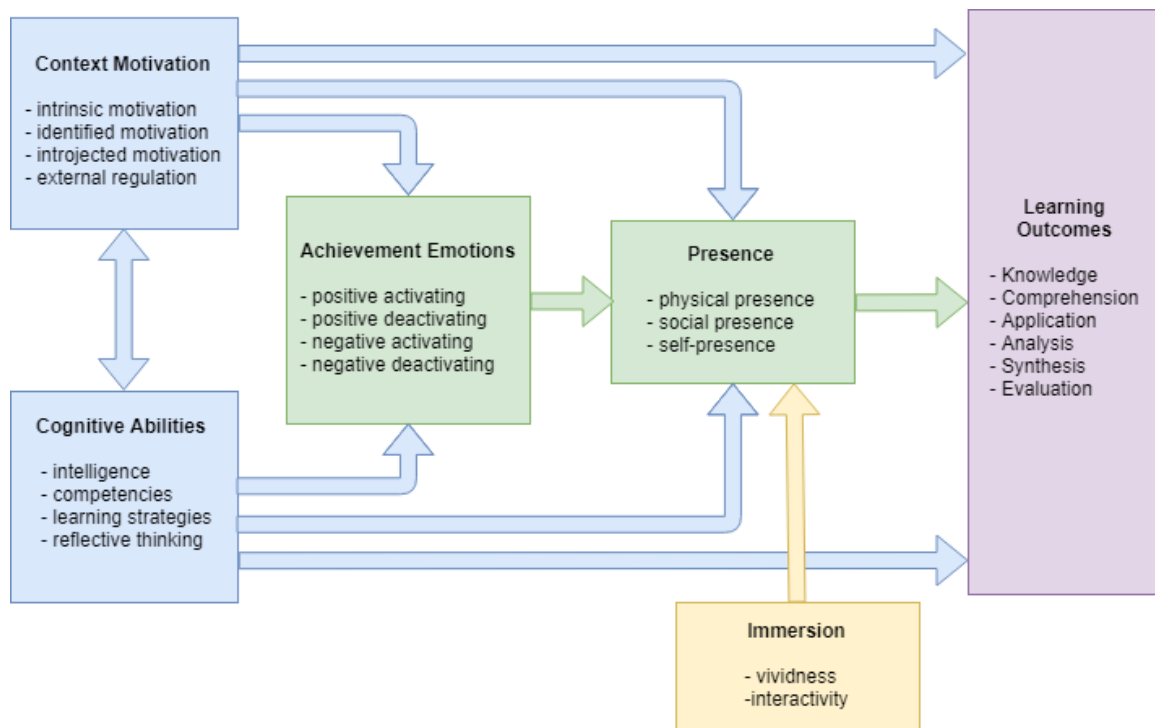
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<sup>18</sup>For a discussion of these VR features on a theoretical level, see chapter 3.1

*emotions, presence, and learning outcomes.* The factor *immersion* describes the technological characteristics of the supplied immersive instructional material in terms of its *vividness* and *interactivity* levels. A learner's *contextual motivation* for learning in a specific subject is given with regards to the perceived level of regulation: *intrinsic motivation, identified motivation, introjected motivation, and external regulation.* *Contextual motivation* is related to the learner's *cognitive abilities* (in terms of previous scholastic performance), which display the criteria *intelligence, competencies, learning strategies, and reflective thinking.* More internally regulated constructs of motivation (*intrinsic motivation and identified motivation*) are thought to be positively related to the *cognitive abilities* while rather external-regulated constructs of motivation (*introjected motivation and external regulation*) are assumed to be negatively related to the *cognitive abilities.* Subjective *achievement emotions* can be *positive or negative and activating or deactivating.* They depend on the *contextual motivation* and on the *cognitive abilities.* The feeling of *presence, in its occurrences physical, social, and self-presence* is displayed as a central subjective factor in the process of Immersive Learning. *Presence* is predicted by *immersion, contextual motivation, cognitive abilities, and achievement emotions.* The *learning outcomes* associated with the cognitive classes *knowledge, comprehension, application, analysis, synthesis, and evaluation* are predicted by *contextual motivation, cognitive abilities, and presence.*

#### Summary 6: Research Model

The research model follows the basic assumptions of the EFIL: The supply-side (given through *immersion*) does not directly lead to learning activities and, therefore, to *learning outcomes.* *Presence* plays a mediating role in the learning process and is influenced by the objective, immersive instructional material and by person-specific characteristics (coined in the EFIL as Immersive Learning potential). The person-specific characteristics *motivation* and *cognitive abilities* also influence the *learning outcomes* on their own. It has to be noted that the research model displays only a small part of the EFIL as it suppresses factors like the teacher, the context variables, the family of the learner, and his/her previous experiences as well as mutual relationships between previous or current learning outcomes and the person-specific variables. Within this selected part of the EFIL, the selected research includes variables with particular theoretical assumptions so that it cannot be seen as an extensive model for explaining all Immersive Learning processes.



*Figure 3.1.* The Research Model for Investigating the Influence of VR Characteristics on Learning Outcomes (yellow: supplied media and media effects; blue: learner's traits and trait effects; green: learner's states and state effects; purple: learner's outcomes)



## Chapter 4

# Immersive Learning in Computer Science Education

In this part, the theoretical concepts acquired and developed in chapters two and three are complemented by the didactical perspective of various topics from Computer Science Education (CSE). Following Bricken’s (1990) idea of substituting the actual for the virtual, this chapter pursues the concept of Computer Science Unplugged (section 4.1) by refining hands-on activities for learning computer science (CS) with the help of immersive technology, introducing the idea of *Computer Science Replugged*.

### 4.1 The Idea of Computer Science Unplugged

“Computer science is no more about computers than astronomy is about telescopes, biology is about microscopes or chemistry is about beakers and test tubes. Science is not about tools, it is about how we use them and what we find out when we do.” (Fellows & Parberry, 1993, p. 7)

*Computer Science Unplugged* (CS Unplugged)<sup>1</sup>, which involves solving problems in order to achieve a certain goal, “takes the unusual approach of exposing children to the great ideas of Computer Science without using computers” (Bell et al., 2009, p. 21). Bell, Rosamond, and Casey (2012) present the *Sorting Network* as a popular example of an Unplugged activity: A structure like the one shown in Figure 4.1 is used to engage students in a number sorting activity. In the original version, six students, each provided with a number, start in the boxes shown on the ‘in’ side of

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<sup>1</sup>The CS Unplugged project was created in 1992, combining Bell and Fellow’s ideas for communicating CS to young children. First materials like cards for teaching binary numbers quickly raised the interest of teachers, parents, and students alike, leading to the development of an Unplugged book, written by Tim Bell, Ian H. Witten, and Mike Fellows.

the network. They follow the arrows until they arrive at a circle (node), where they meet another student with whom they compare their numbers. The student with the smaller number follows the arrow on their left; the student with the larger number follows the arrow on their right, until they arrive at the next circle. The procedure is repeated until students arrive at the boxes on the 'out' side in an ascending order. Bell et al. note that students and teachers alike are surprised by the result when they finish the activity. Activities like the parallel sorting network teach much more than just logic or algorithms: If a student tries to get to the end as quickly as possible by leaving out a comparison, their haste causes the whole team to fail. Doing so, the sorting network is a model of cooperative learning, leading to questions, critical thinking, and reflection about this type of problem.

More recently, classroom-oriented lessons were developed by the CS Unplugged project including unit plans, lessons, curriculum integrations, and programming challenges. The website provides materials for various topics, for example binary numbers, error detection and correction, image representation, and sorting algorithms. Notes on related curriculum areas help teachers to integrate the activities within their everyday teaching in the classroom (Computer Science Unplugged, 2020).

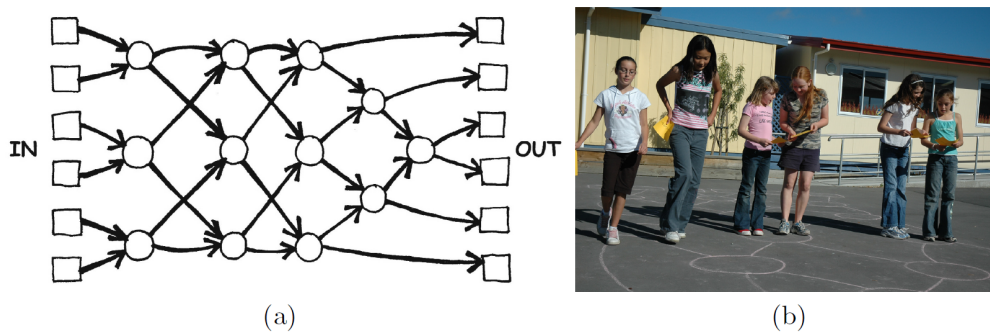


Figure 4.1. a) A 6-Input Parallel Sorting Network b) The Corresponding Activity (Bell et al., 2012, p. 402)

Engaging students in ‘Computational Thinking’ (Wing, 2006)<sup>2</sup>, the patterns of thinking and problem solving for selected problems are relevant and valuable to all

<sup>2</sup>Computational Thinking covers skills related to thought processes for formulating problems and their solutions by using multiple ways of abstraction and decomposition that can be effectively carried out by a computer (Wing, 2006). Computational Thinking tries to foster a deeper understanding of phenomena related to CSE by focusing on 1) abstraction and encoding (transferring information from the real/fictional world into a digital environment) and 2) automatic processing of digitized information (data) (Dengel & Heuer, 2018).

students. CS Unplugged activities can contribute to a better understanding of Computational Thinking skills and to a higher interest in CS (csunplugged.org, 2020b).

On the basis of interviews from six students (7th and 8th grade) who participated in 18 activities from the first CS Unplugged book (Bell, Witten, & Fellows, 1998) in a series of after-school meetings, Taub et al. (2009) assessed the change of attitudes towards CS (the nature of CS, the characteristics of computer scientists and work in CS, the variety of employment in CS) from before and after the series. Their results indicate that using CS Unplugged contributed to the students' understanding of the nature of CS while still perceiving the computer as the essence of CS (not primarily as a tool). The authors argue that activities should build on students' prior knowledge and that central concepts in CS should be linked explicitly to the activities. In addition, students should be informed about careers in CS.

According to Feaster et al. (2011), who ran ten lessons from the Unplugged activities at a high school, CS Unplugged is effective for increasing interest in CS when the initial level of interest is low. These results are similar to the findings of Carmichael (2008): By combining Unplugged with teaching video game programming, an overall increase in interest in taking CS further as a subject was reported by girls who took part in a week long mini-course. Lambert and Guiffre (2009) carried out CS Unplugged activities in three fourth grade classes (a pre-test session, three content sessions, and post-test session). They reported significant increases of interest in CS, cognitive competence in CS, and confidence about Math.

In a research project by Cottam, Foley, and Menzel (2010), the effectiveness of outreach programs like roadshows for communicating the importance and diversity of computing was investigated. Ten statements like *Computing is a sufficiently diverse field*, *Understanding computing is an important life-long skill*, and *Computing is full of exciting opportunities* were assessed on five-point Likert scales. The tests were conducted before and after their *Just Be* roadshow for students ( $N = 520$ ), which included adapted Unplugged activities as hands-on tasks. The authors found significant positive shifts of attitudes for all statements.

Carruthers (2010) notes that, by using the CS Unplugged approach, grade six students are capable of learning graph theory, including an application of graphs for working on mathematical word problems. Teaching the concept can positively impact student performance on at least some types of activities that require problem solving.

Bell et al. (2009) state that “a key principle of the Unplugged program is to develop teaching methods for CS that are independent of using computers” (p. 25).

Some other principles for the design of this kind of engaging activities for teaching and learning CS are:

- focus on CS concepts rather than programming,
- making the activities kinaesthetic through involving teamwork,
- making the activities fun and engaging,
- low cost,
- release under a creative commons license,
- making the activities gender neutral and rather focus on cooperation than on individualistic approaches, and
- adding a sense of story to the activities (Bell et al., 2009).

The sense of story has been identified as a key theme of CS Unplugged: Including pirates, monsters, ice cream vendors, and football teams in the activities' narratives can engage children and adults. Stories remove boundaries and provide compelling descriptions of situations and problems. Moreover, stories can function as a signal for the students to start using their imagination (Bell et al., 2009).

CS Unplugged activities are an engaging way to raise children's motivation to learn about CS; the original activities as well as adapted or pursued versions of them have the potential to be fun and activating for students. While the original format of CS Unplugged consisted of several activities on 20 different CS topics for outreach in a classroom situation, further ideas were carried out into video demonstrations, a show, outdoor events, and competitions.

## 4.2 Immersing the Idea: Computer Science Replugged

Many virtual approaches to teach about these concepts like virtual games or simulations have been developed in recent years. For example, the sorting network that was presented as an Unplugged activity in section 4.1 has been crafted in a virtual world so that students with mobility impairments could engage in the activity as well (see Fig. 4.1). Bell et al. note that some of the activities were adapted as an online game (consisting of several flash-based games) where exercises referring to the learned skills can be found. Patterns and algorithms can be explored in an interactive environment. Some approaches try to combine physical activities with programming exercises in children's languages such as Scratch and Alice (Bell et al., 2009). By visualizing the activities in an interactive book, Chalifour developed a 'replugged' version of the original CS Unplugged book (csunplugged.org, 2020a).



Figure 4.1. a) A *Second Life* Simulation of the *Sorting Network* Activity b) Using the Virtual Sorting Network in Class (Bell et al., 2012, p. 404)

The traditional CS Unplugged activities are easy to use as they require very simple materials (chalk, pens, paper, string, etc.). But there are also topics and corresponding activities in the style of CS Unplugged, where the success depends on multiple factors, such as the idea of mixing colors to visualize the Diffie-Hellman Key Exchange procedure (Art of the Problem, 30.07.2012). While the initial idea has the potential to engage students and to explain the concept of a complex procedure using a simple analogy, the success of this activity depends on a very exact measurement of color to get the exact ‘key’ color in the end. In such cases, virtual activities can be less prone to failure and provide immediate feedback that is already implemented in the game. It is also possible to integrate additional incentives such as coins, highscores, or levels in virtual activities that might increase the students’ motivation to play (see Bartle, 1996). Further, virtual activities are safe, and easy to use and re-use once the school has procured the required hardware. Further, in times of online-schooling, virtual substitutes for existing CS Unplugged activities can be useful when there is no possibility to carry out the activities in a real context. In terms of following the initial concept of CS Unplugged, one question arises: Can virtual activities still provide first-hand experiences to engage the learner? When using a mediated environment, the key thought of CS Unplugged, exposing children to the ideas of CS without using computers, becomes quite contradicted. But what if the students did not perceive their VE as mediated? The benefits of virtual activities could contribute to the learning experience while still being regarded as first-hand experiences. As stated in section 2.2, immersive technology can induce the feeling of presence, resulting in a perception of non-mediation and, therefore, lead to the perception of a first-hand experience. Hence, it seems possible to use VR hardware and software to

simulate activities following the CS Unplugged idea that may even either be impossible, dangerous, or difficult to carry out in reality or that face challenges that cannot be addressed due to restrictions of reality. Bell et al. (2012) note that

"Unplugged is really an attitude rather than a technique. The pragmatics of making the material widely accessible mean that we don't eschew computers per se, but we do avoid the situation where the physical device becomes the object of attention and displaces the great ideas that will engage students' minds" (p. 417).

Bell et al. (2012) add that there has been value gained by integrating digital devices in Unplugged activities. There are examples of using robots to carry out Unplugged activities or simulations of activities in virtual worlds such as Second Life.

For investigating the possibilities to provide immersive experiences that focus on the idea rather than on the technology, it can be beneficial to analyze Schwan and Buder's (2006) taxonomy of VR visualizations for educational purposes. They state that VR is a powerful tool to enhance learning processes by providing spatial, multimodal visualizations that can be:

- *accurately displayed*: These visualizations can be used when the learning content is a real situation and/or when learning in the real environment is expensive or dangerous. Here, accurate simulations of real situations/objects providing a high level of detail are displayed (e.g. a simulation of an airplane cockpit).
- *schematizing*: When it is useful for the learning process to blank out irrelevant details, visualizations can provide simplified versions of real situations/objects with a lower level of detail while focusing on the important/relevant characteristics (e.g. a simulation of the human brain).
- *substantiating*: Abstract contents/concepts can be visualized illustratively (e.g. a spatial representation of physical laws). This type of visualizations requires previous knowledge as an additional step of mental translation is needed in order to understand the provided model.
- *metaphorical*: When metaphors for visual representations are chosen with didactical consideration, such representations can be a powerful tool for fostering the understanding of concepts. VRs like these provide analogies to real/abstract concepts (e.g. visualizing the function of a motherboard by using a virtual person exchanging data packages between different buildings, see section 5.1.1).

These categories can be applied to different forms of visualization other than VR as well. In most CS Unplugged activities, the visualizations are *substantiating* (e.g. binary number counts represented with dots, UC Computer Science Education, 25.10.2008) or *metaphorical* (e.g. simulating the public/private key encryption process with a treasure box filled with a chocolate bar, UC Computer Science Education, 25.10.2008). *Schematizing* ideas can be of interest as well (e.g. the 'parity trick', a visualization of error detection algorithms in a simplified way with black and white cards, UC Computer Science Education, 25.10.2008). Doing so, the use of VR technology for enhancing (or enabling) activities following the CS Unplugged approach should focus these three areas.

As the term Computer Science Unplugged seems a little bit odd when immersive technology is used, this approach could be coined 'Computer Science Replugged' (CS Replugged, in terms of "replugging" existing or new Unplugged ideas to immersive technologies in order to enable/enhance them). This approach differs from Chalifour's 'Replugged' version of the CS Unplugged book since it tries to avoid the perception of a mediated experience, but uses immersive technology to provide a sense of being in the environment. Hence, CS Replugged focuses hands-on activities that are combined with immersive technology providing a perception of non-mediation and making the experience 'real' (even though the setting might be a fantastical world). By doing so, the general idea of being independent of using computers as an educational medium can be followed: The medium is only used to simulate the experience of a perceived-as-'real' activity. The used technology disappears when experiencing the activity in VR rather than being an instrument for teaching and learning (as, for example, a student solving coding tasks on a desktop PC).

Building on the idea of using technology either as a substitute, an augmentation, a modification, or a redefinition of an existing task (Puentedura, 2006), VR has the potential to either enhance or transform CS Unplugged activities. While research on educational VR has been around for a while now (see chapter 3), there is only few research on how VEs can address learning objectives which are related to CSE. There are some non-immersive approaches of using virtual worlds<sup>3</sup> for CSE 3D online environments like *Second Life*<sup>4</sup> and *OpenSim*<sup>5</sup>:

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<sup>3</sup>The term virtual worlds, in this case, refers to a simulated (by a computer), spatial (a space with objects/constructs maintaining spatial relationships), shared (for multiple users), and embodied (representation of users as entities within the world) environment (Nilsen & Thompson, 2008).

<sup>4</sup>In *Second Life* (Linden Lab, 2019), which was developed by Linden Lab in 2003, users can create their own content (e.g. objects, textures, and scripts) and rent virtual land for a monthly fee.

<sup>5</sup>*OpenSimulator* is a free, open source multi-user 3D virtual world server, that can simulate virtual environments similar to *SecondLife*.

- visualizing data structures (Wei, Chen, & Doong, 2009),
- visualizing search algorithms (Grivokostopoulou, Perikos, & Hatzilygeroudis, 2016),
- simulating development processes (Crellin, Duke-Williams, Chandler, & Collinson, 2009; T. Wang & Zhu, 2009),
- teaching basics of programming (Pereira, Paladini, & Schaf, 2012; Pellas, 2014; Vosinakis, Koutsabasis, & Anastassakis, 2014),
- teaching computer networks (Voss, Nunes, Muhlbeier, & Medina, 2013; Sturgeon, Allison, & Miller, 2009),
- teaching hardware fundamentals (Yap, 2011),
- raising information security awareness (Xenos, Maratou, Ntokas, Mettouris, & Papadopoulos, 2017), and
- simulating sensors and actuators (Buiu, Buga, & Coman, 2013).

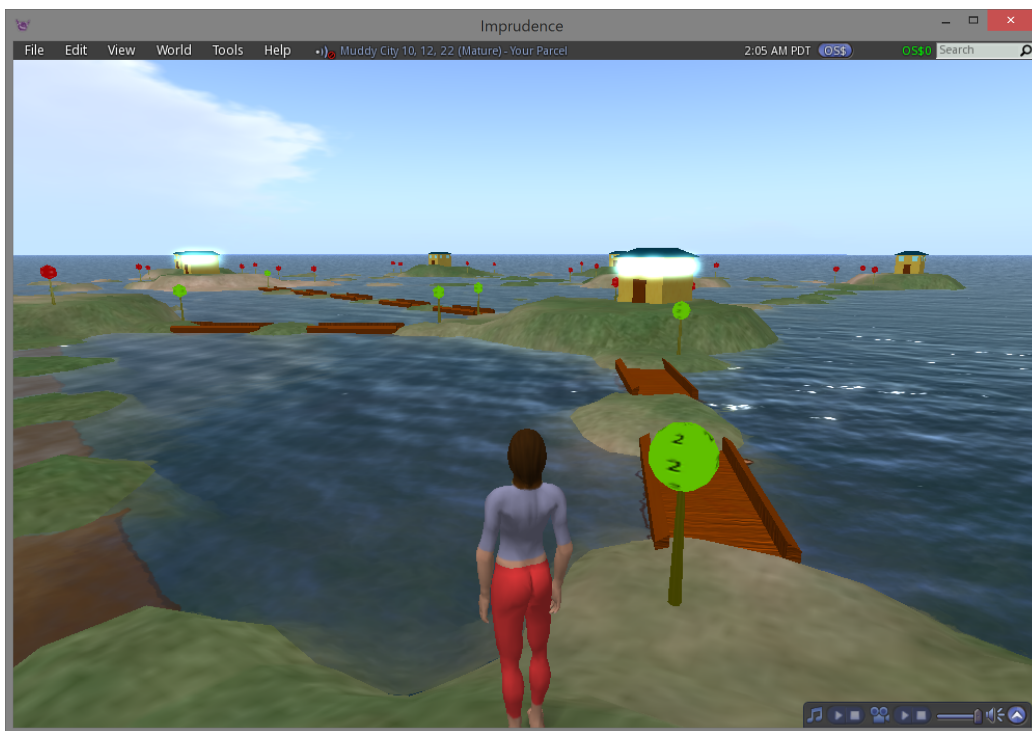


Figure 4.2. The *Muddy City* Activity in *OpenSim* (D. Thompson, 2018, p. 67)

Thompson (2018) simulated CS Unplugged activities for graph theory in *OpenSim* (see Fig. 4.2) and run-length encoding in *MinecraftEdu*<sup>6</sup>. He also points out a

<sup>6</sup>*MinecraftEdu* is an educational version of the sandbox video game *Minecraft*, where players can build and explore a world made out of different blocks.



major advantage of virtual simulations: It is easy to collect data in the VEs by using in-computer, in-client, in-server, or in-simulator methods, which might help to understand how learning works. In the original *Muddy City* activity, learners are presented with a map of houses or islands that can be connected using roads or bridges. For every connection between the houses/islands comes an associated cost (represented by a given number of sections/paving tiles in between). The metaphor used here is that the map represents a graph, each island a vertex, each bridge an edge, and the number of bridge sections the edge cost. A solution set can be interpreted as a minimal spanning tree. Thompson and Bell (2015) compared a 2D and a 3D setting and found that students in the 2D setting were faster in finding first and optimal solutions than in the 3D setting. They also note that students in the 3D setting seem to make their moves in a more considered and careful way. The 3D setting, therefore, seems to foster reflective thinking rather than reinforcing a trial-and-error approach within the VE.

The *Image Representation* activity, which was represented in *MinecraftEdu* (see Fig. 4.3), makes use of run-length encoding, a technique to represent long runs of same colored pixels efficiently. In the VE, students could solve puzzles related to the learning content. Participants rated the activity as easy to use, fun, and as being related to CS contents. Most students would choose *MinecraftEdu* for other activities in CS as well as in other subjects (D. Thompson, 2018).

### 4.3 Virtual Reality in Computer Science Education

Despite these efforts in terms of non-immersive VEs, research on using immersive VR in CSE is scarce. An early way to connect VR and CSE was *Alice*, which was developed as a rapid prototyping environment for generating VR environments using the programming language Python (Conway, Pausch, Gossweiler, & Burnette, 1995). While the effectiveness of *Alice* as a tool for CSE has been used for developing non-immersive rather than immersive applications in most research (e.g. Dann, Cosgrove, Slater, Culyba, & Cooper, 2011; Daly, 2013; Conway et al., 2000; Moskal, Lurie, & Cooper, 2004), current projects try to emphasize VR technology again (e.g. Curiouser, 2019; Team Wonderland, 2019). Regarding these new projects, Harries (2019) argues that VR games can be a new way for visualizing abstract concepts that do not make much sense when visualized in two dimensions. It can further be a way to engage students in exploring, experimenting with, and discovering these concepts for



Figure 4.3. A Run-Length Encoding Activity in *MinecraftEdu* (D. Thompson, 2018, p. 177)

themselves at a fundamental and conceptual level while seeing them completely separated from the involved syntax. This connection between VR and CSE is a promising approach for fostering programming skills. It has to be noted that, as the programs are developed outside the VR, the technology is not used as an instructional medium but rather as a device to evaluate the programming skills obtained outside the VR.

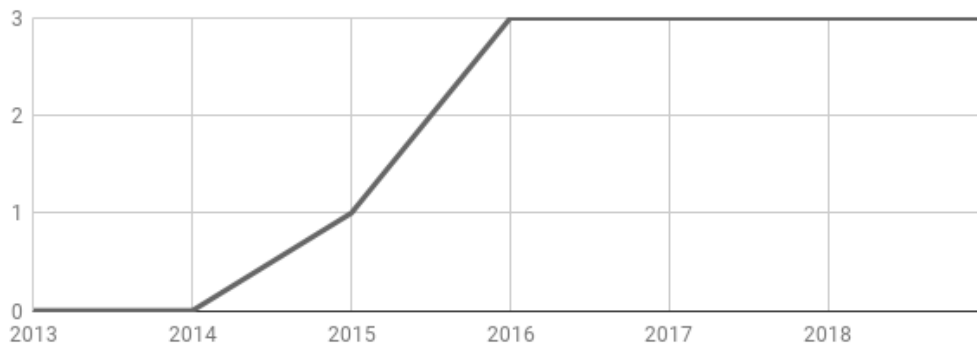


Figure 4.1. Number of Publications for Virtual Reality in Computer Science Education from 2013-2019 (Pirker et al., 2020)

With the release of professional head-mounted displays for the consumer market, research on using VR for CSE took new directions. Pirker, Dengel, Holly, and

Safikhani (2020) provide an overview of immersive VR in CSE between 2013 (the release of the Oculus Rift DK1) and 2019 showing a rise of publications within the last seven years in this field of research (see Fig. 4.1). Most of the published studies were conducted within the last three years.



Figure 4.2. a) The *VRFiWall* Main Scene (Puttawong et al., 2017, p. 4) b) The *VRFiWall* Book of Firewall Security Knowledge (Puttawong et al., 2017, p. 4)

The learning objectives relate to various topics of CSE (see Tab. 4.1), focusing on different cognitive levels. On Bloom's (1968) level of *knowledge*, remembering filtering rules for firewall concepts (Puttawong et al., 2017) or internalizing software architectural models (Rodrigues, 2010) can benefit from an accurate display of the contents (e.g. text, audio, or graphics). In *VRFiWall* (Puttawong et al., 2017), the player is assigned as a packet named Paragon. In order to fulfill a secret mission from his kingdom (the source IP address), Paragon has to reach another kingdom (the destination IP address of the packet). In order to successfully pass the firewall gate at the end of the main scene (see Fig. 4.2a), the student has to learn about filtering rules by interacting with non-player-characters and make himself (as the packet) match with those rules. Here, the analogy of a border control is used to represent the concept of a packet-filtering firewall. During the game, the player can find a book containing knowledge of firewall security that can be used to answer five questions and get to a special ending (see Fig. 4.2b).

Regarding the domain of *comprehension*, especially teaching programming fundamentals can benefit (e.g. Stigall & Sharma, 2017; Tanielu et al., 2019). Within these environments, VR contributes as a visualization tool for metaphorical representations for CS concepts. For example, Tanielu et al. (2019) use the analogy of building a house from a blueprint (as a representation for the class from which multiple objects

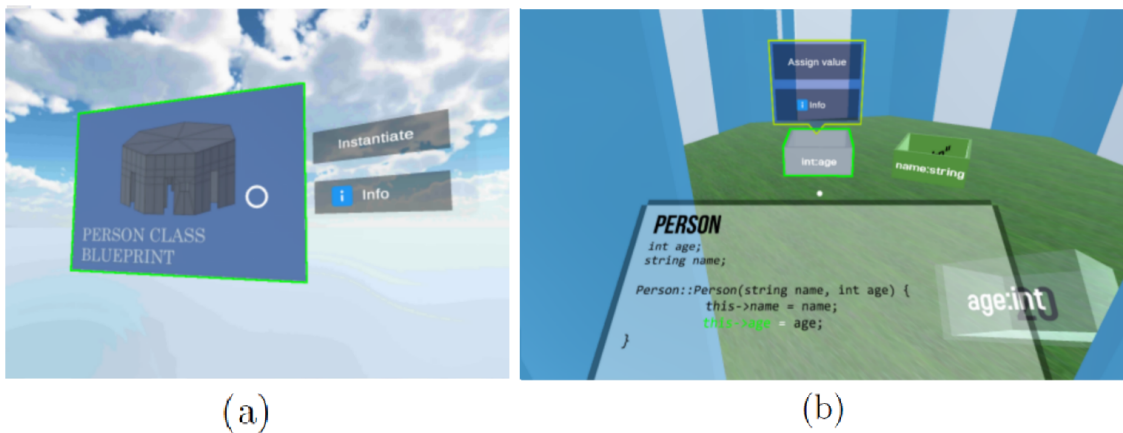


Figure 4.3. a) Building a House from a Blueprint in *OOPVR* (Tanielu et al., 2019, p. 96) b) Assigning a Value to a Variable in an Instance's Central Space (Tanielu et al., 2019, p. 96)

can be instantiated) in their *EVE OOPVR*, see Figure 4.3. In a similar manner, variables are visualized using boxes that can store items (just as a variable can store values or references). The concepts of scope and encapsulation are represented via walls inside the house so that certain variables or methods are only visible when the player is inside a room (visualizing an instance method).

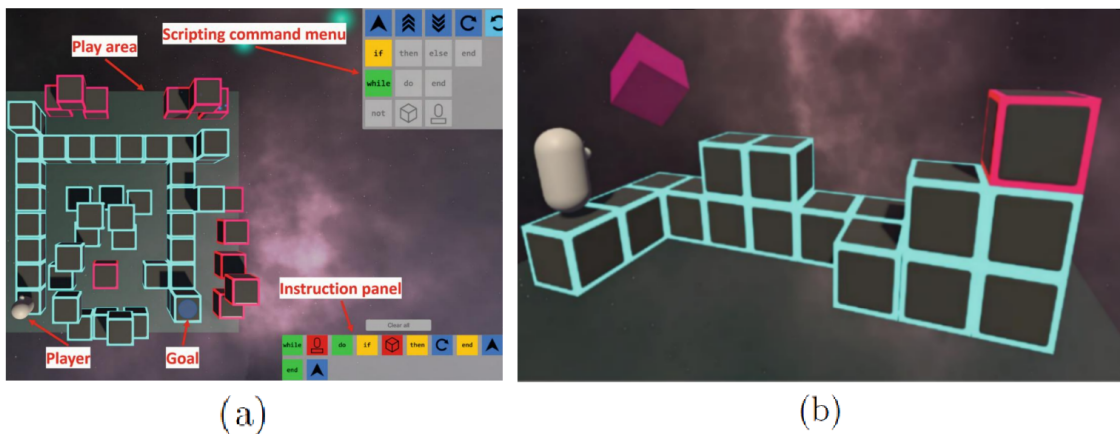


Figure 4.4. a) Top-Down Point of View During the Scripting Mode (desktop) of the *FunPlugs* Application (Horst et al., 2019, p. 498) b) View on a *FunPlugs* Level in VR in the Building Scene (Horst et al., 2019, p. 500)

Similar to the idea of *Alice* introduced before, most modern approaches focusing on the *application* domain have programming as their learning objective with VR

being used as an instrument to display the results (e.g. Berns, Chin, Savitz, Kiesling, & Martin, 2019; Horst et al., 2019). Doing so, VR is used to support the design process: In *FunPlugs*, students solve spatial puzzle-like tasks by using visual scripting components, such as while-loops and if-then-else decisions. Figure 4.4 shows how the game concept is divided into 1) the building scene, where the player can create content for other students and 2) the scripting scene, where the game can be played and dropped down building blocks have to be moved by the player in order to get to a certain goal. Both scenes can be accessed in desktop and VR mode. To play the game, the student iteratively switches between the desktop mode (where the scripts have to be put together) and the VR mode to move in the scene.

Some approaches also focus on higher cognitive levels: In a study led by Harms and Hastings (2016), students developed their own projects using VR technology, which improved their creativity and invention skills. There are only few applications that enable social experiences that can support collaborative learning (e.g. Horst et al., 2019; Bujdosó, Novac, & Szimkovics, 2017).

The literature analyzed in the systematic review of Pirker et al. (2020) tends to use professional HMDs for their studies (see Fig. 4.5). Most applications use an HTC Vive or an Oculus Rift. Some studies used more than one technology. Some of the studies using mobile VR reported performance issues or graphical issues. Only one study (Stigall & Sharma, 2017) used a Corner CAVE system as a second device in addition to the Oculus Rift. Also, using different locomotion systems can lead to differences in the user experience, which is why the choice of the locomotion technique is essential for the comfort of the learners (Pirker et al., 2020).

The CS Replugged concept has potential to provide a basis for developing new VR applications for CSE. The approach can build upon existing ideas while enhancing or transforming them (for a discussion of how technology can be connected to existing tasks, see chapter 3) through the use of immersive media. It has to be noted that, following the argumentation of chapter 3, a sense of presence is related to learning processes. That said, it can not be the aim of the CS Replugged idea to see or use VR technology as a substitute for existing Unplugged activities: As the sense of presence is at its peak in the actual, physical reality, every activity that can be carried out in real conditions should be carried out there. Engaging students into fun activities does not necessarily need technological immersion, that is why the CS Replugged approach can help enabling new activities or improving existing activities. Section 5.1 will present three ideas of how Computer Science Replugged can contribute to existing activities by augmenting/modifying them or how the approach can enable

Table 4.1

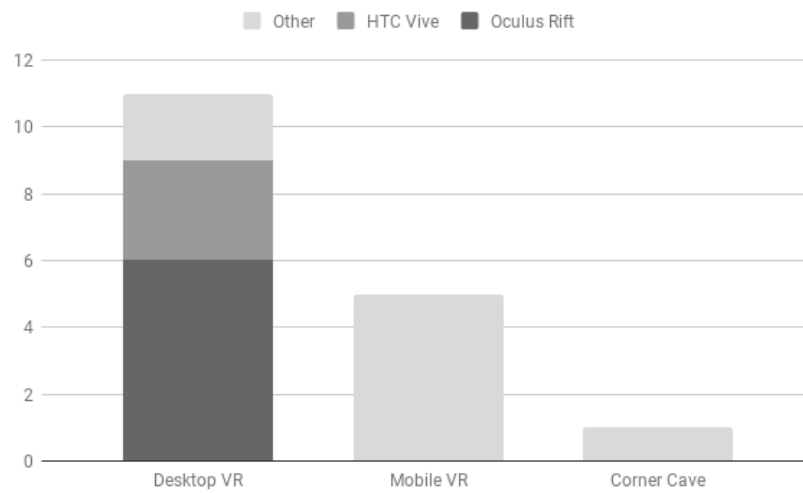
*Learning Objectives in Virtual Realities for Computer Science Education (Pirker et al., 2020)*

CS concept	Concept of VR	Studies
Object Oriented Programming	visualization to enhance understanding	Tanielu et al., 2019
Algorithms, Coding	playful concepts, engagement, joy, collaborative learning	Berns et al., 2019; Horst et al., 2019; Stigall & Sharma, 2017; Vallance et al., 2015
Computational Thinking	embodied activity, natural embodied thinking and cognition, critical thinking via physical actions (VR as metaphor)	Parmar et al., 2016
System Development	spatial freedom, creative interactions, innovation	Bujdosó et al., 2017
Security Concepts	playful interactions, educational entertainment, engaging students	Puttawong et al., 2017; Visoottiviseth et al., 2018
Theoretical Computer Science	visualization of finite state machines and algorithm, playful learning, metaphorical learning, engagement	Dengel, 2018a; Nicola et al., 2018

new activities. Two of the three developed EVEs find their origin in existing CS Unplugged activities (even though the third activity of "repairing a computer" could also be seen as some sort of Unplugged activity).

### Summary 7: Computer Science Replugged

CS Unplugged provides engaging and fun activities that follow a storyline in order to motivate children for general ideas and concepts in CS. CS Replugged pursues the idea of CS Unplugged by conceptualizing hands-on activities for learning CS combined with immersive technology. The virtual activity is supposed to be perceivable-as-real and, therefore, supposed to provide a first-hand experience. The used technology should disappear as an augmentation, modification, or recreation of existing or new activities.



*Figure 4.5.* Distribution of VR Technologies used in the Studies (Pirker et al., 2020)





## Chapter 5

# Effects of Person-Specific and Technological Variables on Learning Outcomes in Educational Virtual Environments for Computer Science Education

In chapter 3, an educational framework for immersive learning was developed by localizing objective and subjective characteristics of educational VEs inside an established framework for the explanation of scholastic learning. Pursuing this approach led to the design of a research model (see section 3.4). These theoretical approaches were applied to didactical considerations on immersive EVEs for teaching and learning CS in chapter 4. This chapter presents the design of three EVEs for CSE, which are then used as treatments in two studies. A first study was designed to evaluate whether the EVEs were effective regarding learning outcomes, whether the technologies could induce different levels of presence, and whether the CS contents were new to the students. The research model, which was developed in section 3.4 for testing particular relations and effects within the EFiL, is investigated further in the second study.

### 5.1 Educational Virtual Environments for Computer Science Education

This section presents the development of and the didactical considerations for the EVEs which were designed as treatments for the studies. The covered topics comprise the topics *components of a computer*, *asymmetric encryption*, and *finite state machines*. All developed EVEs follow the idea of CS Replugged, which was presented

in chapter 4: Students are given hands-on tasks in virtual worlds in order to induce the impression of a first hand experience. All three programs were designed for three different technologies using *Unity*: A laptop version, a mobile VR version, and a SteamVR version for the HTC Vive were developed. Occurring differences in interaction were tried to be kept to a minimum, inevitable variations in the interaction characteristics are reported.

### 5.1.1 Bill’s Computer Workshop: Components of a Computer

The first experience addresses the topic *components of a computer*. One can argue that the best way to learn about the parts of a computer might be to just give the hardware to students and let them tear it apart, repair it, or build it from scratch. While this seems to be an effective method, it is also a somehow expensive and time-consuming one. As some of the components are very sensitive (like the CPU), additional guidance would be needed for some procedures, resulting in dissection-like lessons missing the opportunity to let the students explore the components by themselves. This section presents the concept of the EVE *Bill’s Computer Workshop*: Students repair a PC by shrinking themselves and entering the computer. Inside the computer, the learner has to find several parts that are not inserted correctly in order to get the computer to work again. They are being helped by a mechanic who gives them advice for the quests and explanations for the components. In this scenario, VR technology redefines<sup>1</sup> the task of repairing a computer.

#### 5.1.1.1 Related Work for Learning About Components of a Computer

There are approaches for teaching the von-Neumann architecture using EVEs, some of them have been implemented in teaching units (Dauscher, 2012; M. Weinert, 2018):

- Dauscher (2012) presents the *Johnny*, a simplified von-Neumann simulator. The areas memory (with the RAM), control unit, and arithmetic logic unit are connected through an address bus and a data bus. The instructions consist of micro-commands (e.g. `db->ram`, `acc++`, etc.) and macro-commands (e.g. `ADD x`, `SAVE y`, etc.). The students can decide to hide or show the inside of the control unit, including the instruction register, the microcode, and the program counter.

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<sup>1</sup>Chapter 3 discussed the potential use of technology in education by using Puentedura’s Substitution, Augmentation, Modification, and Redefinition model. *Bill’s Computer Workshop* uses immersive and non-immersive technology to simulate the experience of being inside a computer, a previously inconceivable task.

- Weinert's (2018) *KUR2* (Klassischer Universalrechner 2) aims to demonstrate the objectives proof-of-concept (design of a computational model), simplicity (simple functions), vividness (representation of basic processes inside a computer), and sufficient power (to design simple programs). Like the *Johnny*, the *KUR2* consists of an ALU (Rechenwerk, including two registers named accumulator and operand), the control unit (Steuerwerk, including a FETCH micro-program, an instruction count (Befehlszähler, a data register for storing the current instruction temporarily, as well as a micro-program, representing the instruction in the data register), a storage unit (Speicherwerk), and the input and output unit (Eingabewerk und Ausgabewerk).
- Nisan and Schocken's (2008) *Hack* platform includes many relevant abstraction levels, from boolean logic and logic gates over assembler and virtual machines to operating systems and object-based programming languages. All data is stored in a 16-bit system with two storage areas for the program (32K-ROM) and a working memory (16K-RAM). In order to display peripheral devices as well, the main memory also includes a display memory (for displaying information on a virtual monitor) and a keyboard memory that can be accessed directly from the outside (simulating the keyboard inputs).

EVEs for teaching about the hardware components of a computer, their functions, and the relations between these components are rather scarce. A very simple, game-based example is *Go Kart Grab - Identifying Parts of Computers* (BBC, 2019), which is connected to the British KS3 curriculum topic *understand the hardware and software components that make up computer systems, and how they communicate with one another and with other systems* (Department for Education, 2014). In the game, the protagonists Crash and Boot want to attach a computer to a go-kart, which they try to build. As they are lacking the necessary components for the computer, their mechanical dog DOGG-I helps them by collecting computer parts from the recycling yard. The player's task is to collect these components of a computer by distinguishing computer parts (things inside a computer or that can be attached to one) from other items (e.g. bags of rubbish, a piano, soccer tickets, etc.). The learning objectives focus on the ability to identify some basic hardware components of a computer (without needing to know their names).

The project *CPU City* from Lester et al. (1999) presents a 3D learning environment for the domain of computer architecture and systems for novices. The EVE displays the components of a computer RAM, CPU, hard drive, and the buses connecting them in the form of a virtual computer cityscape. The city is supposed to

represent a simple motherboard that is inhabited by the pedagogical agent WhizLow, an explanatory lifelike avatar, who helps the player to carry out tasks. By using a high-level programming language, the students issue their task specifications and direct WhizLow to perform the tasks within the virtual computer. The EVE focuses on this architecture and the relations between the components by also including a control unit (in terms of a simple decoder) and an ALU (arithmetic logic unit), as well as system algorithms (e.g. the fetch cycle, page faults, virtual memory) and the basics of compilation and assembly. The integrated high-level specification language (including constructs for conditionals, assignments, and iterations) is used to instruct WhizLow, who picks up data and instruction packets, to drop them off in specified locations (e.g. registers), and to interact with the devices, for example for arithmetic and comparison operations. During the learning sessions with *CPU City*, WhizLow explains functions of the compiled instructions, e.g. "It's the *load* instruction. A load instruction allows the CPU to retrieve a value from RAM based on its address" (Lester et al., 1999, p. 29). The learning objectives of *CPU city* consist of machine-oriented assembler coding skills (though represented through a high-level specification language, which is then compiled) but further set a focus on the interaction between CPU, RAM, and hard drive.

In the immersive environment *Inside a Computer* (Tiporari, 2018), the user can enter a computer and explore its inside. The user can teleport freely in the environment, which consists of several parts of a computer (e.g. the user can teleport onto the graphics card). The experience is not interactive and has no underlying learning objectives; it is designed primarily for entertainment purposes.

Another idea is that a good method to teach about hardware components of a computer might be working on a real computer. The teacher can provide a real computer that can be torn apart or put together. But, if there is only one computer and it is the teacher doing the work, this can seem quite dull and boring for the students. On the other side, getting enough used computers for the students (even if they work in pairs) for a single lesson a year can be expensive and time-consuming. Moreover, working with the actual working PCs in the computer lab is not recommended as parts like the CPU and the CPU cooler are quite as fragile as expensive. Furthermore, there is an electrical danger for students working inside computers.

An immersive experience designed with learning objectives focusing hardware components of a computer can contribute to CS classes: for motivational purposes and for teaching about those contents. The next sections present the learning objectives and the design of the immersive EVE *Bill's Computer Workshop*.

### 5.1.1.2 Learning Objectives

Regarding the components of a computer, possible learning topics can be separated into conceptual frameworks like the von-Neumann architecture<sup>2</sup> and modern system architecture<sup>3</sup> including the actual, haptic components that are important when assembling or buying a computer. Both topics are relevant learning contents to understand how a computer works, which is why both became part of several secondary school curricula (e.g. Staatsinstitut für Schulqualität und Bildungsforschung München, 2019). As there are already some visualizations for the von-Neumann architecture, the developed EVE focuses on the components of a modern desktop computer<sup>4</sup>.

The learning objectives for *Bill's Computer Workshop* follow the Bavarian CS curriculum for the 12th grade: In the Lernbereich (learning area) 4, the students are supposed to develop skills for explaining the schematic design and function of a computer system including the components *processor*, *storage* (*primary* and *secondary memory*), *input* and *output components* as well as the *bus system*. Following a representation of computer systems in the German school book Klett (Brichzin et al., 2010), *Bill's Computer Workshop* was designed according to the scheme shown in Figure 5.1. The learning objectives are based on the lowest cognitive level of Bloom's taxonomy, remembering contents (referring to *knowledge*). The learner is supposed to be able to name the components and their functions.

### 5.1.1.3 Narrative

At the beginning of the game, the learner enters a room similar to a home office. Some introductory text is displayed in front of the user, explaining the *teleport* function. After teleporting next to a computer, the user tries to activate the monitor

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<sup>2</sup>The von-Neumann architecture derived from the document *First Draft of a Report on the ED-VAC* (for a full version, see Godfrey, 1993), where von Neumann describes a "very high speed automatic digital computing system" (Godfrey, 1993, p. 9). The proposed digital computer consists of a *processing unit* (including an *arithmetic logic unit* and *processor registers*), a *control unit* with an *instruction register* and a *program counter*, a *memory* (storing *data* and *instructions*), an *external mass storage*, as well as *input* and *output mechanisms* (Godfrey, 1993).

<sup>3</sup>The beginning of modern system architecture can be seen in the rise of personal computers (PCs). For example, the early *IBM Personal Computer* included a "microprocessor, the 40 K-byte extended Microsoft BASIC in ROM (read-only memory), up to 64 K bytes of dynamic memory, up to two disk drives, a cassette interface, a built-in speaker, and five expansion slots" (G. Williams, 1982, p. 37). It was expandable with a supplemental graphics adapter card (G. Williams, 1982). Most of the components' functions are identical those of their more powerful versions of today.

<sup>4</sup>When introducing the new Computing curriculum for the UK, the report *Shut Down or Restart?: The Way Forward for Computing in UK Schools* (Great Britain, 2012) noted that one of the main concepts of CS refers to *architecture*, describing the large scale structure of computer systems, including the real physical structure.

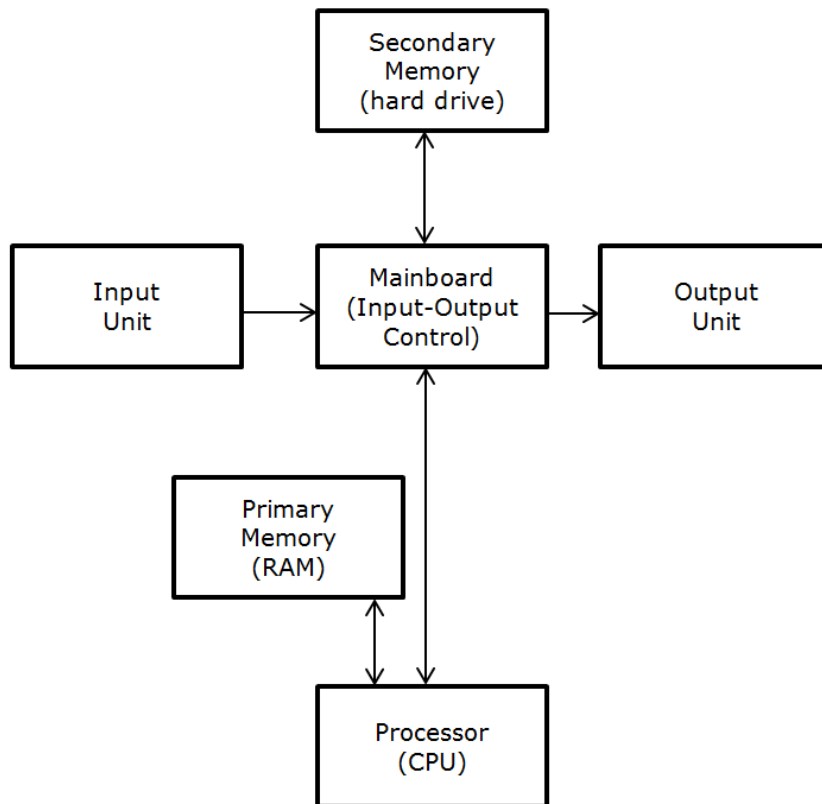


Figure 5.1. Schematic Design of a Computer System (Brichzin et al., 2010, p. 89)

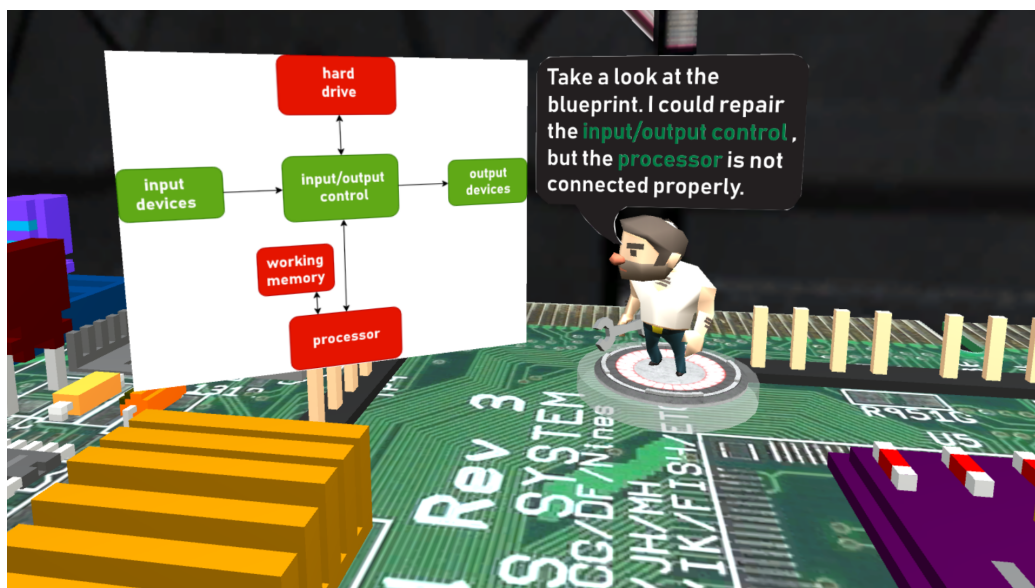


Figure 5.2. Bill's Computer Workshop - Bill Explains the Computer's Architecture

of the computer but gets an error. Another textbox explains the *interaction with objects*. The user enters the computer by pressing its on/off button. The user can explore the inside of the computer on several levels (ground level: mainboard, middle level: graphics card, top level: hard drive). After some time of exploring, the user finds a mechanic named Bill as a social actor who first asks for the player's help for repairing the computer and then explains the function of the mainboard (Fig. 5.2). Bill shows the blueprint of the computer (the schematic design shown in Fig. 5.1) and the user gets his/her first task: Finding the CPU, which is located right behind the player. When picked up, the user holds the CPU in his/her hand (in the HTC Vive setting, the user can take a closer look at the component by moving the controller) and gets an explanation for the function of the CPU. Bill gives a hint that the CPU has to be inserted into the CPU socket from above, meaning that the user has to use another teleporter in order to go up one level. After inserting the CPU into the socket, the user sees a notification that the CPU was inserted correctly and that the computer can now run programs and process data again. When returning to Bill, he explains that the mainboard and the processor are now connected and that the CPU can now communicate with the peripheral devices. But he also tells the user that the primary memory is not working yet, so the player has to find it on the graphics card and insert it into the RAM slots. After finding the RAM, a message explaining its function as primary memory is shown. Again, the user has to insert the RAM from above into the right slots, followed by an explanation that the computer can store and load data and programs temporarily. The return to Bill is followed by short tests of executing programs and of processing and storing data, ending up with Bill noting that long-term storage is still not possible. Bill assumes that something might be wrong with the hard drive on the top level of the computer. After taking a couple of teleporters to the highest level of the environment, the user can reconnect the power supply to the hard drive. A message is shown, describing the hard drive as the long-term memory of the computer. The user returns to Bill who praises him/her for the good work. Bill carries out two tests (with the affected components being highlighted on the blueprint), simulating a key press from the keyboard (input device) that is processed through the mainboard by the CPU, resulting in a printed "S" on the monitor (output device). The second test simulates opening and storing a video. The processor accesses the RAM to buffer the video before saving it to the hard drive for long-term storage. On top of the tests, Bill, again, summarizes the components shown on the blueprint: mainboard (input-/output-control), processor (CPU), primary memory (RAM), secondary memory (hard drive), input devices (e.g.

keyboard), and output devices (e.g. monitor). Bill sends the player off and tells him/her that there is a teleportation point near the entry point that will transport the user outside. After the user activates this teleportation point, he/she finds him-/herself back in the home office room again, being smiled at by a laughing face on the monitor.

#### 5.1.1.4 Interaction

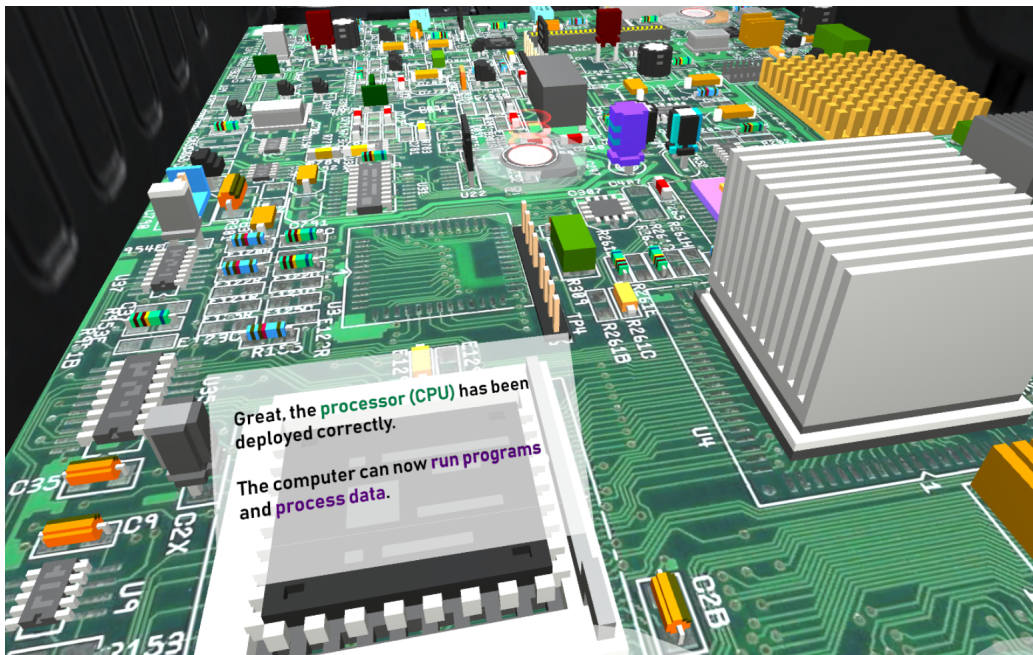


Figure 5.3. Bill's Computer Workshop - Interaction with the Environment

The interaction in *Bill's Computer Workshop* is gaze-based (Fig. 5.3); the user is able to teleport between various teleporter points by looking at them and pressing a button/clicking the mouse<sup>5</sup>. Picking up/activating objects basically works the same: The user looks at an object and presses a button/clicks the mouse, leading to the selected object appearing in the user's hand (which was, in terms of the mobile VR and the laptop, the lower right corner). Picked up objects (CPU, RAM) can only be put down by inserting them into the right slots that are, for each task, described by Bill. The same goes for speaking with the mechanic: The user has to look towards Bill and press a button/click the mouse in order to get new quests or to read the explanations for the repaired components. In the HTC Vive setting, the user is

<sup>5</sup>The gaze-based interaction via looking/clicking is the same for all different technologies and varies only in the ability of moving the hands/controllers when using the HTC Vive.



able to walk off the teleportation points and explore the surrounding area within the boundaries of the VR room scale area (when standing on a hovering teleporter, this may lead to the user floating in the air). Picked up objects were attached to one of the controllers of the HTC Vive. Doing so, the user could take a closer look at them. While these are nice gimmicks to enhance presence, they do not add any functionality to the software. To read the texts, the user would have to return to the teleporter points anyway as the room-scale area was not big enough to cover the whole computer environment.

### 5.1.2 Fluxi's Cryptic Potions: Asymmetric Cryptography

The next environment focused on a metaphorical approach to teaching and learning about asymmetric cryptography in terms of public and private key encryption/decryption. In *Fluxi's Cryptic Potions*, the user gets transported into a medieval chamber where he/she writes letters to several people, trying to win the heart of his/her heartthrob. The letters can be encrypted, signed, and decrypted through the use of different potions. In the meantime, the player gets advice from his/her carrier dragon who also delivers the letters to the post office.

The secure transmission of information over distances has always been a relevant topic regarding communication. The rise of distributed communication networks, which are characterized by distant participants that never met before, asked for new directions in cryptography, as the exchange of one secret key to encrypt and decrypt messages (symmetric cryptography) was no longer always possible. A key idea trying to solve this problem is the asymmetric encryption/decryption. Public and private key algorithms like the Diffie-Hellman key exchange<sup>6</sup> (Diffie & Hellman, 1976) or the RSA encryption/decryption process<sup>7</sup> (Rivest et al., 1978) present concepts of how distant parties can communicate securely without having any prior contact. All scenarios deal with the danger of a third party, the man in the middle, who intercepts messages in the network.

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<sup>6</sup>In their article *New Directions in Cryptography*, Diffie and Hellman proposed an asymmetric encryption/decryption method for ensuring privacy in distributed networks by utilizing one-way functions (easy to compute in one direction, but computationally infeasible to solve in the other direction).

<sup>7</sup>Rivest, Shamir, and Adleman (1978) suggested an encryption method that includes a public revelation of one part of a key (the public key for encryption) and a corresponding private key to decrypt the message. In terms of signing a message, the privately held decryption key can be used to encode a message, which can be revealed with the corresponding publicly revealed encryption key.

### 5.1.2.1 Related Work for Learning About Asymmetric Cryptography

While the topic is relevant for understanding the secure transfer of messages between distant senders/receivers, which makes up a considerable amount of our everyday communication, the underlying mathematical concept of one-way functions can seem quite abstract and complicated to explain to children. For fostering understanding skills at a conceptual rather than a mathematical level, various metaphorical approaches have been developed to teach the concept of public and private keys.

An idea from the CSE show includes the use of locks and keys (UC Computer Science Education, 25.10.2008) to raise awareness for problems occurring in an anonymous network and then find a (metaphorical) solution. In the activity, a few students are lined up in a row, representing a network. Then, a student on one side is supposed to send a box with a bar of chocolate to the other side of the network. As the student does not want anyone else in the network to get the chocolate, he/she puts a padlock on the box before sending it over. Once the box reaches the other side of the network, students quickly realize that it would be dangerous to just send the key for the padlock through the network as well. A possible solution is that the student on the other side of the network puts his/her own padlock on the box as well (so that there are now two padlocks on the box) and sends the box back to the sender. The sender then removes his/her first lock using his/her own, private key and sends the box back again. When the student on the other side of the network receives the box again (which is now only locked with one padlock), he/she can open the box by using his/her own key and, finally, gets the chocolate. Tim Bell, the founder of the CS Unplugged program notes that this particular technique remains with a possible attack where a man-in-the-middle pretends to be the intended receiver and sends the box back with his/her own padlock. Some students are able to figure this problem out by themselves what gives them the experience of a security analyst's work, creating the opportunity to spark discussions about how to address this weakness (UC Computer Science Education, 25.10.2008). The concept engages students to think about the problems of distant communication in networks in a metaphorical way. Doing so, they do not need to understand the underlying mathematical functions behind the key and the lock. While this metaphor can raise awareness for problems occurring in distant communication processes, the process of signing messages (verifying the sender's identity) cannot be explained. The analogies of the padlock and the key struggle with the physical characteristics of a key (a key can not lock something by itself) and those of a lock (usually, copies of a lock are not distributed).

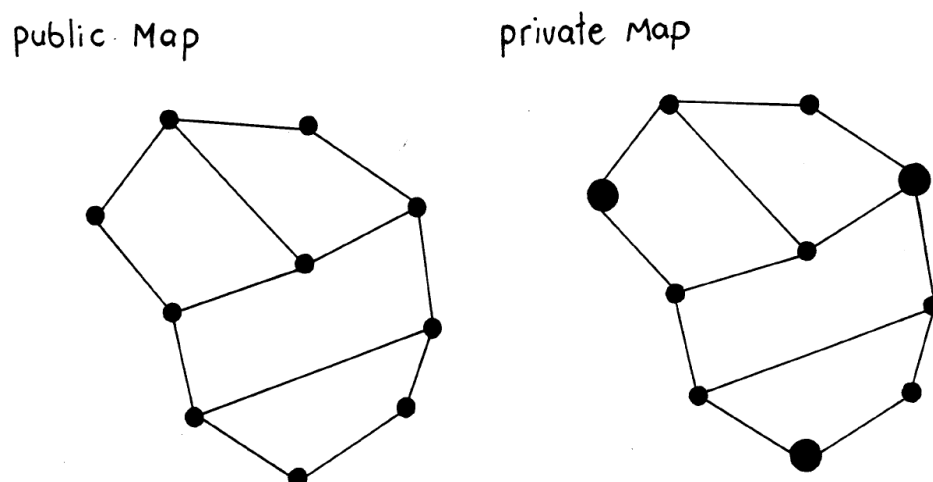


Figure 5.4. The Public Map and the Private Map in the *Kid Krypto* Activity

Another, more technical approach from the CS Unplugged project involves a public and a private map (see Fig. 5.4), where the private map displays a hidden solution for the Minimum Dominating Set problem (represented as enlarged intersections), applied to the public map (Bell et al., 1998). In the activity, a student picks a number and places random number on each intersection on the map so that all the numbers add up to the chosen number (e.g. if the chosen number was 42, the random numbers could be 4,6,3,1,8,1,2,7,8,2 so that they add up to 42). Then, for every intersection, he/she adds the numbers of its three neighbors to the intersection's current number and adds the total as a second number to the intersection (e.g. if the intersection has the number 3 and its two neighbors have the numbers 6 and 4, the intersection gets the second number 13). The student erases the first numbers and sends the map (now only containing the second numbers) to the other student who has the private map. By just adding up the numbers at the intersections that are enlarged on the private map (e.g. 13, 17, and 12), the other student receives the original message (42). The activity is quite challenging but it gives students an idea of how information can be securely exchanged using only public information. In addition, the activity gives an insight into computational complexity as the Tourist Town activity (Bell et al., 1998) should be explained first in order grasp the idea of the Minimum Domination Set problem. A simpler understanding of one-way functions is given in the video for cryptographis protocols (UC Computer Science Education, 2008), where a telephone book is used to demonstrate how solutions can be easy to find in one direction (searching for a person's phone number) while the other direction (searching for the person to whom a given number belongs to) can be quite hard. A

classroom activity for this idea has been introduced as *The Peruvian Coin Flip*, where and-gates and or-gates are used to build up a circuit that processes binary inputs in order to verify a coin toss over a telephone (Bell et al., 1998).

The YouTube channel *Art of the Problem* presents an activity where the Diffie-Hellman Key Exchange is visualized through mixing colors (Art of the Problem, 30.07.2012). They introduce the idea of a one-way-function as the process of color mixture, stating that it is 1) easy to mix a new color with two known colors and 2) hard to reverse a mixed color in order to find its exact original colors. In the first step, both participants agree publicly on a starting color. Then each participant adds an own, secret color to the starting color. The resulting mixed colors are sent to each other. Even though these messages (and the agreement on the starting color) can be indoctrinated by a third party, this party would not know the original secret colors. By adding their own private colors to the obtained color mixture, both participants receive the exact same mixed secret color without anyone else knowing it. In their video, they pursue this metaphorical approach by explaining this method with modular arithmetic (Art of the Problem, 30.07.2012). The mixture of colors works well for introducing the idea of a distant key exchange (like the Diffie-Hellman key exchange) but its applications for really encrypting and decrypting messages in the form of an activity are limited. The realization sometimes fails in reality as the amount of color has to be measured exactly for successfully mixing colors to the same color.

The website *IDEA* presents nonverbal algorithm assembly instructions (similar to assembly instructions for IKEA furniture). In their instruction *Public Key Krypto*, they present methods for encryption/decryption and signing, using the metaphor of a box that can be locked in two directions: While one part of a key pair can lock/unlock the box towards the right, the other part of the pair can lock/unlock the box towards the left. This procedure makes sure that the box cannot be unlocked using the same key twice. The box can only be opened when the lock is in the middle. One part of a participant's pair (the public key) is spread among all other participants of the network. The first scenario (encryption/decryption) shows how anyone in the network can encrypt messages using the public key (locking the box towards the left), which can only be unlocked by the participant with the private key (which unlocks the box towards the right). The second scenario (signing) shows that if the box is locked with a participant's private key, the box can only be unlocked by using the corresponding public key, thus making sure that the box was locked by the participant owning the private key (Fekete & Morr, 14.02.2018). *IDEA* describes an idea rather than an activity. It might be possible to build a box like this, but the metaphor still needs

some explanation. Like the CS Unplugged idea, a related activity would rely on the use of a box rather than encrypting/decrypting the message itself.

The concept of *Fluxi's Cryptic Potions* integrates ideas from all three approaches, but presents a new metaphor: Messages can be encrypted/decrypted/signed by using potions. Each potion belongs to a pair, consisting of a public and a private potion. While the public potion is stored at a public location (such as a post office) where anybody can ask for a copy/a few drops of the public potion, the private potion only belongs to one person. An encrypted letter can only be decrypted with the corresponding potion. Trying to decrypt a message with the same potion used for the encryption results in further encryption. This EVE modifies (see chapter 3 for a discussion on the use of VR in education and Puentedura's SAMR model) the existing approaches by adding technology, in order to transform the learning experience.

### 5.1.2.2 Learning Objectives

With *Kid Krypto*, Fellows and Koblitz (1993) introduced ways to communicate cryptographic ideas and protocols to children. By distinguishing cryptosystems in terms of their *accessibility* in addition to their *efficiency* and *security*, they propose a hierarchy including notions like *accessible and secure for ages 5–10*, *accessible and secure for high school students*, etc. For presenting cryptographic ideas to young children, three 'building block' ideas were selected:

- the notion of an algorithm, and of computational complexity,
- the notion of a one-way function, and
- the notion of an information hiding protocol.

There are some interesting activities presented in section 5.1.2.1 that build upon the idea of computational complexity. While some of them rely on a mathematical background, the purpose of the developed EVE is to teach the general idea of a one-way function without mathematical notions.

Thus, the aim for *Fluxi's Cryptic Potions* environment is to foster the understanding of the concept of asymmetric cryptography as well as to enhance an understanding of the reasons and processes of encrypting and signing messages in a network. The learning objective is, therefore, to enable the student to explain the basic idea of asymmetric cryptography using the example of public/private key encryption/decryption. This learning objective can be allocated to the second level of Bloom's taxonomy, *comprehension*, in terms of understanding concepts, as the required skills to explain the concept exceed simple remembering processes.

### 5.1.2.3 Narrative



Figure 5.5. Fluxi's Cryptic Potions - Fluxi Explains How the Potions Work

When the game is started, the player finds him-/herself in a medieval chamber, sitting in front of a desk with a dragon saying “Hey! Look here and click on me!”, hovering in the window. On the left-hand side, the player finds a cupboard with some potions on it. The dragon, Fluxi, tells the user that he/she received a new letter and places it on the table. After a short explanation of the interaction, the player can open the letter. In the letter, the player’s best friend, Nikolay, tells that Sir Dance-A-Lot (the player’s master) organizes a feast this evening and asks the player if he/she will be there too. After placing the letter back on the table, Fluxi suggests to write back a letter to Nikolay. In the letter, the player writes that he/she is going to be at the party but has not received an invitation yet. Fluxi delivers the letter to the post office and returns with an answer from Nikolay. The new letter is encrypted and does not make any sense. Fluxi explains that the post office provides two potions for every customer: one public potion, which can be requested by everyone from the post office, and a private potion, which solely belongs to the customer. A letter encrypted with one of the potions can only be decrypted with the other one. As Nikolay has encrypted the letter with the player’s public potion, it has to be decrypted with the player’s private potion (Fig: 5.5). After spilling some drops of the user’s private potion on the letter, it is possible to read the message: Nikolay

heard that Princess Isolde, Prince Charming, and Fluxi's aunt Gertrud are about to join the festivity as well. As Nikolay knows, the player always wanted to dance with one of them. He suggests that the player should write a letter and ask this person to dance with him/her. Because Sir Dance-A-Lot wants to dance with them all, the letters should be encrypted to make sure that he does not get wind of the plan. The player replies that this might be a good idea as otherwise, Sir Dance-A-Lot might not invite him/her to his party and encrypts the letter with Nikolay's public potion. Fluxi, again, delivers the letter to the post office and returns with the party invitation from Sir Dance-A-Lot. The letter seems to be encrypted too. Fluxi explains that Sir Dance-A-Lots tends to sign his letters in order to make sure that people know that the letter really comes from him. By signing the letter with his own private potion, the letter can only be encrypted with his public potion. As nobody else owns Sir Dance-A-Lot's private potion, the recipient can be sure that it was him who sent the letter. The player decrypts the invitation with Sir Dance-A-Lot's public potion. Afterward, as Fluxi suggests, he/she writes back a letter that the player signs with his/her own private potion. After returning to the chamber, Fluxi asks the player who it is that he/she wants to dance with. The player can select either Princess Isolde, Prince Charming, or Fluxi's aunt Gertrud (with this third option, it was tried to overcome gender biases). Once a potential dancing partner is selected, Fluxi suggests that the player should write a letter to the person/dragon. After writing the letter, which asks the other for a dance, Fluxi gets the public potion of the communication partner from the post office, which is then used to encrypt the letter. Shortly after bringing the letter to the post office, Fluxi returns with a signed answer from the selected partner. Again, the user decrypts the letter using the potion that Fluxi brought from the post office for encrypting the last letter. The chosen person/dragon complains that he/she does not believe that the letter is real and that he/she wants to receive a letter that is signed by the user. Following the request, the player writes the letter again and, this time, encrypts it with the public potion from the partner and signs it with his/her own private potion. Fluxi delivers the letter and returns with a signed and encrypted response. After encrypting the message using the user's private potion and the partner's public potion, the hidden message is displayed: The other one appreciates the invitation and looks forward to dancing with the player. Fluxi congratulates the player for winning the selected person's/dragon's heart and for learning how asymmetric cryptography works.

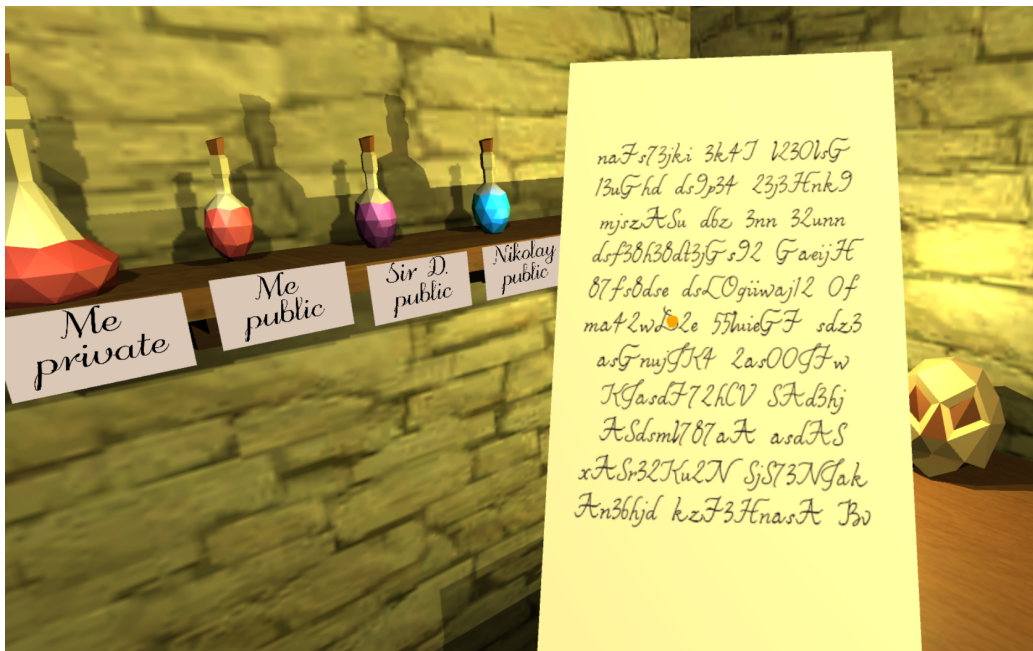


Figure 5.6. Fluxi's Cryptic Potions - Interacting with the Letters

#### 5.1.2.4 Interaction

The interaction in *Fluxi's Cryptic Potions* is gaze-based as well (Fig. 5.6). The user can talk to the dragon by looking at him and pressing a button/clicking the mouse. When looking at the stack of paper and pressing a button/clicking the mouse, the player can place a blank letter on the desk if the current task is to write a new letter. Another click on the empty letter on the desk changes the empty letter to a written letter. A written letter can be picked up (so the user can read it) and put down. The potions could be picked up from the cupboard and be placed back again. When holding a potion, a written letter could be changed to an encrypted/signed one, an encrypted/signed letter could be changed to a decrypted letter when using the right potion. When using a wrong potion, the letter changed anyway to an encrypted letter but changed back after some seconds, leading the dragon to say that this would not make any sense and that the player should try again. As the game was played in a sitting position, there was no need for further locomotion or interaction with the world. For the HTC Vive setting, it would have been possible to stand up and walk around (even though no user came up with this idea).



### 5.1.3 Pengu's Treasure Hunt: Deterministic Finite State Machines

The EVE *Pengu's Treasure Hunt* focused on a metaphor for deterministic finite state machines where states were represented through islands, input characters from the alphabet through boats, transition functions through ship routes, and a final state through a treasure island. The EVE features a pirate treasure hunt where the player has to find three treasure chests. To do so, he/she has to discover ship routes between islands in order to complete a treasure map and to find key parts. Once the treasure map is completed and all key parts collected, the player can open the treasure chest of the current world and return to the main menu.

#### 5.1.3.1 Related Work for Learning About Finite State Machines

In fact, the finite state machine itself is actually a metaphorical representation of the entirety of regular language of the type-3 grammar in the Chomsky hierarchy (Chomsky, 1959). To describe a given regular language  $L$  with a finite state machine  $M$ , we use  $M = (Q, \Sigma, \delta, s_0, F)$ , with

- $Q = \{q_0, q_1, q_2, \dots, q_n\}$  as the finite set of states,
- $\Sigma$  as the alphabet containing the symbols of the language,
- $\delta$  as the set of the language's transition functions,
- $\delta = Q \times \Sigma \rightarrow Q$ ,
- $s_0 \in Q$  as the start state, and
- $F \subseteq Q$  as the amount of accept states (Sipser, 2009).

The automaton processes a string  $w$ , starting in its initial state  $q_0$ .  $M$  reads the symbols of the string one by one from left to right. After each symbol,  $M$  moves from one state to another according to the corresponding transition function. After reading the last symbol,  $M$  produces the output (accept or reject), depending on whether the machine is in an accept state or not. The word  $w$  is accepted by  $M$  if the current state after reading the last symbol is an accept state, otherwise, it is rejected (Sipser, 2009). Finite state machines find usage in many situations of everyday life like automatic doors and various electromechanical devices. Furthermore, Sipser (2009) uses the finite state machine as an introduction to computational models in order to understand the functionality of a real computer, naming the finite state machine the simplest computational model. Language, in general, has been identified as a fundamental idea of CS based on four criteria (Schwill, 1997). Based on the work of

Bruner (1960), Schwill (1997) states that a fundamental idea “is a schema for thinking, acting, describing or explaining” (p. 2) that

- has to be applicable or observable in many areas of a domain (horizontal criterion),
- may be taught at every intellectual level (vertical criterion),
- is observable in the domain’s historical development, and
- is related to the everyday life.

Finite state machines belong to the section *syntax* and the subsection *accepting* in the category *language* from Schwill’s (1997) taxonomy of fundamental ideas of CS. The concept of regular languages, which are represented by finite state machines, finds many uses in CS (Shaw, 1985), in everyday life (Computer Science Unplugged, 2018), and in language (Mohri, 1996). Furthermore, Wing (2006) describes finite state machines as a class of computational abstraction that helps developing Computational Thinking as a thought process to formulate a problem and its solution using multiple ways of abstraction and decomposition so that a computer could effectively carry out a program to solve the problem.

As supposed by Schwill (1997) in his fundamental ideas of CS, languages pose an important learning content; they are involved in several school curricula (e.g. Staatsinstitut für Schulqualität und Bildungsforschung München, 2019). Since the use of regular languages (as theoretical CS in general) is difficult to explain to students, finite state machines are a popular way to visualize this type of language (Hromkovič, 2004). Such visualizations of simple automata can be used to explain corresponding phenomena, situations or devices of the digital world like the function of a digital watch (Computer Science Unplugged, 2018).

As a part of the curriculum of CS undergraduate studies and of some school curricula, several kinds of software for the transformation of regular expressions to drawn state machines are already established (Diehl, 2007; Hulden, 2009; van Zijl, Harper, & Olivier, 2001). To increase visualization and interaction in automata theory courses, Hung and Rodger (2000) present the learning and teaching tools *JFLAP* (Java Formal Languages and Automata Package) and *Pâté*. Both *JFLAP* and *Pâté* visualize the transformation process between different representations of languages. *JFLAP*, for example, contains the preparation of regular expressions and their conversion from and to nondeterministic finite automata. This helps the learner to explore and understand the connection between different representations of the same language. This visualization process can be helpful during the learning process for finite state

machines and for regular languages but requires adequate previous knowledge in the topic, so it may not be adequate as an introduction. Because of the importance of regular languages for understanding everyday life concepts and enhancing Computational Thinking skills, an early adaptation of the concept of finite state machines, which fits children's cognitive abilities and interests, is needed.

Research has shown that using games for teaching basic concepts of theoretical CS like finite state machines and Turing Machines can be a useful approach. Korte, Anderson, Pain, and Good (2007) developed a didactical sequence to teach these concepts using a purpose-built game engine. In this learning by game-building approach, undergraduate students were asked to copy an existing game or to write their own game using the game engine. In case of the finite state machines topic, students took existing finite state machines and set them into a narrative context. In a student's game, *Becoming Leader of the Conservative Party*, the player has to complete several steps (which represent the transition functions) in order to become the new leader of the conservatives. The requirements for designing a game corresponding to the finite state machines topic were:

- It is always possible to reach the goal;
- the game contains at least one 'long' cycle (i.e. at least five states before a repeat);
- within at least one game-level it is always possible to reach the initial state;
- the game has at least one interleave.

By giving the students the possibility to create their own game, they could choose a context that was relevant to them personally. Doing so, the students did not only understand the concepts of finite state machines but created a connection to their everyday life and thinking all by their own (Korte et al., 2007).

With regard to everyday life problems and thinking patterns, a CS Unplugged activity based on finite state machines was introduced. The activity "is based around a fictitious pirate story which leads to the unlikely topic of reasoning about patterns in sequences of characters" (Computer Science Unplugged, 2018). The goal of the game Treasure Hunt is to find a way to the Treasure Island (the final state) on a map that consists of several islands (the states of the finite state machine, which are represented by other students) and a fixed set of routes (the state-transition functions). The two departing ships on every island, A and B, are the two possible inputs from the alphabet and lead to another (or the same) island. In the activity, seven children are chosen to represent the islands, holding cards to identify their island. The cards

have secret instructions (namely the shipping routes) on their back. On each island, a student gets to choose between the two boats, not knowing their destination. After making a decision, the student representing the island tells the player his/her next destination. Every student gets a blank map where only the islands are drawn without the routes of the ships. During the game, the students complete their map with the discovered ship routes what results in an abstract representation of the underlying finite state machine (Computer Science Unplugged, 2005). The treasure hunt game of CS Unplugged is widely accepted and has been adopted in analog (Heeren, Magliery, & Pitt, 1998; K. Anderson, López, Ho, & Martens, 2014) and digital (swisseduc.ch, 2017) ways. The concept of the developed *Pengu's Treasure Hunt* application tries to refine the ideas of CS Unplugged and puts the user into an immersive EVE for an introduction into the Theory of Computation. The initial idea of CS Unplugged is augmented<sup>8</sup> by using technology to immerse the user in the game, to include all students, and to simplify the creation of the map.

### 5.1.3.2 Learning Objectives

The aim of *Pengu's Treasure Hunt* was to ease the learning process for finite state machines by creating a metaphor that is orientated on the original CS Unplugged activity. The learning objective of the designed EVE is to understand finite state machines in such manner that students are able to create their own finite state machines to a given task. Even though the map is created automatically in the game (Fig. 5.7), as the game gets harder, the player has to understand the concept of the underlying language and has to cognitively map the language with the incomplete treasure map. The player also needs to develop the ability to reconstruct the missing transition functions between the states. Users trying to apply a simple trial-and-error approach would not even get past the second level as the finite state machines underlying the island worlds increase in complexity. Thus, the student has to develop skills in terms of (re-)constructing the language for a given problem. This can support a categorization of the intended learning objectives of *Pengu's Treasure Hunt* as *application* skills, representing the third level of Bloom's taxonomy.

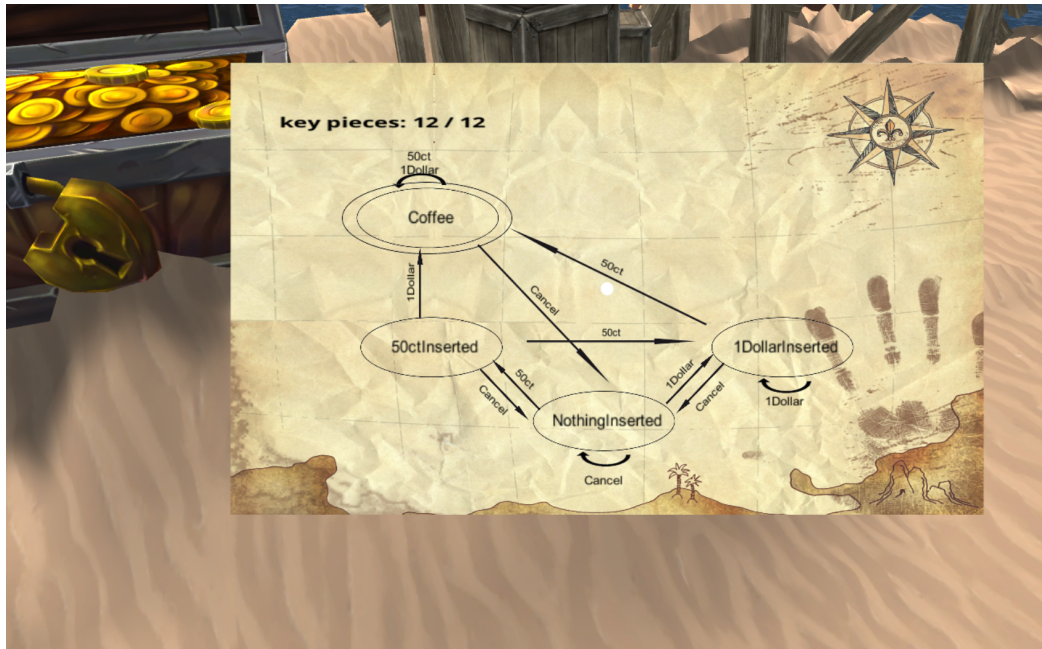


Figure 5.7. Pengu's Treasure Hunt - the Map Showing a Finite State Machine

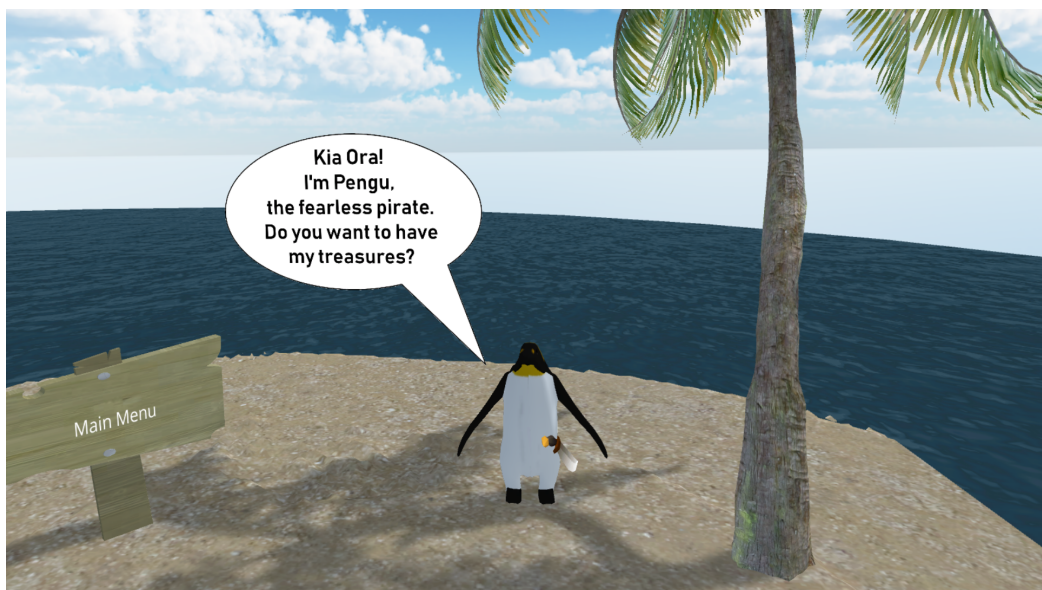


Figure 5.8. Pengu's Treasure Hunt - Pengu Introduces Himself

### 5.1.3.3 Narrative

The player lands on an island that is inhabited by a penguin. The penguin introduces himself as Pengu, the fearsome pirate and offers the player his treasures (Fig. 5.8). Pengu explains that in order to attain his treasures, the player has to find the treasure chests in three island worlds and open them by collecting all key parts, which are hidden on the ship routes between the islands. Only if the player finds all possible routes, he/she completes the key and is able to open the chest. After trying out a boat on the main menu island, Pengu draws the player's attention to the map that the user holds in his/her hands. The map shows all islands and routes that the player has yet discovered in the current world as well as the number of key parts, both collected and needed, to open the chest. Pengu explains the first world: On each island, only one boat will take the player to the next island, the other boat will go back to the same island. The player gets teleported to a new island, called the Palm Island. From here, he/she can explore the three islands (an island with palms, an island with penguins, and an island with a shipwreck) by taking one of the two boats, *sloop* or *galley* (the player can choose between the same two boats on every island). When the player gets to Treasure Island for the first time, he/she finds a treasure chest but is not able to open it. Through traveling to the different islands, the player finds more and more routes and parts of the key. After finding all routes and collecting all parts, the player returns to Treasure Island and opens the treasure chest. The player returns to the main menu island where the fearsome Pengu praises the player for attaining the first treasure. Then, Pengu explains the logic of the second world: The player will only get to the Treasure Island if the last three boats on any journey are *banana boats* (the *apple boat* will always lead back to the start island). After the explanation, the player gets teleported to the new world, again starting on the Palm Island. This time, the player can explore four islands (the three islands mentioned above plus a desert island with a wooden scaffold). After finding all eight routes, the player can open the treasure chest on Treasure Island and returns to the main menu island. Pengu is impressed and explains the third world: The player will enter a coffee vending machine and explore its different states. The automaton only accepts 1€ and 50ct coins. If the total of the inserted coins exceeds 1.50€, the last inserted coin is returned (so there is no change and the amount has to be exact). There is also a Cancel button that resets the machine to the initial

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<sup>8</sup>In this context, *Augmentation* means that the technology is used as a substitute for the CS Unplugged activity while providing functional improvement, see chapter 3 for a discussion about Puentedura's SAMR approach.

state and returns all the inserted coins. When the 1.50€ are inserted correctly, the coffee is being brewed<sup>9</sup>. The player enters the world and explores the four islands (the same islands as before), which are now named after the current state of the machine (“nothing inserted”, “50ct inserted”, “1€ inserted”, and “coffee”). Again, after finding all twelve routes, the player can open the treasure chest on the “coffee” island. Back in the main menu, Pengu is shocked that the player attained all his treasures and therefore stole his rent. He congratulates that player for becoming a true pirate.

#### 5.1.3.4 Interaction



Figure 5.9. Pengu’s Treasure Hunt - Interaction with the Boats

The interaction with the objects and the social actor was gaze-based (Fig. 5.9). The dialogue with the penguin proceeded by looking at the penguin and pressing a button/clicking the mouse (sometimes, a task had to be fulfilled first). The same interaction was applied for the boats: By looking at a boat and pressing a button/clicking the mouse, the player switched scenes (rather than just geographical teleportation) to another island. While this might diminish the sense of presence due to the lack of orientation, this locomotion method was chosen as the development of a mental model including geographical locations of the states and therefore assumptions concerning the outcomes of the transition functions (destinations of the boat routes) had

<sup>9</sup>Even though it would make more sense that the machine would not react to any user inputs in the final state, it was decided that the “Cancel” input still leads back to the initial state. Otherwise, the player could not complete the map as he/she could not leave the last island.

to be avoided. In the laptop and mobile VR program, the map was shown when the user looked down. In the HTC Vive program, the user held the map in his/her hand (attached to one of the controllers). In all three cases, the map was updated after every boat route and the discovered islands and routes between the islands were added; the number of collected keys was also updated. For the laptop and mobile VR program, no movement was possible besides the scene switches between the islands. In the case of the program for the HTC Vive, the user could walk around the islands freely. It did not add content to the story or changed the interaction possibilities with the boats but as the islands were small enough to be entirely explored by the user, this feature was supposed to contribute to the user's sense of presence.

## 5.2 Study One: Test of Effectiveness, Immersion, and Learning Topics

The first study with early prototypes of the software was conducted in November 2018. These prototypes were developed in a seminar for Immersive Learning at the University of Passau by pre-service teachers who had CS as their main subject (section 5.1 shows the final versions of the programs). The aims of the study were:

- to check whether the software prototypes are effective and how they could be improved in order to address the learning objectives better,
- to check the aptitude of the used immersive technologies to induce different levels of presence, and
- to check whether the topics covered in the EVEs are new to and suitable for the age group so that the results would not be influenced by previous experiences.

Therefore, the following hypotheses were formulated:

1. The students' performance in the posttest is significantly higher than their pretest performance.
2. There is a difference between the students' perceived sense of presence in the different provided technologies.
3. There is no correlation between the students' previous scholastic performance and their pretest performance.

Furthermore, the pilot study was supposed to be a test of the general procedure for the main study as well as an evaluation of the questionnaires and VR experiences in terms of understandability and required time for the children.



### 5.2.1 Sample

23 students (seven female) from the eighth grade of an Austrian school participated in this study in the 'DiLab', a laboratory for teaching and learning, at the University of Passau. The CS topics featured in the EVEs were not covered in their CS classes before. The students' scholastic performance<sup>10</sup> was conspicuously good in CS ( $M = 1.68$ ,  $SD = 0.67$ ) and ordinary in the subjects Math ( $M = 3.00$ ,  $SD = 1.25$ ) and German ( $M = 2.84$ ,  $SD = 1.12$ ).

### 5.2.2 Instruments

As the focus was set on the role of physical presence, the Slater-Usch-Steed (SUS) questionnaire was used (Slater et al., 1994). The translated questionnaire (Appendix C) assessed physical presence with six questions on a seven-point Likert scale<sup>11</sup> ( $\alpha = .88$ ). External regulation (six items,  $\alpha = .81$ ), introjected motivation (four items,  $\alpha = .52$ ), identified motivation (four items,  $\alpha = .79$ ), and intrinsic motivation (five items,  $\alpha = .84$ ) were assessed on a five-point Likert scale with a questionnaire evaluated by Hanfstingl, Almut, Andreitz, and Müller (2010). The original survey asked for motivation towards an unspecified subject. The questionnaire was adapted to assess the students' motivation towards the subject of CS (Appendix A). The emotional state questionnaire (Appendix B) included the items shame, enjoyment, anger, hope, pride, hopelessness, relief, anxiety, and boredom, displayed on a six-point Likert scale. The questionnaire was adapted from a survey used by Titz (2001). The emotions were categorized into the scales positive emotions ( $\alpha = .83$ ) and negative emotions ( $\alpha = .35$ ). The scale reliability of negative emotions is alarming and has to be investigated further in the main study. When interpreting the scales' Cronbach's alpha values (Cronbach, 1951) with a number of items  $k < 4$  (as it was the case for the pre- and post-tests, shown in ), and a cut-off value of  $\alpha = .70$  as acceptable scale reliability, sample sizes equal to or higher than 24 are recommended in order to meet at least 90.0% power of the Cronbach's alpha test (Bujang, Omar, & Baharum, 2018), which is why scale reliabilities for the pre- and posttests (Appendix D) and the self-efficacy questionnaire (Appendix E) are not reported.

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<sup>10</sup>The parents gave their permission that the teacher shared the students' grades with the investigator (anonymized via the ID code). Austrian grades range from 1 to 6 with 1 being the best and 6 being the worst grade.

<sup>11</sup>All used Likert scales measured the associated construct with 1 representing a low extent and the highest number representing a high extent of the construct.

### 5.2.3 Procedure

The procedure of the pilot study is shown in Figure 5.1. Prior to the pilot study, the students completed the motivation questionnaire and the learning objective examinations for the three learning areas (pretest). The participants used an individual code for these pre-questionnaires, which they would also use again later for the questionnaires in the study. In order to guarantee the anonymity of the students, their teacher noted their scholastic performance in the subjects German, Math, and CS on the pre-questionnaire without noting down the individual code. For the pilot study, the class was randomly separated into three groups. The participants of every group experienced all three software prototypes, but each group was provided a different technological setting (laptop, Mobile VR, or HMD) for every program. Within every group, each participant was handed a sheet to collect stamps for all the technological settings (one stamp) and the filling out of the related questionnaires for presence and learning outcome (another stamp). The questionnaires had to be filled out right after the corresponding VR experience. The six stamps could be collected for

- the completion of the laptop experience and the related questionnaires,
- the completion of the Mobile VR experience and the related questionnaires, and
- the completion of the HTC Vive experience and the related questionnaires.

The order of the programs was randomly mixed within the groups. All students could take their own time for completing the VR experiences and the questionnaires. After separating the students and leading them to their rooms, they were asked to fill out the emotion questionnaire. After finishing their stamp cards, the students saw a presentation explaining the metaphors used in the games and the desired learning objectives. After the presentation, the participants had to fill out a self-efficacy questionnaire about their confidence in solving tasks related to the learning objectives.

### 5.2.4 Findings

This section presents the findings of the pilot study in order to test the hypotheses. Outliers in negative emotions (1), anger (3), hopelessness (1), anxiety (1), boredom (1), presence (2), and post-test finite state machines (4) were not excluded due to the small sample size. Normal distribution of the dataset was tested using the Shapiro-Wilk method. Calculated  $W$  values were significant ( $p < .05$ ) for the scholastic performance in CS, negative emotions, and for all pre-tests. For all other variables, the dataset was normally distributed.

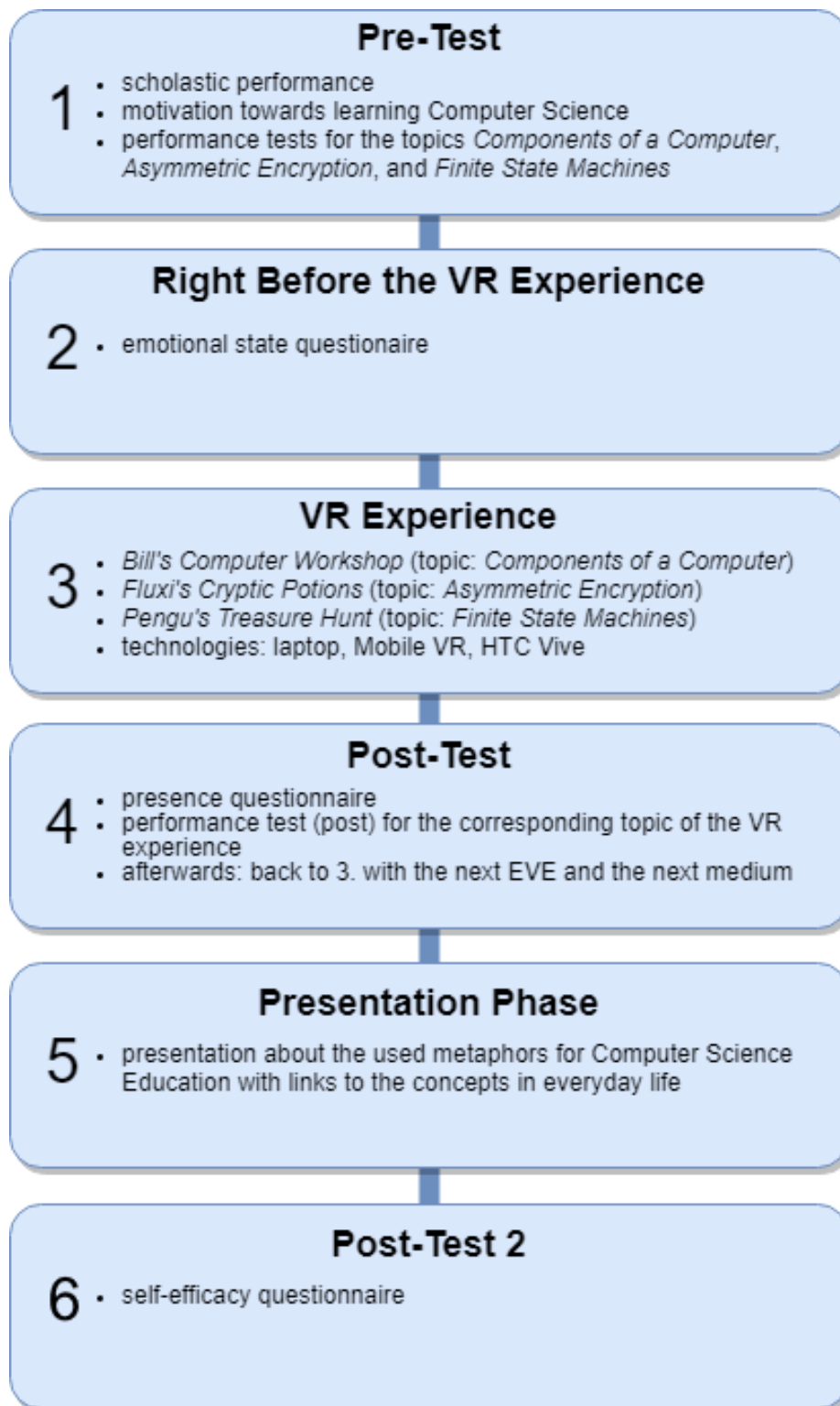


Figure 5.1. The Procedure of the Pilot Study

**5.2.4.1 Descriptive Statistics for Motivation, Emotion, and Self-Efficacy**

Table 5.1

*Results of the Pilot Study's Motivation Questionnaire*

	<i>N</i>	<i>mean</i>	<i>sd</i>
intrinsic motivation	23	3.52	0.83
identified motivation	23	3.27	1.01
introjected motivation	23	2.18	0.82
extrinsic motivation	23	2.20	0.92

Because of the small sample size, it was not possible to run a factor analysis on the used motivation questionnaire. As the questionnaire was evaluated by Hanfstingl et al. (2010, p. 48–49), the proposed factors intrinsic motivation, identified motivation, introjected motivation and extrinsic motivation (in terms of external regulation, see section 3.3.3) with their corresponding items were used for the evaluation of the pilot study. Doing so, the students were found to be predominantly motivated in a more self-regulated way (intrinsic and identified motivation) for learning CS (Tab. 5.1). The introjected type of motivation had the lowest score.

Table 5.2

*Results of the Pilot Study's Emotion Questionnaire*

	<i>N</i>	<i>mean</i>	<i>sd</i>
Security	23	3.43	1.16
Shame	22	0.36	0.66
Enjoyment	22	3.73	1.16
Anger	23	0.26	0.69
Hope	23	3.65	1.30
Pride	23	2.78	1.24
Hopelessness	23	0.35	0.71
Relief	23	1.91	1.56
Anxiety	23	0.61	1.08
Boredom	23	1.13	1.87

The emotion with the highest mean in the emotion questionnaire was enjoyment, followed by hope and security (Tab. 5.2). The weakest emotions were anger, hopelessness, and shame. Positive emotions ( $M = 3.03$ ,  $SD = 1.09$ ) including enjoyment, hope, pride, and relief were, on average, higher than negative emotions ( $M = .53$ ,  $SD = 0.56$ ) including shame, anger, hopelessness, anxiety, and boredom.

Table 5.3

*Results of the Pilot Study's Self-Efficacy Questionnaire*

	<i>N</i>	<i>mean</i>	<i>sd</i>
Self-Efficacy <i>Components of a Computer</i>	23	2.87	0.71
Self-Efficacy <i>Asymmetric Encryption</i>	23	2.72	0.82
Self-Efficacy <i>Finite State Machines</i>	23	3.07	0.59

The participants' self-efficacy values were high (with a maximum value of four) compared to their previous performance outcomes (see next section). The topic of finite state machines showed the highest self-efficacy means (Tab. 5.3).

**5.2.4.2 Results of the Pilot Study's Pre- and Posttests**

Table 5.4

*Results of the Pretest*

	<i>N</i>	<i>mean</i>	<i>sd</i>
Pretest <i>Components of a Computer</i>	23	1.74	2.58
Pretest <i>Asymmetric Encryption</i>	23	1.61	2.41
Pretest <i>Finite State Machines</i>	23	5.39	5.90

Most of the students had poor to no previous knowledge as the results from the pretests for the topics *components of a computer* (max. 9 points), *asymmetric encryption* (max. 8 points), and *finite state machines* (max. 19 points) show (Tab. 5.4). Some students handed in blank sheets. This was a problem as some of them were not even trying to solve the tasks as they were unfamiliar with the topics.

Table 5.5

*Results of the Pilot Study's Posttest*

	<i>N</i>	<i>mean</i>	<i>sd</i>
Posttest <i>Components of a Computer</i>	23	4.43	3.06
Posttest <i>Asymmetric Encryption</i>	23	2.91	2.56
Posttest <i>Finite State Machines</i>	23	10.14	4.53

The students' performance improved in the posttest in general. But, especially for the *asymmetric encryption* topic, results remained on a low level (Tab. 5.5).

When comparing the mean values of the pre- and posttest using the Wilcoxon Signed Rank test<sup>12</sup>, highly significant differences for the "Components of a Computer" [ $Z = -3.44, p < .01$ ] and *Finite State Machines* [ $Z = -3.38, p < .01$ ] tests and a significant difference<sup>13</sup> for the *Asymmetric Encryption* [ $Z = -2.25, p < .025$ ] test were found.  $H_{10}$  has to be declined;  $H_1$  is supported: There is a difference between the students' performance in the pre- and the posttest. As the students did the pretest just some days before the study and as they did not have any topic-related lessons in the meantime, it can be assumed that these differences derive from the use of the software. Regarding these results, EVEs can be considered effective.

Even though the topics were completely new for the students, the overall scholastic performance seems to correlate (using Pearson's  $r$ ) negatively (with 1 being the best and 6 being the worst scholastic performance) with the pretest performance for the topics *components of a computer* and *finite state machines* (Tab. 5.6). The scholastic performance in Math was found to be significantly correlated with the pretest of the topic *asymmetric encryption*. Thus, it is necessary to decline  $H_{30}$  and to consider  $H_3$  for all content areas: There is a correlation between the students' previous scholastic performance and their pretest performance. A student with better grades (especially in Math but also in CS) seems to be able to solve the pretest tasks better than a student with worse grades despite the lack of previous knowledge in these topics. But it could also be assumed that strong students had more interest in trying the tasks. These correlations were found for the posttests of the topics *components of a computer*

<sup>12</sup>As noted at the beginning of this section (5.2.4), the dataset is not normally distributed for the pretests. Thus, using a paired t-test is not recommended, which is why the non-parametric Wilcoxon Signed Rank test is used.

<sup>13</sup>A significance level of  $p < .025$  was used to assume a one-tailed, directed relationship.

Table 5.6

*Correlations between Scholastic Performance and Pretest Performance*

	Informatics	German	Math	Overall
Pretest <i>CoaC</i>	-.45	-.23	-.71**	-.55*
Pretest <i>AE</i>	-.30	-.20	-.51*	-.40
Pretest <i>FSM</i>	-.48*	-.36	-.55*	-.54*
Posttest <i>CoaC</i>	-.67**	-.53*	-.62**	-.69**
Posttest <i>AE</i>	-.40	-.28	-.44	-.43
Posttest <i>FSM</i>	-.52*	-.26	-.68**	-.56*
Improvement <i>CoaC</i>	-.33	-.38	-.02	-.25
Improvement <i>AE</i>	-.10	-.08	.05	-.03
Improvement <i>FSM</i>	.30	.27	.24	.31

*Note.* \* $p < .05$ ; \*\* $p < .01$ ; *CoaC* = Components of a Computer; *AE* = Asymmetric Encryption; *FSM* = Finite State Machines

and *finite state machines* as well. There are indicators that more correlations could also exist between the topics and the scholastic performances, which may not be found to be significant because of the small sample size. Furthermore, there are indicators that improvement from the pre- to the posttest might be associated with the scholastic performance as well, as a strong student might improve his/her performance with the *Bill's Computer Workshop* environment better than a weak student would while the improvement for the *Pengu's Treasure Hunt* environment could be more beneficial for a weak student. These assumptions were not found to be significant which, again, could be due to the small sample size of the pilot study.

#### 5.2.4.3 Results for the Students' Sense of Presence

Three different methods for the calculation of a presence value have been suggested: the original SUS method counting all items with a value of six or higher (max. total points: six) (Slater et al., 1994), the adapted method counting all items with a value of five or higher (max. total points: six) (Peck, Fuchs, & Whitton, 2011), and the mean value with a maximum of seven (Slater et al., 1994). The methods lead to different values, but all lead to the same result of *Bill's Computer Workshop* inducing the highest and *Pengu's Treasure Hunt* the lowest sense of presence (Tab. 5.7)<sup>14</sup>.

<sup>14</sup>As the distribution of the students was not equal, there is room for error on these findings.

Table 5.7

*Results of the Presence Questionnaire in the VR Experiences*

	<i>mean presence</i> <sup>A</sup>	<i>mean presence</i> <sup>B</sup>	<i>mean presence</i> <sup>C</sup>
Bill's Computer Workshop	3.65	2.78	4.88
Fluxi's Cryptic Potions	2.87	1.65	4.04
Pengu's Treasure Hunt	2.48	1.33	4.02

*Note.* <sup>A</sup> method counting all presence items 5 and above; <sup>B</sup> method counting all presence items 6 and above; <sup>C</sup> mean value.

Regarding the levels of immersion, the different measurement methods lead, again, to the same results, with the HTC Vive inducing the highest sense of presence and the laptop setting inducing the lowest sense of presence (Tab. 5.8).

Table 5.8

*Results of the Presence Questionnaire in the Different Immersive Settings*

	<i>mean presence</i> <sup>A</sup>	<i>mean presence</i> <sup>B</sup>	<i>mean presence</i> <sup>C</sup>
Laptop	1.52	0.52	3.22
Mobile VR	3.22	2.09	4.54
HTC Vive	4.43	3.33	5.29

*Note.* <sup>A</sup> method counting all presence items 5 and above; <sup>B</sup> method counting all presence items 6 and above; <sup>C</sup> mean value.

By analyzing 67 of the 69 presence questionnaires (two were excluded because of missing items), an ANOVA measuring variation between the students' presence means in the three different immersive settings (Tab. 5.9) showed significant differences between the settings laptop, Mobile VR and HTC Vive [ $F(2, 64) = 15.27, p < .01, \eta_p^2 = .32$ ]. A higher level of immersion leads to a higher sense of presence (Tab. 5.9). This result supports H2: There is a difference between the students' perceived sense of presence in the different provided technologies. It can be assumed further that the laptop setting induces the lowest sense of presence while the HTC Vive is capable of inducing the highest sense of presence.



Table 5.9

*ANOVA showing the Variation between Presence Means in the Three Different Technologies*

	<i>N</i>	<i>mean</i>	<i>sd</i>	<i>Sum of Squares</i>
Laptop	23	3.22	1.17	
Mobile VR	23	4.54	1.39	4.76
HTC Vive	21	5.29	1.20	

### 5.2.5 Discussion and Conclusions for the Main Study

Even though the sample was too small to evaluate further assumptions of the research model, it was possible to draw some conclusions for the further approach with the main study. The software was effective in its prototype state but has to be improved in terms of the learning objectives, which are examined in the tests. In particular, the software for learning about *asymmetric encryption* (*Fluxi's Cryptic Potions*) had to be enhanced as the mean value for the posttest still lay below half of the achievable score. This was supposed to be done by revising and prolonging the story as well as editing the contents of the in-game hints. Further improvement was also needed for the software covering the *finite state machines* topic (*Pengu's Treasure Hunt*) in terms of presence. Some of the students noted that the program “was stuck” as it had to load between the different island scenes or that it “did not work” when they took a boat that led them back to the same island. This might indicate that speed performance is an important factor of the environment, influencing the experience in general. Therefore, a fade-out animation was added during the change of scenes/islands. These changes were integrated as shown before in section 5.1.

The overall atmosphere of the study was good and the students were excited about working with the immersive technologies as the results from the emotion questionnaire show with enjoyment, hope, and security being the strongest emotions right before the study. Further, it could be shown that the used technology is capable of inducing different levels of presence. The differences in the pretest results related to the previous scholastic performance could derive from some students' lack of confidence in trying the new tasks, especially when they were not performing well in the subject CS before. Regarding this issue, a clear introduction for the pretest with a request to try the tasks, even if they seem unfamiliar, could be beneficial.

## 5.3 Study Two: Effects of Person-Specific and Technological Variables on Learning Outcomes

After the pilot study, the EVEs were improved (see section 5.1 for the final versions) and the questionnaires were revised. In February 2019, the main study was conducted with the same Austrian school. This time, the facilities of the school were used as the study had to fit into the students' regular class schedules.

### 5.3.1 Sample

78 (36 female, four blank responses) students from different classes took part in the main study. The students were aged between 13 and 16 ( $M = 13.95$ ,  $SD = 0.74$ ). 41 of the participants went to eighth grade; 33 were in ninth grade (4 blank responses). As in the pilot study, the selected topics from CS were not covered previously by their CS teachers. The students achieved moderate performance in the subjects Maths ( $M = 2.51$ ,  $SD = 0.91$ ) and German ( $M = 2.42$ ,  $SD = 0.96$ ) as well as showing high performance in the subject CS ( $M = 1.16$ ,  $SD = 0.50$ ). Scholastic performance in German was moderately correlated with performance in Maths ( $r = .51$ ,  $p < .01$ ). As there was almost no deviance within the scholastic performance in CS, this subject was excluded from the further analysis. Most of the students had never used VR technology before (44.90 %), some of them tried it once (29.50 %), only a few had used it several times (11.50 %). None of the participants used VR frequently (11 blank responses).

### 5.3.2 Instruments

For the main study, most of the instruments from the pilot study were used. This section describes changes in the instruments as well as their scale reliabilities and the correlations between the factors of the measured constructs. The self-efficacy questionnaire was not used in the main study due to time restrictions.

#### 5.3.2.1 Motivation

The motivation questionnaire (Appendix A) used the same questions as in the pilot study, but the analysis differed. The original scale of Hanfstingl et al. (2010) (based on Deci and Ryan's Self-Determination Theory, see section 3.3.3) assessed students' context motivation for learning in a subject with 19 items. The original design did not

ask for a specific subject but was used for multiple subjects. Hanfstingl et al. evaluated the instrument with two samples ( $N_1 = 869$ ;  $N_2 = 897$ ). A confirmatory factor analysis replicated four subscales that were interpreted as external regulation, introjected motivation, identified motivation, and intrinsic motivation. The used items were selective regarding the scales with  $\alpha = .78$  for intrinsic motivation,  $\alpha = .53$  for introjected motivation,  $\alpha = .67$  for identified motivation, and  $\alpha = .39$  for extrinsic motivation. The questionnaire of Hanfstingl et al. (2010) measures context motivation for several subjects; it is not specific to CS. Even though the evaluated study included 104 students answering the questions for the subject CS, they only pose a small part (4,4 %) of the study. Factor analyses and evaluations regarding the particular subjects were not reported. It can be assumed that context motivation towards learning in a particular subject depends on the scholastic conditions regarding the subject (number of hours in the curriculum, relevance of the subjects contents for the students' everyday life, relevance and influence of the subject's grade on advancing to the next grade). This is why an evaluation of the instrument is necessary when formulated specifically for the subject of CS. Hence, the questionnaire's main statement was changed so that it asked for the motivation towards learning and working in the subject of CS. The items and the measurement method using the Likert scale were maintained.

In order to evaluate the resulting questionnaire for the particular subject of CS, a study with 137 students of grades seven, eight, nine, and ten was conducted. The students came from different German secondary schools (German school form 'Realschule').

To evaluate whether the german questions of the interdisciplinary Hanfstingl et al. (2010) questionnaire could be used for the specific statement asking about the motivation for working and learning in the subject CS as well, a confirmatory factor analysis was conducted. The sample was appropriate for the analysis ( $KMO = .82$ , Bartlett's  $p < .01$ ). While the four factors intrinsic motivation, introjected motivation, identified motivation, and external regulation were thought of as consolidated theoretical constructs (resulting in four fixed factors for the analysis), it was questionable if the items were selective and could be assigned to one the factors, respectively. Doing so, the confirmatory factors analysis shown in Table 5.1 was conducted with a fixed set of four factors. While strong correlations between the factors can be expected<sup>15</sup>, the items should measure the related factor as distinctively as possible

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<sup>15</sup>As argued in section 3.3.3, the motivational constructs lie on a continuum of self-regulation and can occur simultaneously.

Table 5.1

*Confirmatory Factor Analysis (Varimax Rotation) with the Original Items from the Hanfstingl et al. (2010) Questionnaire*

Item	component			
	1	2	3	4
<i>intrinsic motivation</i>				
M1	.68			
M2	.78			
M3	.82			
M4	.73			
M5	.76			
<i>identified motivation</i>				
M6			.80	
M7			.82	
M8			.77	
M9	.59		.56	
<i>introjected motivation</i>				
M10		.73		
M11		.62		
M12		.73		
M13		.50		
<i>extrinsic motivation</i>				
M14		.78		
M15		.53		
M16				.60
M17				.54
M18				.69
M19		.71		

*Note.* Factor loadings under .40 are suppressed. Items M1–M19 refer to the statements shown in Appendix A.

(resulting in low factor loadings on other factors) in order to assess the underlying construct. Therefore, varimax rotation was used as an orthogonal rotation method.

The components correspond with the postulated motivation factors in general, but the factor loadings show that the items M14, M15, and M19, which were supposed to measure identified motivation and external regulation, are not selective. M9 could not differentiate between intrinsic motivation and identified motivation. The questionnaire was reduced by the items M9, M14, M15, and M19. Doing so, it was possible to replicate the postulated factor structure of Hanfstingl et al. (2010), suppressing factor loadings  $<.40$ . A mental projection of M9 to the students' intrinsic motivation could derive from the relevance of the learned contents for the students' everyday life as well as their later professional life. Contents that are relevant now (and, hence, for the student him-/herself) contribute to the students' intrinsic motivation. When the same contents are relevant for the students' later professional lives, learning these contents can be as well intrinsically motivated as deriving from identified motivation. Mental overlaps between items M14 and M10 as well as between items M19 and M12 can be explained by the similarity of the questions. A mental projection of M15 to the introjected motivation can derive from the sample: In the Bavarian Realschule, the subject corresponding to CS is called Informationstechnologie and covers many different topics (not all relevant to CS). As part of the elective subjects, parents might not value the subject as much as compulsory subjects, leading rather to social appreciation (in terms of the students wanting to impress the parents) than social pressure, which is how students could have interpreted this item (similar to social appreciation from classmates, as assessed with M12). These reductions lead to a questionnaire assessing intrinsic motivation via five items, identified motivation via three items, introjected motivation via four items, and external regulation via three items.

To get a short version of the questionnaire, three items were selected for each factor due to the Cronbach alpha values of the subscales (intrinsic motivation:  $\alpha = .84$ ; identified motivation:  $\alpha = .79$ ; introjected motivation:  $\alpha = .84$ ; external regulation:  $\alpha = .65$ ). Removing items M1, M3, and M10 left the scales intrinsic motivation ( $\alpha = .77$ ) and introjected motivation ( $\alpha = .69$ ) above the questionable scale reliability of  $\alpha = .65$  for external regulation. Table 5.2 shows the results of the confirmatory factor analysis using these short version's items with the varimax rotation method. As it was not possible to improve the external regulation scale's reliability by removing or adding items, it was decided to keep its current structure despite its questionable  $\alpha$  value. The resulting questionnaire that was used for the analysis of the main study's

Table 5.2

*Confirmatory Factor Analysis (Varimax Rotation) with the Short Version's Items*

Item	component			
	1	2	3	4
<i>intrinsic motivation</i>				
M2	weil ich neue Dinge lernen möchte.	.79		
M3	weil ich es genieße, mich mit dem Fach auseinanderzusetzen.	.82		
M5	weil ich gerne über Dinge des Faches nachdenke.	.82		
<i>identified motivation</i>				
M6	um später eine bestimmte Ausbildung machen zu können (z.B. Schule, Lehre oder Studium).		.83	
M7	weil ich damit mehr Möglichkeiten bei der späteren Berufswahl habe.		.85	
M8	weil ich mit dem Wissen im Fach später einen besseren Job bekommen kann.		.77	
<i>introjected motivation</i>				
M10	weil ich möchte, dass meiner Lehrerin/meinem Lehrer denkt, ich bin ein/e gute/r Schüler/in.	.72		
M11	weil ich ein schlechtes Gewissen hätte, wenn ich wenig tun würde.	.82		
M13	weil ich mich vor mir selbst schämen würde, wenn ich es nicht tun würde.	.73		
<i>external regulation</i>				
M16	weil ich sonst Ärger mit meiner Lehrerin/meinem Lehrer bekomme.			.67
M17	weil ich sonst schlechte Noten bekomme.			.58
M18	weil ich es einfach lernen muss.			.70

*Note.* Factor loadings under .40 are suppressed.

results, assessing *intrinsic motivation*, *identified motivation*, *introjected motivation*, and *external regulation*, each with three items.

As shown in Table 5.3, *identified motivation* scored, on average, highest, with the least variance, while *introjected motivation* scored, on average, lowest, with the highest variance. The scale reliability values were good except for the scale *external regulation*. It might be questionable if it is useful to include *external regulation* in the analysis. For now, it has been included in the further analysis but findings relating to external regulation have to be discussed.

Table 5.3

*Motivational Traits in the Main Study*

	<i>N</i>	<i>mean</i>	<i>sd</i>	$\alpha$
intrinsic motivation	73	3.10	1.02	.85
identified motivation	72	3.34	0.97	.79
introjected motivation	73	2.39	1.07	.76
external regulation	73	2.70	1.02	.65

For further analysis, the correlations (Pearson's  $r$ ) between the motivational constructs were calculated (Tab. 5.4). Moderate correlations between *intrinsic motivation* and *identified motivation* as well as between *introjected motivation* and *external regulation* were found.

Table 5.4

*Correlations between the Motivational Constructs*

	1	2	3
1. intrinsic motivation			
2. identified motivation	.50**		
3. introjected motivation	-.09	-.02	
4. external regulation	-.12	.06	.59**

Note. \*\* $p < .01$

### 5.3.2.2 Emotion

The emotion questionnaire (Appendix B) was not changed from the version used in the pilot study. The questionnaire, again, assessed security, shame, enjoyment, anger, hope, pride, hopelessness, relief, anxiety, and boredom on a six-point Likert scale. The emotion items were categorized into *positive activating emotions*, *positive deactivating emotions*, *negative activating emotions*, and *negative deactivating emotions*. For the analysis, the item assessing *security* was excluded as it did not contribute to any of the academic emotions. Table 5.5 shows that *positive activating emotions* scored highest while *negative activation emotions* scored lowest. Due to poor scale reliabilities for *negative activating emotions* and *negative deactivating emotions*, it was decided to exclude the item assessing *fear* and to join the *positive activating emotions* scale and the *positive deactivating* scale as well as the *negative activating* scale and the *negative deactivating* scale. Thus, *positive emotions* ( $M = 2.91$ ,  $SD = 0.98$ ,  $\alpha = .73$ ) and *negative emotions* ( $M = .69$ ,  $SD = 0.68$ ,  $\alpha = .68$ , without *fear*) were calculated. There was a moderate, negative correlation ( $r = -.38$ ,  $p < .01$ ) between *positive emotions* and *negative emotions*.

Table 5.5

*Emotional States in the Main Study*

	<i>N</i>	<i>mean</i>	<i>sd</i>	$\alpha$
positive activating emotions	74	3.22	1.01	.73
positive deactivating emotions	74	1.99	1.50	–
negative activating emotions	73	0.62	0.62	.15
negative deactivating emotions	73	0.81	0.97	.67

### 5.3.2.3 Levels of Immersion

For the main study, the immersive EVE's described in section 5.1 were used. A laptop (Intel HD Graphics 5500, i5-5300U CPU, a 16-inch monitor), a Mobile VR (a Daydream View with a Moto Z smartphone), and an HTC Vive were used as distinct immersive settings. The HTC Vive was regarded as the most immersive setting (immersion level 3); the laptop was regarded as the least immersive setting



(immersion level 1). This hierarchy<sup>16</sup> follows the discussion of section 2.1.2, assigning the HTC Vive and the Mobile VR a higher level of *Presence Metaphor* than the laptop setting and the HTC Vive a higher level of *Reproduction Fidelity* than the Mobile VR (immersion level 2). For the interaction, a standard mouse (laptop), a Bluetooth clicker (mobile VR) and the default HTC Vive controllers (HTC Vive) were provided.

#### 5.3.2.4 Presence

The presence questionnaire (Appendix C) from the pilot study consisting of six questions, which were translated from Slater, Usoh, and Steed (1994) and adapted for the specific EVEs, was used again. As the pilot study showed that using the mean value rather than counting methods (as promoted by Slater et al., 1994 or Peck et al., 2011) can map the students' heterogeneous manifestations of presence better, we decided in favor for calculating the participants' mean present values. This also allows a higher accuracy when using statistical methods. Table 5.6 shows that the questionnaires scored high in terms of internal scale reliability, mean values<sup>17</sup> and standard deviations are reported. Correlations between the person-specific presence scores in the EVEs (participants rating presence higher/lower in general) were not significant.

Table 5.6

*Presence in the different EVEs*

	<i>N</i>	<i>mean</i>	<i>sd</i>	$\alpha$
Bill's Computer Workshop	72	4.41	1.49	.87
Fluxi's Cryptic Potions	70	4.14	1.56	.91
Pengu's Treasure Hunt	71	3.96	1.56	.92

#### 5.3.2.5 Learning Outcomes: Pre- and Post-Test

The performance tests (Appendix D) were designed to evaluate the students' learning outcomes regarding the CSE contents covered in the EVEs. As the EVEs were designed to address capabilities on different cognitive levels, the tests, also, examined

<sup>16</sup>Note that this hierarchy is not metrical. It is not possible to quantify how more or less immersive one technology is in comparison to another.

<sup>17</sup>It is to be noted that the mean values cannot be interpreted in terms of establishing a hierarchy of the EVEs depending on their presence inducing characteristics. It is known that the technical immersion (in terms of the used hardware) has a strong moderating effect. As the technologies were not distributed to an exact equal, interpretation concerning these results should be taken carefully.

learning outcomes on the cognitive level of the corresponding EVE. Cronbach's Alpha values for the pre-test were not calculated as it was assumed that students would show little or no previous knowledge in the selected content areas.

The test for the content area *components of a computer* (nine points total) tested the remembering skills of the students with two tasks: (1) the students had to fill in gaps in a displayed scheme with the provided terms of computer components (six points) and (2) for three of these components (processor, RAM/primary memory, and secondary memory), they had to name the corresponding functions (three points). The post-test's Cronbach's Alpha was alarming ( $\alpha = .16$ ) and raised questions about the reliability of the test. In the end, the test was accepted as it examined two very different parts of remembering the contents of the EVE. It can be argued that students who spent more time talking to the NPC would remember the displayed scheme better while students setting greater attention towards the tasks might be better at grasping the functions of the components, which are explained in more detail when completing the tasks. Still, both activities contributed to remembering the computer's components plus their functions. The mean performance was better in the post-test ( $M = 5.86$ ,  $SD = 2.36$ ) than in the pre-test ( $M = 3.28$ ,  $SD = 2.04$ ).

The understanding skills for the topic *asymmetric encryption/decryption* (eight points total) were tested with three tasks: The first and the second task asked the student to explain why a specific encryption/decryption method was used for a specific objective. In the third task, the user should fill in the right encryption/decryption method to decipher a message. The post-test's reliability value ( $\alpha = .61$ ) was poor. By removing the third task from the analysis, the Cronbach's Alpha value could be increased to  $\alpha = .68$ . A total of four points remained for further analysis. The mean performance for the asymmetric encryption/decryption topic was better in the post-test ( $M = 1.83$ ,  $SD = 1.20$ ) than in the pre-test ( $M = 1.32$ ,  $SD = 1.16$ ).

The *finite state machines* test (21 points total) consisted of three tasks: (1) The students were asked to draw the 'map' of a finite state machine<sup>18</sup> that was described in a text; (2) A text with gaps was provided, describing the transition functions (boat routes) between several states (islands) where the students had to fill in the blanks in order to meet the objective of the finite state machine (the map of the islands); (3) The students had to draw a finite state machine (map) that met a certain objective and followed a particular sequence of transitions by themselves. Again, the scale reliability value was poor ( $\alpha = .54$ ). As the scale reliability could not be improved

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<sup>18</sup>As in the EVE, the metaphor of islands being states of the machine and the boats being characters of an input alphabet was used in the post-test.

by removing single tasks from the test, the presented test was maintained. Still, results deriving from the *finite state machines* test have to be discussed in the further analysis. Again, the results of the post-test ( $M = 12.30$ ,  $SD = 3.70$ ) were better than the results of the pre-test ( $M = 9.89$ ,  $SD = 2.89$ ).

### 5.3.3 Hypotheses

The hypotheses display the relationships assumed in the research model. As cognitive abilities were assessed in a simplified way via the students grades, only the subject CS was assumed to mutually correlate with the motivational constructs, while German and Math were assumed to be predicted by these factors<sup>19</sup>. As CS was excluded from further analysis (see section 5.3.1), only predictive relationships are hypothesized between motivation and previous scholastic performance. While the research model assumes a mediating effect of presence on the relationship between immersion and learning outcomes, this effect is modeled here in order to control for the mediation.

1. The student's motivation towards learning CS predicts his/her scholastic performance (aa: intrinsic motivation increases performance in Maths; ab: identified motivation increases performance in Maths; ac: introjected motivation decreases performance in Maths; ad: external regulation decreases performance in Maths; ba: intrinsic motivation increases performance in German; bb: identified motivation performance in German; bc: introjected motivation decreases performance in German; bd: external regulation decreases performance in German).
2. The student's motivation towards learning CS predicts his/her emotional state (aa: intrinsic motivation increases positive emotions; ab: identified motivation increases positive emotions; ac: introjected motivation decreases positive emotions; ad: external regulation decreases positive emotions; ba: intrinsic motivation decreases negative emotions; bb: identified motivation decreases negative emotions; bc: introjected motivation increases negative emotions; bd: external regulation increases negative emotions).
3. Higher previous scholastic performance predicts the student's emotional state (aa: higher performance in German increases positive emotions, ab: higher performance in Maths increases positive emotions; ba: higher performance in Ger-

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<sup>19</sup>This follows the idea presented in section 3.3.3 that contextual motivation is a relatively stable construct (and, thus, not changeable through grades in other subjects) while influencing behaviors related to learning processes can also be assigned to other subjects (and, therefore, predict the grades in other subjects).

- man decreases negative emotions, bb: higher performance in Maths decreases negative emotions).
4. A higher level of immersion predicts a higher sense of presence.
  5. The student's motivation towards learning CS predicts his/her sense of presence (a: intrinsic motivation increases presence; b: identified motivation increases presence; c: introjected motivation decreases presence; d: external regulation decreases presence).
  6. Higher previous scholastic performance predicts a higher sense of presence (a: German, b: Math).
  7. The student's emotional state predicts his/her sense of presence (a: positive emotions increase presence; b: negative emotions decrease presence).
  8. Higher previous scholastic performance predicts a better pre-test performance. (a: German, b: Math).
  9. The student's motivation towards learning CS predicts the pretest performance (a: intrinsic motivation increases pre-test performance; b: identified motivation increases pre-test performance; c: introjected motivation decreases pre-test performance; d: external regulation decreases pre-test performance).
  10. A higher sense of presence predicts a better post-test performance.
  11. A higher level of immersion predicts a better post-test performance.
  12. A higher score in the pre-test predicts a better post-test performance.
  13. Higher previous scholastic performance predicts a better post-test performance. (a: German, b: Math).
  14. The student's motivation towards learning CS predicts the post-test performance (a: intrinsic motivation increases post-test performance; b: identified motivation increases post-test performance; c: introjected motivation decreases post-test performance; d: external regulation decreases post-test performance).
  15. Presence mediates the effect of immersion on post-test performance.

#### 5.3.4 Procedure of the Main Study

The procedure of the main study (see Fig. 5.1) was similar to the pilot study. One week prior to the VR experiences, the participants filled out the pre-questionnaire, consisting of questions assessing demographic data (gender, age, and class), their academic motivation towards learning in the subject CS (see section 5.3.2.1) as well as the pre-performance tests (see section 5.3.2.5) for the topics *components of a computer*, *asymmetric encryption/decryption*, and *finite state machines*. Right before the VR experience, the students had to fill out a questionnaire asking about their

emotional state (see section 5.3.2.2), previous experiences with VR, and previous scholastic performance<sup>20</sup> (see section 5.3.2.2).

The sample was split into groups of four to six, depending on their class schedule and other school activities. Every participant had three VR experiences throughout the study. The respective VR experience was presented either on a laptop, a mobile VR or an HTC Vive. These constellations were constant within the groups but varied between the groups<sup>21</sup>. Right after each VR experience, the participant switched to another room and filled out the corresponding presence questionnaire (see section 5.3.2.4) and, afterward, the performance post-test (section 5.3.2.5). After completing the questionnaires, the student waited until the next medium was available to explore the next VR experience. In order to maintain an overview of which student completed which environment and filled out which questionnaires, each participant received a stamp card where they had to collect stamps for completing the environments and for filling out the questionnaires (as in the pilot study). Thus, they were instructed to collect six stamps in total. Each group took around two hours to complete all environments and the corresponding questionnaires. All questionnaires were identified using an individual code that the participants noted down on every page.

### 5.3.5 Findings of the Main Study

After reporting advance analyses, the factors motivation, emotion, and scholastic performance and their relationships are reported. Predictors of pre-test performance, presence, and post-test performance are then presented. Path analyses for all environments and an overall path analysis investigate the hypotheses further. The variables in this study are assessed as manifest rather than latent variables (due to the design of the instruments, which allow the calculation of means/scores for all factors), it has to be noted a path analysis could be carried out directly according to the research model. But, as the research model derives from a not-yet evaluated theoretical framework, taking a deeper look into relationships between the factors can contribute to a further understanding and to the discussion of the results.

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<sup>20</sup>The parents were informed that the students would be asked about their scholastic performance. If they did not want their children to answer these questions, they could just tell them to leave these fields blank.

<sup>21</sup>For example, one group was provided with the setting *Bill's Computer Workshop* on the laptop, *Fluxi's Cryptic Potions* on the Mobile VR, and *Pengu's Treasure Hunt* on the HTC Vive; another group experienced *Bill's Computer Workshop* on the Mobile VR, *Fluxi's Cryptic Potions* on the HTC Vive, and *Pengu's Treasure Hunt* on the laptop, etc.



Figure 5.1. Procedure of the Main Study

### 5.3.5.1 Advance Analyses

There were three statistical outliers in the performance pre-test for the *finite state machines* topic and five statistical outliers for the performance post-test for the *components of a computer* topic. Using the method of Tukey's fences (Tukey, 1977), all outliers can be considered as mild outliers (z-values beyond the inner fence of  $z = 1.5$  but inside the outer fence of  $z = 3.0$ ). As the outliers could not be explained by measurement errors, they were not excluded from the analysis.

The normal distribution of the dataset was tested using the Shapiro-Wilk method. The  $W$  values were significant ( $p < .05$ ) for all post-tests, the *asymmetric encryption* and *finite state machines* pre-tests, the introjected and external regulation scales, the negative emotions scale, and for the scholastic performances in Math and German. For all other variables, the dataset was normally distributed.

Table 5.7

*Associations Between Control Variables And Model Variables*

	<i>gender</i>	<i>age</i>	<i>class</i>	<i>experience</i>
<i>motivation</i>				
intrinsic motivation	interaction	n.s.	n.s.	interaction
identified motivation	n.s.	n.s.	n.s.	n.s.
introjected motivation	interaction	n.s.	n.s.	n.s.
external regulation	interaction	n.s.	n.s.	n.s.
<i>scholastic performance</i>				
Math	n.s.	n.s.	n.s.	n.s.
German	interaction	n.s.	n.s.	n.s.
<i>emotion</i>				
positive emotions	interaction	n.s.	n.s.	n.s.
negative emotions	n.s.	n.s.	n.s.	interaction
<i>presence</i>				
Bill's Computer Workshop	n.s.	interaction	n.s.	n.s.
Fluxi's Cryptic Potions	n.s.	n.s.	n.s.	n.s.
Pengu's Treasure Hunt	n.s.	interaction	n.s.	n.s.
<i>pre-test</i>				
Components of a Computer	interaction	n.s.	n.s.	interaction
Asymmetric Encryption	n.s.	n.s.	n.s.	n.s.
Finite State Machines	n.s.	n.s.	n.s.	n.s.
<i>post-test</i>				
Components of a Computer	interaction	n.s.	n.s.	n.s.
Asymmetric Encryption	n.s.	n.s.	n.s.	n.s.
Finite State Machines	n.s.	n.s.	n.s.	n.s.

Associations that were not based on the theoretical assumptions of the EFIL between the control variables gender, age, class, and previous VR experiences with the variables of the model are summarized in Table 5.7. The respective calculations for the interactions can be found in Appendix F. For the analysis of gender interaction effects, t-tests were used for variables with normally distributed samples; Mann-Whitney-U tests were used for variables with not normally distributed samples. For all other variables, Spearman-Rho correlation was calculated<sup>22</sup>.

There were interactions between gender and the motivational constructs intrinsic motivation, introjected motivation, and external regulation. This relation between gender and motivation towards learning CS is well known: Girls' low affinity and confidence in terms of CS contents affects their motivation pursuing CS-related careers (Hur, Andrzejewski, & Marghitu, 2017). A Mann-Whitney-U test indicated that the scholastic performance in the subject German was significantly higher (as 1 indicated the best and 6 the worst performance) for female participants than for male participants. It has to be tested whether gender moderates the effect of motivation on scholastic performance in further analyses. A t-test revealed that positive emotions were significantly higher for male participants than for female participants. This could be explained through boys' higher intrinsic motivation related to a higher sense of self-regulation and control, inducing positive prospective outcome emotions (according to Pekrun's control-value theory, see section 3.3.4). The differences in the performance pre-test and the performance post-test for the *components of a computer* topic can be explained via girls' lower affinity and confidence regarding CS as this topic directly referred to computers while the other topics used metaphors. It has to be checked if gender moderates the effect of scholastic performance on learning outcomes or the effect of motivation on learning outcomes in further analyses.

The interaction between age and presence in *Bill's Computer Workshop* and *Pengu's Treasure Hunt* is conform to other studies showing that the average sense of presence decreases with age (e.g. Sharar et al., 2007). As age does not interact with other variables (neither does class), this effect can be neglected.

A positive correlation between experience with VR and intrinsic motivation towards learning CS was expected as both refer to technology: A student who likes to learn about technology is likely to use innovative media; a student that uses immersive media more often is more likely to be interested in how the technology works.

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<sup>22</sup>Age is often interpreted as an interval scale. In fact, a participant who just turned 14 is not exactly one year older than a classmate at the age of 13. Hence, age is interpreted on an ordinal scale, justifying the use of non-parametrical correlations instead of parametrical correlation values.



The negative correlation between experience with VR and negative emotions can be explained in a similar manner: One who likes to experiment with VR technology is less likely to experience negative emotions like shame, anger, hopelessness, anxiety, and boredom before a VR study. The positive correlation between experience with VR and the pre-test performance for the *components of a computer* topic could be explained as well with the relation between experimenting with technology and interest in technology (in terms of "how a computer works"). The previous experience with VR has to be included in further analyses in order to determine whether this factor moderates the effect of intrinsic motivation on emotions or the effect of intrinsic motivation on the pre-test for the *components of a computer topic* (if relevant).

### 5.3.5.2 Scholastic Performance

Table 5.8

*Summary of Hierarchical Regression Analysis for Variables Predicting Scholastic Performance in Math*

Variable	$\beta$	$t$	<i>corr. R</i> <sup>2</sup>
Step 1			.03
intrinsic motivation	.03	0.18	
identified motivation	-.26	-1.86	
introjected motivation	-.05	-0.35	
external regulation	.14	0.97	
Step 2			.04
identified motivation	-.25	-2.01*	
introjected motivation	-.04	-0.34	
external regulation	.13	0.97	
Step 3			.06
identified motivation	-.25	-2.01*	
external regulation	.11	0.92	

*Note.* \* $p < .05$

A multiple linear regression<sup>23</sup> was calculated (see Tab. 5.8) to predict the scholastic performance in Maths based on intrinsic motivation, identified motivation, introjected motivation, and external regulation. The resulting model (corrected  $R^2 = .06$ ,

<sup>23</sup>For all multiple linear regression analyses, a backwards elimination process with a cut-off significance level of  $p < .05$  was used. For all calculations, the model highest corrected variance explanation was selected.

$F(2, 66) = 3.01, p = .056, n.s.$ <sup>24</sup>) after two elimination steps includes the factors identified motivation and external regulation as predictors for the scholastic performance in Maths.

Table 5.9

*Summary of Hierarchical Regression Analysis for Variables Predicting Scholastic Performance in German*

Variable	$\beta$	$t$	<i>corr. R</i> <sup>2</sup>
Step 1			.15
gender	.41	2.05**	
intrinsic motivation	.01	0.04	
identified motivation	-.17	-1.25	
introjected motivation	.05	0.40	
external regulation	.26	1.91	
Step 2			.16
gender	.41	3.48**	
identified motivation	-.16	-1.41	
introjected motivation	.05	0.42	
external regulation	.26	2.00	
Step 3			.17
gender	.41	3.48**	
identified motivation	-.16	-1.41	
external regulation	.28	2.32*	

Note. \* $p < .05$ ; \*\* $p < .01$

The same analysis was carried out for the scholastic performance in German, adding the factor gender (because of a possible interaction effect, see section 5.3.5.1). The linear regression analysis shown in Table 5.9 resulted in a model (corrected  $R^2 = .17, F(3, 66) = 5.61, p < .01$ ) including the predictors gender, identified motivation, and external regulation. Neither the effect of identified motivation nor the effect of external regulation on the scholastic performance in German was moderated by gender ( $p > .05, n.s.$ ).

<sup>24</sup>Because of the small sample size, exact  $p$  values are reported between .05 and .10 for the purpose of better interpretation.

### 5.3.5.3 Emotion

Positive emotions correlated significantly (one-tailed, Pearson's  $r$ ) with scholastic performance in German ( $r = .23$ ,  $p < .05$ ). Correlations with intrinsic motivation, identified motivation, introjected motivation, external regulation, and scholastic performance in Maths were not significant. Negative emotions correlated significantly (one-tailed, Pearson's  $r$ ) with scholastic performance in German ( $r = -.24$ ,  $p < .05$ ). Correlations with intrinsic motivation, identified motivation, introjected motivation, external regulation, and scholastic performance in Maths were not significant. As all motivational factors were insignificant, they were excluded from the regression model.

Table 5.10

*Summary of Hierarchical Regression Analysis for Variables Predicting Positive Emotions*

Variable	$\beta$	$t$	<i>corr.</i> $R^2$
Step 1			.13
gender	.26	2.13*	
scholastic performance Math	-.17	-1.29	
scholastic performance German	.27	1.95	

*Note.* \* $p < .05$

To investigate the predictors of the emotional factors, a multiple linear regression for positive emotions was calculated integrating scholastic performance German and scholastic performance Maths, according to the research model, and gender (see section 5.3.5.1). The resulting model (corrected  $R^2 = .13$ ,  $F(3, 68) = 4.28$ ,  $p < .01$ , see Table 5.10) included the predictors scholastic performance in German, scholastic performance in Math, and gender.

Regarding negative emotions, removing the factor gender (see section 5.3.5.1) led to the model (corrected  $R^2 = .04$ ,  $F(1, 70) = 4.13$ ,  $p < .05$ ) displayed in Table 5.11, including scholastic performance in German as the only predictor. An assumed moderating effect of gender on the relation between scholastic performance in German and positive emotions was not significant ( $p > .05$ , n.s.). In further analyses (i.e. for the path analyses), both factors, scholastic performance German and scholastic performance Math, will be included as it can be assumed that the insignificant results regarding the subjects Math derive from the small sample size.

Table 5.11

*Summary of Hierarchical Regression Analysis for Variables Predicting Negative Emotions*

Variable	$\beta$	$t$	<i>corr.</i> $R^2$
Step 1			.06
scholastic performance Math	-.13	0.94	
scholastic performance German	-.34	-2.54*	
Step 2			.06
scholastic performance German	-.28	-2.40*	

Note. \* $p < .05$

#### 5.3.5.4 Pre-Test Performance

The z-standardized overall pre-test performance correlated significantly (one-tailed, Pearson's  $r$ ) with intrinsic motivation ( $r = .23, p < .01$ ), introjected motivation ( $r = -.19, p < .01$ ), and external regulation ( $r = -.27, p < .01$ ). Correlations with identified motivation, scholastic performance in Maths and scholastic performance in German were not significant.

A multiple linear regression was calculated to predict the overall pre-test performance based on intrinsic motivation, introjected motivation, external regulation, according to the research model, and gender (see section 5.3.5.1). The resulting model (corrected  $R^2 = .09, F(2, 213) = 11.21, p < .001$ , see Table 5.12) included the predictors intrinsic motivation and external regulation.

The pre-test performance in the *components of a computer* test could be predicted through intrinsic motivation ( $\beta = .32, p < .01$ ) and external regulation ( $\beta = -.34, p < .01$ ), with a corrected  $R^2$  of .28. The model was significant ( $F(2, 67) = 14.53, p < .001$ ). An assumed, moderating effect of gender on the relation between intrinsic motivation and the pre-test performance was not significant ( $p > .05, n.s.$ ). An assumed, moderating effect of VR experience on the relation between intrinsic motivation and pre-test performance was also insignificant ( $p > .05, n.s.$ ).

When trying to explain the pre-test performance in the *asymmetric encryption* test by using this model (corrected  $R^2 = .06, F(2, 70) = 3.27, p < .05$ ), the model itself was significant, while the effects of intrinsic motivation ( $\beta = .12, p > .05, n.s.$ ) and extrinsic motivation ( $\beta = -.23, p = .069, n.s.$ ) on the pre-test performance were

Table 5.12

*Summary of Hierarchical Regression Analysis for Variables Predicting Pre-Test Performance*

Variable	$\beta$	$t$	<i>corr.</i> $R^2$
Step 1			.09
gender	.01	0.18	
intrinsic motivation	-.15	2.03*	
introjected motivation	-.10	-1.40	
external regulation	-.17	-2.22*	
Step 2			.09
intrinsic motivation	-.16	2.28*	
introjected motivation	-.11	-1.48	
external regulation	-.17	-2.24*	
Step 3			.09
intrinsic motivation	.15	2.16*	
external regulation	-.22	-3.09**	

*Note.* \* $p < .05$ ; \*\* $p < .01$

insignificant. This insignificance is assumed to be caused by the small sample size rather than by flaws in the regression model.

The model was insignificant for explaining the *finite state machines* pre-test performance (corrected  $R^2 = -.02$ ,  $F(2, 70) = .34$ ,  $p > .05$ , n.s.). It is assumed that this is due to the poor scale reliability reported in section 5.3.2.5.

The model including intrinsic motivation and external regulation as predictors of the pre-test performance was found to be a fitting model for the standardized overall pre-test results, the pre-test performance for *components of a computer*, and for the pre-test performance in the *asymmetric encryption* test.

### 5.3.5.5 Presence

The z-standardized overall presence<sup>25</sup> showed significant differences [ $F(2, 212) = 35.31$ ,  $p < .001$ ,  $\eta_p^2 = .25$ ] in an ANOVA for the different levels of immersion (Fig. 5.2): laptop ( $M = -.63$ ,  $SD = 0.89$ ), Mobile VR ( $M = .03$ ,  $SD = 0.87$ ), and HTC

<sup>25</sup>The presence value was standardized for each environment as it can be assumed that different environments induced different levels of presence (see section 5.3.2.4).

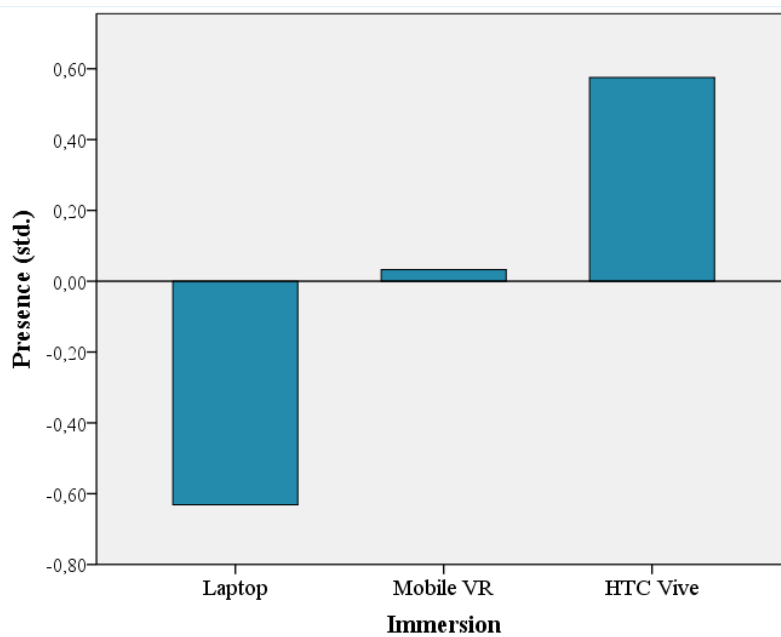


Figure 5.2. Standardized Presence Scores for the Different Levels of Immersion

Vive ( $M = .58$ ,  $SD = 0.84$ ). Post hoc comparisons using the Gabriel test<sup>26</sup> indicated that the mean level of presence in the laptop condition group differed significantly at a  $p < .001$  level. The mean level of presence in the Mobile VR and the HTC Vive settings differed significantly at a  $p < .001$  level.

Overall presence correlated significantly (one-tailed) with immersion<sup>27</sup> ( $r = .49$ ,  $p < .001$ ), identified motivation ( $r = .15$ ,  $p < .05$ ), introjected motivation ( $r = .12$ ,  $p < .05$ ), positive emotions ( $r = .18$ ,  $p < .01$ ) and negative emotions ( $r = -.13$ ,  $p < .05$ ).

Table 5.13 shows the multiple linear regression that was calculated to predict the level of presence based on immersion, identified motivation, introjected motivation, positive emotions, and negative emotions. The resulting model (corrected  $R^2 = .30$ ,  $F(3, 188) = 18.66$ ,  $p < .001$ ) included the predictors immersion, identified motivation and positive emotions.

By using this model, the level of presence in the *components of a computer* environment could be predicted significantly through immersion ( $\beta = .41$ ,  $p < .01$ ); effects of identified motivation ( $\beta = .18$ ,  $p > .05$ , n.s.) and positive emotions ( $\beta = .11$ ,  $p > .05$ , n.s.) were insignificant, with a corrected  $R^2$  of .17. The model was significant ( $F(3, 62) = 5.51$ ,  $p < .01$ ).

<sup>26</sup>The Gabriel test was used due to slightly different group sizes.

<sup>27</sup>Spearman-Rho correlation was calculated due to the ordinal scale of the immersive settings.

Table 5.13

*Summary of Hierarchical Regression Analysis for Variables Predicting Presence*

Variable	$\beta$	$t$	<i>corr. R</i> <sup>2</sup>
Step 1			.30
immersion	.50	8.25***	
identified motivation	.16	2.71**	
introjected motivation	.10	1.67	
positive emotions	.10	1.63	
negative emotions	-.05	-0.72	
Step 2			.30
immersion	.50	8.27***	
identified motivation	.17	2.79**	
introjected motivation	.11	1.79	
positive emotions	.11	1.89	
Step 3			.30
immersion	.51	8.31***	
identified motivation	.16	2.68**	
positive emotions	.12	2.00*	

Note. \* $p < .05$ ; \*\* $p < .01$ ; \*\*\* $p < .001$

The model was also significant ( $F(3, 60) = 12.64, p < .001$ , corrected  $R^2 = .357$ ) for the *asymmetric encryption* environment. The effect of immersion on presence ( $\beta = .57, p < .001$ ) was significant while the effects of identified motivation ( $\beta = .13, p > .05$ , n.s.) and positive emotions ( $\beta = .04, p > .05$ , n.s.) on presence were not.

For the *finite state machines* environment, the level of presence could be predicted using this model ( $F(3, 61) = 9.96, p < .001$ , corrected  $R^2 = .296$ ). Immersion, again, had a significant effect on presence ( $\beta = .55, p < .001$ ); the effects of identified motivation ( $\beta = .15, p > .05$ , n.s.) and of positive emotions ( $\beta = .16, p > .05$ ) on presence were insignificant.

While the effects of positive emotions and identified motivation were insignificant in the regression analyses for the particular environments, they add 3.0% to the overall model's corrected variance explanation of presence, 5.0% for presence in the *components of a computer* environment, 1.6% for presence in the *asymmetric encryption* environment, and 4.5% for presence in the *finite state machines* environment. Both factors, therefore, pose a small, but integral part of the model.

### 5.3.5.6 Post-Test Performance

The standardized overall post-test performance correlated significantly (one-tailed) with presence ( $r = .13, p < .05$ ), pre-test performance ( $r = .35, p < .001$ ), intrinsic motivation ( $r = .17, p < .05$ ), positive emotions ( $r = .15, p < .05$ ), scholastic performance in Maths ( $r = -.14, p < .05$ ) and scholastic performance in German ( $r = .12, p < .05$ ). Correlations with immersion, identified motivation, introjected motivation, external regulation, and negative emotions were not significant.

The multiple linear regression shown in Table 5.14 was calculated to predict the post-test performance based on presence, the pre-test-performance, intrinsic motivation, positive emotions, scholastic performance in Maths, scholastic performance in German, according to the research model, and gender (see section 5.3.5.1). The resulting model (corrected  $R^2 = .22, F(4, 184) = 14.31, p < .001$ ) included the predictors presence, pre-test performance, scholastic performance in Maths, and scholastic performance in German.

The post-test performance in the *components of a computer* test could be predicted through significant effects of the pre-test performance ( $\beta = .38, p < .01$ ) and scholastic performance in German ( $\beta = .32, p < .05$ ) as well as insignificant effects from the user's presence ( $\beta = .19, p = .09, \text{n.s.}$ ) and the scholastic performance in Maths ( $\beta = -.09, p > .05, \text{n.s.}$ ), with a total corrected  $R^2$  of .28. The model was significant ( $F(4, 59) = 7.58, p < .001$ ).

For the *asymmetric encryption* post-test performance, the model was also significant ( $F(4, 59) = 6.59, p < .001, \text{corrected } R^2 = .26$ ). The post-test performance could be predicted through presence ( $\beta = .24, p < .05$ ), the pre-test performance ( $\beta = .50, p < .001$ ), the scholastic performance in German ( $\beta = .29, p < .05$ ), and the scholastic performance in Maths ( $\beta = -.27, p < .05$ ).

The regression model was significant for the *finite state machines* post-test performance as well ( $F(4, 59) = 2.64, p < .05$ ), explaining a corrected  $R^2$  value of .09<sup>28</sup>. The effects of the scholastic performances in Maths ( $\beta = -.44, p < .01$ ) and German ( $\beta = .33, p < .05$ ) were significant; the effects of presence ( $\beta = .15, p > .05, \text{n.s.}$ ) and pre-test performance ( $\beta = .21, p = .10, \text{n.s.}$ ) were not.

The model showed significance for all post-tests and all of the predictors showed, at least partly, significant effects on the post-test performance. Therefore, the model including presence, pre-test performance as well as scholastic performances in German and Maths for predicting post-test performance will be used for further analyses.

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<sup>28</sup>Here, again, the low  $R^2$  value might be a result from the poor scale reliability reported in 5.3.2.5



Table 5.14

*Summary of Hierarchical Regression Analysis for Variables Predicting Post-Test Performance*

Variable	$\beta$	$t$	$corr. R^2$
Step 1			.22
presence	.20	3.02**	
pre-test performance	.33	5.04***	
intrinsic motivation	.00	-0.01	
positive emotions	.00	0.00	
scholastic performance Math	-.26	-3.36**	
scholastic performance German	.27	3.26**	
gender	.12	1.45	
Step 2			.22
presence	.20	3.08**	
pre-test performance	.33	5.05***	
intrinsic motivation	.00	-0.01	
scholastic performance Math	-.26	-3.40**	
scholastic performance German	.27	3.34**	
gender	.12	1.48	
Step 3			.22
presence	.20	3.12**	
pre-test performance	.33	5.17***	
scholastic performance Math	-.26	-3.42**	
scholastic performance German	.27	3.38**	
gender	.12	1.68	
Step 4			.22
presence	.20	3.07**	
pre-test performance	.35	5.40***	
scholastic performance Math	-.28	-3.73***	
scholastic performance German	.32	4.17***	

Note. \*\*p<.01; \*\*\*p<.001

In order to determine the effect of immersion on performance, the most immersive setting (HTC Vive) was compared to the non-immersive setting of the laptop. Even though Levene's tests were insignificant for all paired groups (indicating equal variances), all post-tests were not normally distributed (see section 5.3.5.1). Hence, Mann-Whitney tests were used for all comparisons. The post-test performance for

the *components of a computer* topic for the HTC Vive group ( $Mdn = 27.22$ ) was higher than for the laptop group ( $Mdn = 21.78$ ). The difference was not significant [ $U = 225.50, p > .05, n.s.$ ]. For the *asymmetric encryption* post-test scores, the performance of the HTC Vive group ( $Mdn = 28.72$ ) was better than the performance of the laptop group ( $Mdn = 23.77$ ); the result was not significant with  $U = 259.50, p > .05, n.s.$  Regarding the *finite state machines* post-test, the HTC Vive group ( $Mdn = 19.68$ ) scored lower than the laptop group ( $Mdn = 23.16$ ). Those differences were not significant as well ( $U = 183.50, p > .05$ ).

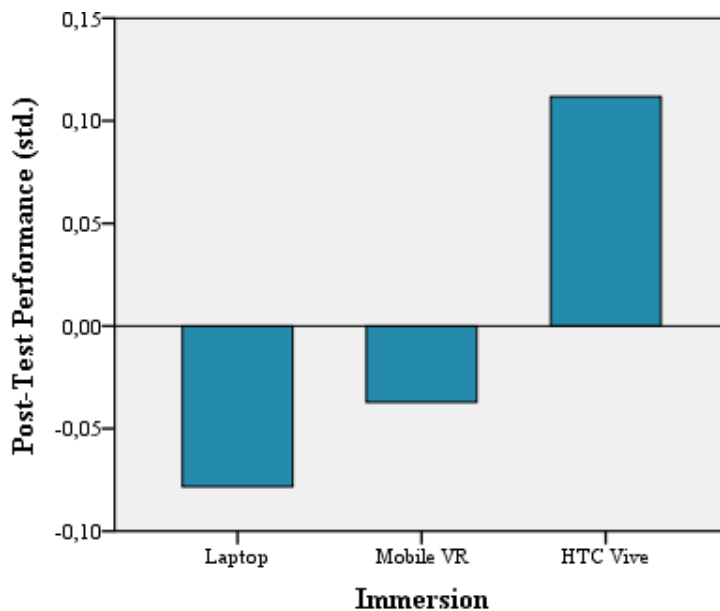


Figure 5.3. Standardized Post-Test Results for the Different Levels of Immersion

In order to compare the post-test results for the three levels of immersion, a Kruskal-Wallis test<sup>29</sup> was conducted for the differences in the z-standardized overall results (Fig. 5.3, showing the standardized mean values) according to the levels of immersion. No significant differences ( $X^2 = .92, p > .05, df = 2$ ) were found among the three levels (laptop, Mobile VR, HTC Vive). An analysis investigating the hypothesized mediating positive influence of presence on the effect of immersion on learning outcomes was not conducted as the effect of immersion on learning outcomes was insignificant.

<sup>29</sup>The overall results, too, were not normally distributed, which is why an ANOVA could not be used.

### 5.3.5.7 Path Analysis

Regression analyses can only display relationships between variables that are either dependant or independant. As the factors presence and pre-test performance influence the post-test-performance while being dependent on other variables as well, an adequate analysis of the predictors of the post-test-performance needs to include these relations as well. In order to investigate these relations in depth, a path analysis approach is chosen to display the correlations and predictive effects in a subsuming model including multiple factors. For this study, the software MPlus 8.3 (Muthén & Muthén, 2007) was used for calculating the path analyses. The estimation procedure was maximum likelihood estimation.

As path analyses employ structural equation modelling as an analytical technique, a variety of indices can be used to assess the model fit. A simple measure is the ratio of the Chi<sup>2</sup> statistic to its degree of freedom (a value of less than 5 indicates an acceptable fit). As another estimate of model fit, the root mean square error of approximation (RMSEA) analyzes the discrepancy between the data and the hypothesized model (with a value of less than .06 indicating an acceptable fit). The comparative fit index (CFI) and the Tucker Lewis Index (TLI) also examine the discrepancy between the population covariance matrix and the hypothesized model and adjust their value for issues of sample size (with a value higher than .90 indicating an acceptable fit). The standardized root mean square residual (SRMR), which has no penalty for model complexity, can be seen as an absolute measure of fit by assessing the standardized difference between the observed correlation and the predicted correlation (with a value lower than .05 indicating an acceptable fit). Each fit index only examines a certain perspective on the model (Kline, 2010). A good-fitting path analysis model is presented and analyzed in this section. First, the results for the standardized overall-test results are shown before displaying the results for each environment/learning content.

The factors scholastic performance Math, scholastic performance German, intrinsic motivation, external regulation<sup>30</sup>, positive academic emotions, negative academic emotions, presence (z-standardized), pre-test performance (z-standardized), post-test performance (z-standardized), and the level of technological immersion were included in the path analysis. Missing data sets were included listwise. The model consisted of the following assumptions:

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<sup>30</sup>It was decided to exclude identified motivation and introjected motivation and to focus on the highest and lowest constructs of self-regulation due to simplicity and with regards to the results of section 5.3.5.4.

1. *Motivation*

Intrinsic motivation (MotInt) correlates negatively with external regulation (MotExt).

2. *Scholastic Performance*

- (a) Scholastic performance German (German) is predicted by a) external regulation (decrease) and b) intrinsic motivation (increase).
- (b) Scholastic performance Maths (Maths) is predicted by a) external regulation (decrease) and b) intrinsic motivation (increase).
- (c) Scholastic performance German correlates positively with scholastic performance Maths.

3. *Academic Emotions*

- (a) Positive academic emotions (EmoPo) are predicted by a) scholastic performance German (decrease) and b) scholastic performance Maths (increase).
- (b) Negative academic emotions (EmoNe) are predicted by a) scholastic performance German (increase) and b) scholastic performance Maths (decrease).
- (c) Positive academic emotions are correlated negatively with negative academic emotions.

4. *Pre-Test Performance*

Pre-test performance (PerfPre) is predicted by a) external regulation (decrease) and b) intrinsic motivation (increase).

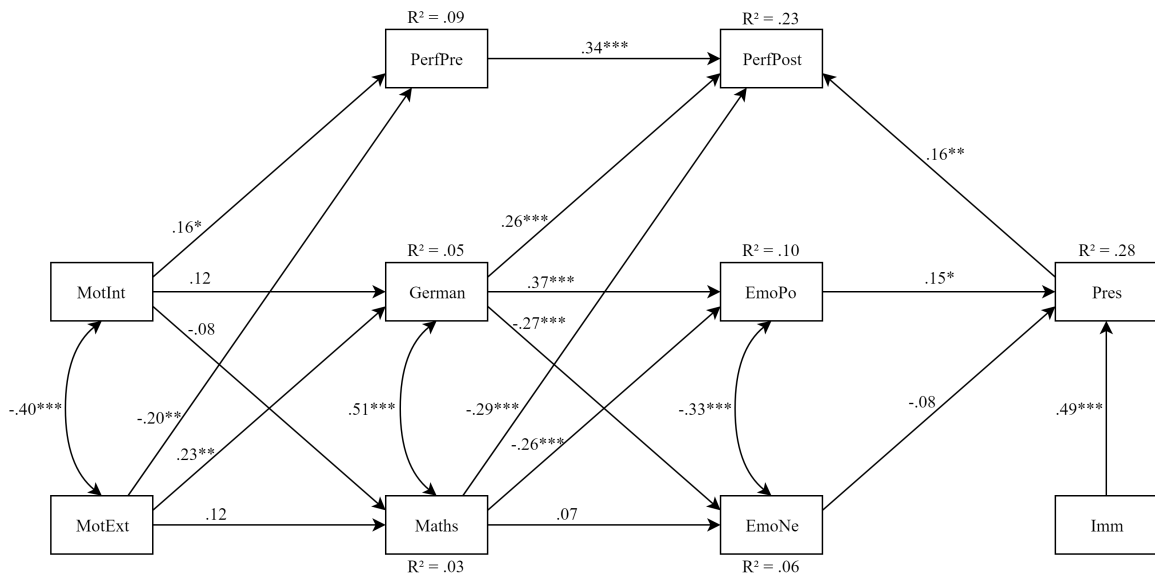
5. *Presence*

Presence (Pres) is predicted by a) immersion (Imm) (increase), b) positive emotions (increase), and c) negative emotions (decrease).

6. *Post-Test Performance*

Post-test performance (PerfPost) is predicted by a) presence (increase), b) pre-test performance (increase), c) scholastic performance German (decrease), and d) scholastic performance Maths (increase).

Thus, the model included seven endogeneous variables (scholastic performance German, scholastic performance Maths, positive academic emotions, negative academic emotions, presence, pre-test performance, and post-test performance) and three exogeneous variables (intrinsic motivation, external regulation, immersion). As in the regression analyses, the overall model included all datasets (N=234); the models for the specific environments included their respective datasets (N=78 for each model).



Note. MotInt, intrinsic motivation; MotExt, external regulation; PerfPre, pre-test performance; German, scholastic performance in German; Maths, scholastic performance in Maths; PerfPost, post-test performance; EmoPo, positive academic emotions; EmoNe, negative academic emotions; Pres, presence; Imm, level of technological immersion; \* $p < .05$ ; \*\* $p < .01$ ; \*\*\* $p < .001$ ; Coefficients presented are standardized linear regression coefficients.

Figure 5.4. Path Analysis Model of the Standardized Overall Results

**Overall Model** The overall model including standardized values for presence, for the pre-test, and for the post-test (Fig. 5.4) showed good model fit values ( $Chi^2 p = .45$ ,  $RMSEA = .005$ ,  $CFI = .999$ ,  $TLI = .999$ ,  $SRMR = .043$ ). The standardized results of the model show that intrinsic motivation and external regulation for learning CS were correlated<sup>31</sup> negatively ( $r = -.40$ ;  $p < .001$ ). The pre-test performance was predicted by intrinsic motivation ( $\beta = .16$ ;  $p < .05$ ) and external regulation ( $\beta = -.20$ ;  $p < .01$ ). For the scholastic performance in German, intrinsic motivation ( $\beta = .12$ ;  $p > .05$ , n.s.) and external regulation ( $\beta = -.40$ ;  $p < .01$ ) were predictors in the same

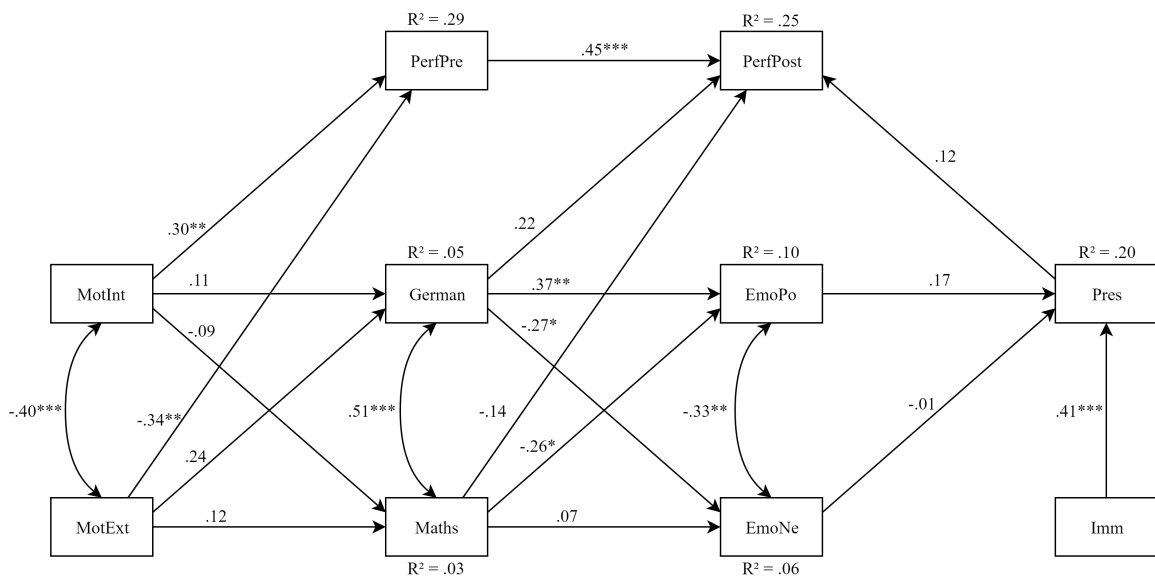
<sup>31</sup>It has to be noted that the significance of correlations and predictive effects between the motivational traits, the scholastic performances, and the emotional states have to be regarded critically for the overall model as those variables were included three times for each participant in the overall data set. While their sense of presence, the level of immersion, the pre-test performance, and the post-test performance changed, the assessed motivational and emotional constructs as well as the previous scholastic performance did not. For a proper interpretation (in terms of significance) of these factors, see paragraph *Components of a Computer* in this section.

direction; the scholastic performance in Maths was predicted insignificantly through intrinsic motivation ( $\beta = -.08$ ;  $p > .05$ , n.s.) and external regulation ( $\beta = .12$ ;  $p > .05$ , n.s.) in contradictive directions. The scholastic performances in German and Maths correlated positively ( $r = .51$ ;  $p < .001$ ). Both, scholastic performance in German ( $\beta = .37$ ;  $p < .001$ ) and scholastic performance in Maths ( $\beta = -.26$ ;  $p < .001$ ) predicted positive emotions; negative emotions could be predicted through the scholastic performances in German ( $\beta = -.27$ ;  $p < .001$ ) and Maths ( $\beta = .07$ ;  $p > .05$ ) as well. Positive and negative emotions were correlated negatively ( $r = -.33$ ;  $p < .001$ ). Presence was predicted by positive emotions ( $\beta = .15$ ;  $p < .05$ ), negative emotions ( $\beta = -.08$ ;  $p > .05$ , n.s.), and immersion ( $\beta = .49$ ;  $p < .001$ ). The post-test performance was predicted by presence ( $\beta = .16$ ;  $p < .01$ ), pre-test performance ( $\beta = .34$ ;  $p < .001$ ), and the scholastic performances in German ( $\beta = .26$ ;  $p < .001$ ) and Maths ( $\beta = -.29$ ;  $p < .001$ ). Regarding these results, significant proportions of variance explanation were found for positive emotions ( $R^2 = .10$ ;  $p < .01$ ), presence ( $R^2 = .28$ ;  $p < .001$ ), pre-test performance ( $R^2 = .09$ ;  $p < .05$ ), and post-test performance ( $R^2 = .23$ ;  $p < .001$ ). Variance explanation was insignificant ( $p > .05$ ) for the scholastic performances in Maths ( $R^2 = .03$ ) and German ( $R^2 = .05$ ), as well as for negative emotions ( $R^2 = .06$ ).

**Components of a Computer** The path analysis model for the topic *Components of a Computer* with the corresponding immersive EVE *Bill's Computer Workshop* is shown in figure 5.5. The model fit values were good in general ( $\chi^2 p = .35$ ,  $RMSEA = .035$ ,  $CFI = .976$ ,  $TLI = .960$ ,  $SRMR = .097$ ), the SRMR can be considered as still acceptable. The path analysis model's standardized results reproduce the overall model's findings in general. As the sample was the same as for the overall model, the correlations between intrinsic and external regulation, between the scholastic performances in Maths and German, and between the positive and negative emotions stayed (almost<sup>32</sup>) the same, while the significancy values changed: Intrinsic motivation correlated negatively with external regulation ( $r = -.40$ ;  $p < .001$ ); scholastic performance German correlated positively with the scholastic performance in Maths ( $r = .51$ ;  $p < .001$ ); positive emotions correlated positively with negative emotions

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<sup>32</sup>Due to dropouts, there were very slight changes between the path analyses. As they were too small to affect the results, they are not reported in particular, but they are integrated in the figures displaying the path analyses.

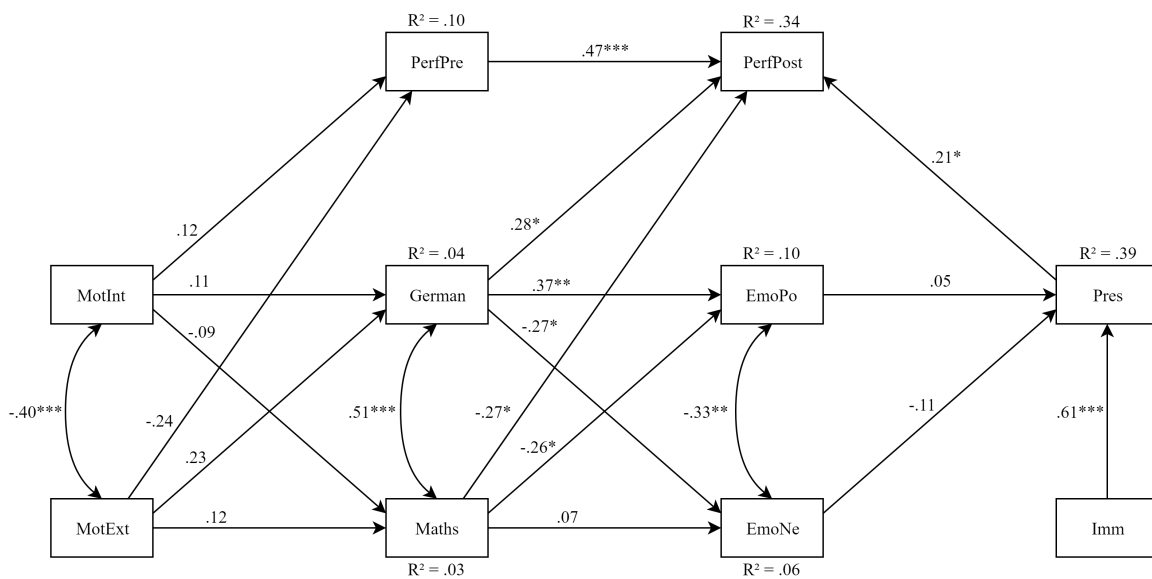


Note. MotInt, intrinsic motivation; MotExt, external regulation; PerfPre, pre-test performance; German, scholastic performance in German; Maths, scholastic performance in Maths; PerfPost, post-test performance; EmoPo, positive academic emotions; EmoNe, negative academic emotions; Pres, presence; Imm, level of technological immersion;  $*p < .05$ ;  $**p < .01$ ;  $***p < .001$ ; Coefficients presented are standardized linear regression coefficients.

Figure 5.5. Path Analysis Model of the Results for the Components of a Computer Topic

( $r = -.33$ ;  $p = .001$ ). The predictive effects of intrinsic motivation and external regulation on the scholastic performances as well as the predictive effects of scholastic performances on emotions stayed the same as well, with different significancy values: Scholastic performance German was predicted by intrinsic motivation ( $\beta = .11$ ;  $p > .05$ , n.s.) and external regulation ( $\beta = .24$ ;  $p > .05$ , n.s.); scholastic performance Maths was predicted by intrinsic motivation ( $\beta = -.09$ ;  $p > .05$ , n.s.) and external regulation ( $\beta = .12$ ;  $p > .05$ , n.s.) as well, those predictive effects were insignificant. Positive emotions were predicted by scholastic performances in German ( $\beta = .37$ ;  $p < .01$ ) and Maths ( $\beta = -.26$ ;  $p < .05$ ); negative emotions were predicted by those performances [German ( $\beta = -.27$ ;  $p < .05$ ) and Maths ( $\beta = .07$ ;  $p > .05$ , n.s.)] as well. The pre-test performance was predicted by intrinsic motivation ( $\beta = .39$ ;  $p < .01$ ) and external regulation ( $\beta = -.34$ ;  $p < .01$ ). Presence was predicted by positive emotions ( $\beta = .17$ ;  $p > .05$ , n.s.), negative emotions ( $\beta = -.01$ ;  $p > .05$ , n.s.), and immersion ( $\beta = .41$ ;  $p < .001$ ). The post-test performance could be predicted by the factors

presence ( $\beta = .12; p > .05$ , n.s.), pre-test performance ( $\beta = .45; p < .001$ ), and the scholastic performances in German ( $\beta = .22; p > .05$ , n.s.) and Maths ( $\beta = -.14; p > .05$ , n.s.). Significant proportions of variance explanation were found for presence ( $R^2 = .20; p < .05$ ), pre-test performance ( $R^2 = .29; p < .01$ ), and post-test performance ( $R^2 = .25; p < .01$ ). Variance explanation was insignificant ( $p > .05$ , n.s.) for the scholastic performance in Maths ( $R^2 = .03$ ), scholastic performance in German ( $R^2 = .05$ ), positive emotions ( $R^2 = .10$ ), negative emotions ( $R^2 = .06$ ).



Note. MotInt, intrinsic motivation; MotExt, external regulation; PerfPre, pre-test performance; German, scholastic performance in German; Maths, scholastic performance in Maths; PerfPost, post-test performance; EmoPo, positive academic emotions; EmoNe, negative academic emotions; Pres, presence; Imm, level of technological immersion; \* $p < .05$ ; \*\* $p < .01$ ; \*\*\* $p < .001$ ; Coefficients presented are standardized linear regression coefficients.

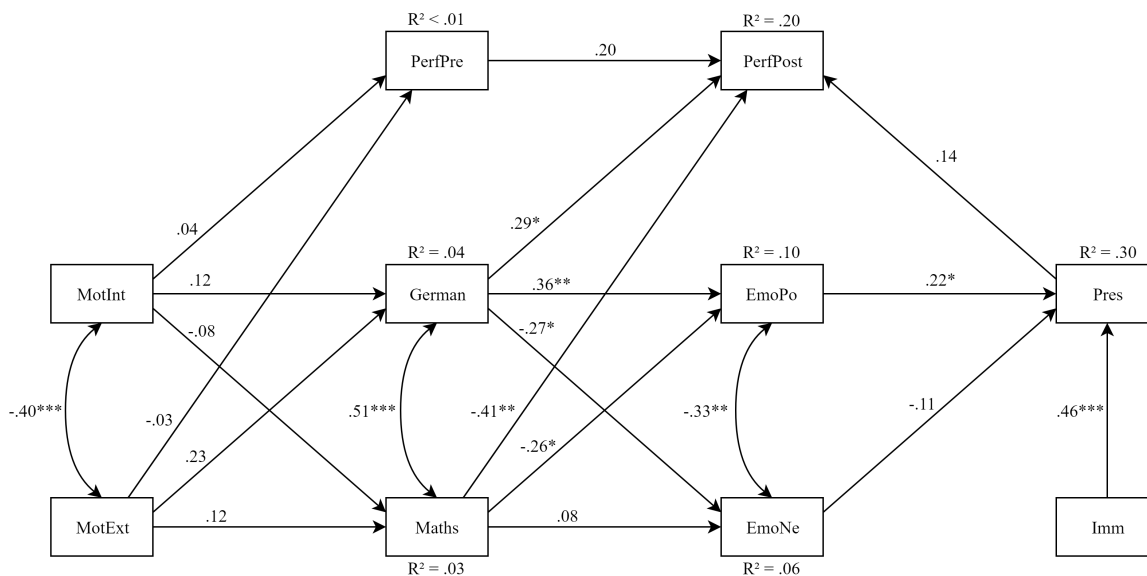
Figure 5.6. Path Analysis Model of the Results for the Asymmetric Encryption Topic

**Asymmetric Encryption** For the analysis of the *Asymmetric Encryption* tests and the corresponding immersive EVE *Fluxi's Cryptic Potions*, the path analysis model (Fig. 5.6) showed good model fit values as well ( $Chi^2 p = .30$ ,  $RMSEA = .041$ ,  $CFI = .968$ ,  $TLI = .946$ ,  $SRMR = .073$ ). Here too, the standardized results are able to reproduce the overall model's findings in general. For the correlations between



intrinsic and external regulation, between the scholastic performances in Maths and German, and between the positive and negative emotions, as well as for the predictive effects of the motivational constructs on scholastic performances and of scholastic performances on emotional states, see paragraph *Components of a Computer* in this section. Predictive effects for the pre-test performance derived from intrinsic motivation ( $\beta = .12$ ;  $p > .05$ ) and external regulation ( $\beta = -.24$ ;  $p < .05$ ). Presence could be predicted with positive emotions ( $\beta = .05$ ;  $p > .05$ , n.s.), negative emotions ( $\beta = -.11$ ;  $p > .05$ , n.s.), and immersion ( $\beta = .61$ ;  $p < .001$ ). Predictors of the post-test performance were presence ( $\beta = .21$ ;  $p < .05$ ), pre-test performance ( $\beta = .47$ ;  $p < .001$ ), and the scholastic performances in German ( $\beta = .28$ ;  $p < .05$ ) and Maths ( $\beta = -.27$ ;  $p < .05$ ). Significant proportions of variance explanation were found for presence ( $R^2 = .39$ ;  $p < .001$ ) and post-test performance ( $R^2 = .34$ ;  $p < .001$ ). The variance explanation for the pre-test performance ( $R^2 = .10$ ) was insignificant ( $p > .05$ , n.s.). For the variance explanations of the other dependant factors, see paragraph *Components of a Computer* in this section.

**Finite State Machines** For the path analysis regarding the topic *Finite State Machines* and the immersive *EVE Pengu's Treasure Hunt* (Fig. 5.7), the model fit values were poor ( $Chi^2 p < .001$ ,  $RMSEA = .125$ ,  $CFI = .637$ ,  $TLI = .390$ ,  $SRMR = .114$ ). Still, the directions of the standardized results were similar to the overall model's findings. Again, for the correlations between intrinsic and external regulation, between the scholastic performances in Maths and German, and between the positive and negative emotions, as well as for the predictive effects of the motivational constructs on scholastic performances and of scholastic performances on emotional states, see paragraph *Components of a Computer* in this section. Predictive effects for the pre-test performance deriving from intrinsic motivation ( $\beta = .04$ ;  $p > .05$ ) and external regulation ( $\beta = -.03$ ;  $p > .05$ , n.s.) were insignificant. Presence could be predicted with positive emotions ( $\beta = .22$ ;  $p < .05$ ), negative emotions ( $\beta = -.11$ ;  $p > .05$ , n.s.), and immersion ( $\beta = .46$ ;  $p < .001$ ). The post-test performance was predicted by presence ( $\beta = .14$ ;  $p > .05$ , n.s.), pre-test performance ( $\beta = .20$ ;  $p > .05$ , n.s.), and the scholastic performances in German ( $\beta = .29$ ;  $p < .05$ ) and Maths ( $\beta = -.41$ ;  $p = .001$ ). Significant proportions of variance explanation were found for presence ( $R^2 = .30$ ;  $p = .001$ ) and post-test performance ( $R^2 = .20$ ;  $p < .05$ ). The variance explanation for the pre-test performance ( $R^2 < .01$ ) was insignificant ( $p > .05$ , n.s.). For the variance explanations of the other dependant factors, see paragraph *Components of a Computer* in this section.



Note. MotInt, intrinsic motivation; MotExt, external regulation; PerfPre, pre-test performance; German, scholastic performance in German; Maths, scholastic performance in Maths; PerfPost, post-test performance; EmoPo, positive academic emotions; EmoNe, negative academic emotions; Pres, presence; Imm, level of technological immersion; \* $p < .05$ ; \*\* $p < .01$ ; \*\*\* $p < .001$ ; Coefficients presented are standardized linear regression coefficients.

Figure 5.7. Path Analysis Model of the Results for the Finite State Machines Topic

### 5.3.6 Discussion and Limitations

The study was designed to investigate singular relationships of the EFiL presented in chapter 3. Three EVEs for CS Education were developed as treatments, which were provided with three different technologies. In order to test the hypotheses presented in section 5.3.3, various analyses were carried out. This section presents a discussion of the results from a theoretical and a methodological perspective.

#### 5.3.6.1 Theoretical Limitations

As noted before (see section 3.2.3), the Educational Framework for Immersive Learning is not a final theory but rather a localization of VE characteristics in an existing supply-use framework. In section 3.2.1, it was pointed out that there are several approaches to explain scholastic learning using supply-use frameworks. An explanation of immersive learning processes could have used a different approach as well

what might have lead to other factors for the further investigation. Helmke's (2014) supply-use model, which was used for this localization, gathers many learner-specific and external variables and theories to display relations between these factors, learning processes, and learning outcomes by analyzing numerous studies. Some of these theoretical approaches were selected according to their relations to the VE characteristics; section 3.3 discussed their basic ideas (while not providing an extensive theoretical overview). Many context variables had to be blanked out to simplify the study. Doing so, the research model for the study is limited in a way that

- it uses a specific supply-use framework for the initial selection of variables;
- it represents only part of the factors that might influence immersive learning processes;
- the selected factors display particular theoretical ideas within broader theoretical constructs.

The idea of CS Replugged has to simplify the learning objectives in a way so that the students can grasp the underlying concept/idea on a metaphorical level. The narratives behind the virtual activities often blank out further problems concerning the topics in order to create a sense of story for the game (as suggested by the initial CS Unplugged approach). In such game-based settings, the separation of several cognitive levels (e.g. knowledge, comprehension, application, etc.) is difficult as the learning takes place during a dynamic and interactive gameplay inducing numerous cognitive processes. The limitations of the EVEs were discussed in sections 5.1.1–5.1.3. As the idea of CS Unplugged, motivating children to learn about computers in an engaging way, is pursued in the CS Replugged approach, the factor of context motivation for learning in the subject CS cannot be considered to be a strong predictor for learning outcomes (particularly in CS Replugged EVEs). While learning in other EVEs might be influenced from prospectively assessed motivational variables, the developed EVEs provided learning experiences in metaphorical ways, so that some students might not even realize the underlying CS topic while engaging in the virtual activity.

### 5.3.6.2 Discussion of the Method and Limitations

The hypothesis for the studies (see section 5.3.3) derived from the research model presented in section 3.4. This section tests the hypotheses based on the findings of the second study.

Table 5.15

*Results of the Hypotheses Tests (H1)*

Hypothesis	Relation	$\beta$	Supported?
Scholastic Performance			
H1 <sub>aa</sub>	$\uparrow\text{Mot}_{\text{int}} \longrightarrow \uparrow\text{Maths}$	(-.13)	No
H1 <sub>ab</sub>	$\uparrow\text{Mot}_{\text{id}} \longrightarrow \uparrow\text{Maths}$	-.25*	Yes
H1 <sub>ac</sub>	$\uparrow\text{Mot}_{\text{ij}} \longrightarrow \downarrow\text{Maths}$	(.02)	No
H1 <sub>ad</sub>	$\uparrow\text{Mot}_{\text{ext}} \longrightarrow \downarrow\text{Maths}$	.10	No
H1 <sub>ba</sub>	$\uparrow\text{Mot}_{\text{int}} \longrightarrow \uparrow\text{German}$	(.02)	No
H1 <sub>bb</sub>	$\uparrow\text{Mot}_{\text{id}} \longrightarrow \uparrow\text{German}$	-.16*	Yes
H1 <sub>bc</sub>	$\uparrow\text{Mot}_{\text{ij}} \longrightarrow \downarrow\text{German}$	(.06)	No
H1 <sub>bd</sub>	$\uparrow\text{Mot}_{\text{ext}} \longrightarrow \downarrow\text{German}$	.28*	Yes

*Note.*  $\uparrow\text{A} \longrightarrow \uparrow\text{B}$ : A has a positive effect on B;  $\uparrow\text{A} \longrightarrow \downarrow\text{B}$ : A has a negative effect on B; \* $p < .05$ ; \*\* $p < .01$ ;  $\beta$  values in brackets show excluded simple linear regression coefficients.

The results for H1: *The student's motivation towards learning CS predicts his/her scholastic performance (aa: intrinsic motivation increases performance in Maths<sup>33</sup>; ab: identified motivation increases performance in Maths; ac: introjected motivation decreases performance in Maths; ad: external regulation decreases performance in Maths; ba: intrinsic motivation increases performance in German; bb: identified motivation increases performance in German; bc: introjected motivation decreases performance in German; bd: external regulation decreases performance in German)* showed that scholastic performance can be predicted by identified motivation and external regulation towards learning CS, even though not all predictors were significant (see Tab. 5.15). While effects of intrinsic motivation and identified motivation were not included in the regression model, it has to be noted that the directions of both effects were according to the assumptions of H1. It can be assumed that these effects could be verified by using a larger sample. As the motivation questionnaire assessed the participants' motivation towards learning CS rather than learning Maths or German, the results can be regarded as side effects of the academic motivation towards learning a specific subject reflecting on a motivation (in terms of being regulated in a rather internal or external way) towards learning in general.

<sup>33</sup>It has to be noted that an up-arrow has to be interpreted as better performance in the subject, while a lower grade constitutes a better performance. Hence, the regression coefficients have to be interpreted reversely.

Table 5.16

*Results of the Hypotheses Tests (H2, H3)*

Hypothesis	Relation	$\beta$	Supported?
Emotional State			
H2 <sub>aa</sub>	$\uparrow\text{Mot}_{\text{int}} \longrightarrow \uparrow\text{Emo}_{\text{po}}$	(.17)	No
H2 <sub>ab</sub>	$\uparrow\text{Mot}_{\text{id}} \longrightarrow \uparrow\text{Emo}_{\text{po}}$	(.07)	No
H2 <sub>ac</sub>	$\uparrow\text{Mot}_{\text{ij}} \longrightarrow \downarrow\text{Emo}_{\text{po}}$	(.07)	No
H2 <sub>ad</sub>	$\uparrow\text{Mot}_{\text{ext}} \longrightarrow \downarrow\text{Emo}_{\text{po}}$	(-.02)	No
H2 <sub>ba</sub>	$\uparrow\text{Mot}_{\text{int}} \longrightarrow \downarrow\text{Emo}_{\text{ne}}$	(-.21)	No
H2 <sub>bb</sub>	$\uparrow\text{Mot}_{\text{id}} \longrightarrow \downarrow\text{Emo}_{\text{ne}}$	(-.18)	No
H2 <sub>bc</sub>	$\uparrow\text{Mot}_{\text{ij}} \longrightarrow \uparrow\text{Emo}_{\text{ne}}$	(-.09)	No
H2 <sub>bd</sub>	$\uparrow\text{Mot}_{\text{ext}} \longrightarrow \uparrow\text{Emo}_{\text{ne}}$	(.02)	No
H3 <sub>aa</sub>	$\uparrow\text{German} \longrightarrow \uparrow\text{Emo}_{\text{po}}$	.27	No
H3 <sub>ab</sub>	$\uparrow\text{Maths} \longrightarrow \uparrow\text{Emo}_{\text{po}}$	-.17	No
H3 <sub>ba</sub>	$\uparrow\text{German} \longrightarrow \downarrow\text{Emo}_{\text{ne}}$	-.24*	No
H3 <sub>bb</sub>	$\uparrow\text{Maths} \longrightarrow \downarrow\text{Emo}_{\text{ne}}$	(-.05)	No

*Note.*  $\uparrow\text{A} \longrightarrow \uparrow\text{B}$ : A has a positive effect on B;  $\uparrow\text{A} \longrightarrow \downarrow\text{B}$ : A has a negative effect on B; \* $p < .05$ ;  $\beta$  values in brackets show excluded simple linear regression coefficients.

H2: *The student's motivation towards learning CS predicts his/her emotional state (aa: intrinsic motivation increases positive emotions; ab: identified motivation increases positive emotions; ac: introjected motivation decreases positive emotions; ad: external regulation decreases positive emotions; ba: intrinsic motivation decreases negative emotions; bb: identified motivation performance decreases negative emotions; bc: introjected motivation increases negative emotions; bd: external regulation increases negative emotions)* could not be verified. Table 5.16 shows that none of the motivational traits was found to be a significant predictor of the participants' emotional states. While this is not in line with the assumptions deriving from the control-value theory of Pekrun et al. (2007), it is important to take into account the very specific question about the academic motivation towards learning CS. The students knew that the study was about learning different CS topics, but the key characteristic of the study was the use of VR technology. Thus, the participants' motivation towards learning with VR technology (or using VR in general) could have predicted

the emotional states better. Future studies might include this specific motivation in the questionnaires and apply the control-value theory on Immersive Learning studies.

Regarding H3: *Higher previous scholastic performance predicts the student's emotional state (aa: higher performance in German increases positive emotions, ab: higher performance in Maths increases positive emotions; ba: higher performance in German decreases negative emotions, bb: higher performance in Maths decreases negative emotions)*, scholastic performance in the subject German was found to predict the students' emotional states, but in the opposite directions<sup>34</sup> as assumed, see Table 5.16. When taking into account the insignificant effect of the scholastic performance in Math on positive emotions, this might be due to different interests in the subjects: For example, students pursuing a career in CS are more likely to have a positive attitude towards Maths as well (J. Wang, Hong, Ravitz, & Ivory, 2015). Even though performances in language-oriented subjects and Math are often related (J. C. Chow & Ekholm, 2019), attitudes, interests and emotions towards the topic areas might differ. Thus, a student with a positive attitude towards STEM subjects might have a rather negative attitude towards language-oriented subjects and vice versa.

H4: *A higher level of immersion predicts a higher sense of presence* can be maintained as immersion was included as a predictor for presence in the significant models of the linear regression analyses for the overall model (see Tab. 5.17) as well as for the *components of a computer* model ( $\beta = .41$ ;  $p < .01$ ), the *asymmetric encryption* model ( $\beta = .57$ ;  $p < .001$ ), and the *finite state machines* model ( $\beta = .55$ ;  $p < .001$ ). As all post hoc comparisons differed significantly, it can be assumed that immersion is not a binary variable but rather a spectrum with higher and lower levels. These results confirm the theoretical background presented in section 2.1, the findings presented in section 2.2 and the assumptions deriving from the EFIL.

H5: *The student's motivation towards learning Computer Science predicts his/her sense of presence (a: intrinsic motivation increases presence; b: identified motivation increases presence; c: introjected motivation decreases presence; d: external regulation decreases presence)* has to be discarded for H5<sub>a</sub>, H5<sub>c</sub>, and H5<sub>d</sub>. Even though introjected motivation was found to be significantly correlated (surprisingly, in a positive association) with presence ( $r = .12$ ;  $p < .05$ ), it was later excluded in the multiple linear regression analysis. According to the results displayed in Table 5.17, H5<sub>b</sub> can

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<sup>34</sup>As noted before, in the German school system, a lower grade represents a better scholastic performance.

Table 5.17

*Results of the Hypotheses Tests (H4-H7)*

Hypothesis	Relation	$\beta$	Supported?
Presence			
H4	$\uparrow\text{Imm} \longrightarrow \uparrow\text{Pres}$	.51***	Yes
H5 <sub>a</sub>	$\uparrow\text{Mot}_{\text{int}} \longrightarrow \uparrow\text{Pres}$	(.09)	No
H5 <sub>b</sub>	$\uparrow\text{Mot}_{\text{id}} \longrightarrow \uparrow\text{Pres}$	.16**	Yes
H5 <sub>c</sub>	$\uparrow\text{Mot}_{\text{ij}} \longrightarrow \downarrow\text{Pres}$	(.12)	No
H5 <sub>d</sub>	$\uparrow\text{Mot}_{\text{ext}} \longrightarrow \downarrow\text{Pres}$	(-.05)	No
H6 <sub>a</sub>	$\uparrow\text{German} \longrightarrow \uparrow\text{Pres}$	(-.06)	No
H6 <sub>b</sub>	$\uparrow\text{Maths} \longrightarrow \uparrow\text{Pres}$	(.01)	No
H7 <sub>a</sub>	$\uparrow\text{Emo}_{\text{po}} \longrightarrow \uparrow\text{Pres}$	.12*	Yes
H7 <sub>b</sub>	$\uparrow\text{Emo}_{\text{ne}} \longrightarrow \downarrow\text{Pres}$	(-.13)	No

*Note.*  $\uparrow\text{A} \longrightarrow \uparrow\text{B}$ : A has a positive effect on B;  $\uparrow\text{A} \longrightarrow \downarrow\text{B}$ : A has a negative effect on B; \* $p < .05$ ; \*\* $p < .01$ ; \*\*\* $p < .001$ . Coefficients presented derive from the overall analysis.  $\beta$  values in brackets show excluded simple linear regression coefficients.

be maintained for the overall measure but has to be discarded for the particular environments due to insignificance ( $p > .05$ ). While these results are compliant with the assumptions from the research model (except the indicator for an effect of identified motivation on presence), the findings in section 2.2 assume a clearer association between presence and motivation. It can be argued that the concept of CS Replugged, especially regarding the narrative approaches, tries to teach CS without coining it CS and, sometimes, even without the learner associating the topics with CS. Doing so, several forms of more or less self-regulated motivation towards learning CS might not have been relevant for feeling present in these CS Replugged EVEs as students did not associate the learning content with CS in the first place.

H6: *Higher previous scholastic performance predicts a higher sense of presence (a: German, b: Math)* has to be discarded. Linear regression analysis for presence the overall model did not include the scholastic performances as significant predictors using a cut-off value of  $p < .05$ , see Table 5.17. While these findings do not replicate the assumptions from section 2.2 suggesting cognitive factors as predictors for presence due to increased spatial mental abilities, the results are compliant with the research

model derived from the EFIL. Still, the small sample size has to be kept in mind. Moreover, it has to be noted that scholastic performance is a very rough measure of overall cognitive benefits.

The sub-hypotheses of H7: *The student's emotional state predicts his/her sense of presence (a: positive emotions increase presence; b: negative emotions decrease presence)* have to be regarded separately, as the results shown in Table 5.17 indicate. H7<sub>a</sub> can be maintained for the overall model: Positive emotions were included as a predictor for presence in the overall model. While the directions for the effects of positive emotions on presence were the same in all EVEs, the effects were insignificant. Thus, there are indicators that H7<sub>a</sub> is valid, but due to the small sample size, it can only be assumed for the overall measure. H7<sub>b</sub> has to be discarded: While a correlation analysis showed a significant correlation between presence and negative emotions ( $r = -.13$ ;  $p < .05$ ), negative emotions were not identified as a predictor for presence in the linear regression analysis for the overall measure (and, therefore, not tested for the individual environments). While this result can be seen as an indicator for an effect of negative emotions on presence, further studies with larger sample sizes are needed. Another measure of negative emotions should be used in order to assess the current emotional state of the student better (see section 5.3.2.2). Considering these indicated effects, the findings go along with the results from section 2.2, the assumptions of the EFIL, and the effect directions of the research model.

The assumptions of H8: *Higher previous scholastic performance predicts a better pre-test performance (a: German, b: Math)* have to be discarded as none of the effects were significant (see Tab. 5.18). While the research model suggested this relation, the results are not surprising: The topics were new to the students, meaning that higher intelligence and previous knowledge (especially in different subjects) would not help the students solving the tasks.

The results in Table 5.18 show that H9: *The student's motivation towards learning CS predicts the pre-test performance (a: intrinsic motivation increases pre-test performance; b: identified motivation increases pre-test performance; c: introjected motivation decreases pre-test performance; d: external regulation decreases pre-test performance)* can be assumed for the most internally regulated form of motivation (H9<sub>a</sub>, intrinsic motivation with  $\beta = .15$ ;  $p < .05$  for the overall model) and for external regulation (H9<sub>d</sub>,  $\beta = -.22$ ;  $p < .01$ ). Larger sample sizes might show significant effects of identified motivation and introjected motivation on pre-test performance as well.



Table 5.18

*Results of the Hypotheses Tests (H8-H9)*

Hypothesis	Relation	$\beta$	Supported?
Pre-Test Performance			
H8 <sub>a</sub>	$\uparrow$ German $\longrightarrow$ $\uparrow$ Perf <sub>pre</sub>	(-.09)	No
H8 <sub>b</sub>	$\uparrow$ Maths $\longrightarrow$ $\uparrow$ Perf <sub>pre</sub>	(.03)	No
H9 <sub>a</sub>	$\uparrow$ Mot <sub>int</sub> $\longrightarrow$ $\uparrow$ Perf <sub>pre</sub>	.15*	Yes
H9 <sub>b</sub>	$\uparrow$ Mot <sub>id</sub> $\longrightarrow$ $\uparrow$ Perf <sub>pre</sub>	(.07)	No
H9 <sub>c</sub>	$\uparrow$ Mot <sub>ij</sub> $\longrightarrow$ $\downarrow$ Perf <sub>pre</sub>	(-.19**)	No
H9 <sub>d</sub>	$\uparrow$ Mot <sub>ext</sub> $\longrightarrow$ $\downarrow$ Perf <sub>pre</sub>	-.25**	Yes

*Note.*  $\uparrow$ A  $\longrightarrow$   $\uparrow$ B: A has a positive effect on B;  $\uparrow$ A  $\longrightarrow$   $\downarrow$ B: A has a negative effect on B; \* $p < .05$ ; \*\* $p < .01$ . Coefficients presented derive from the overall analysis.  $\beta$  values in brackets show excluded simple linear regression coefficients.

H10: *A higher sense of presence predicts a better post-test performance* can be maintained as presence was integrated as a predictor (see Tab. 5.19) for the post-test performance in the linear regression analysis (cut-off value  $p < .05$ ). While the effects of presence on the post-test performances in the *components of a computer* test ( $\beta = .19$ ) and the *finite state machines* test ( $\beta = .15$ ) were insignificant ( $p > .05$ ), they were both positive. The poor scale reliability values of those tests have to be kept in mind (both discussed in section 5.3.2.5). Regarding the *asymmetric encryption* post-test, presence was identified as a significant predictor ( $\beta = .24$ ;  $p < .05$ ). Regarding these results, a generalization of H10 has to be discarded for now. But as previous results show, both presence and post-test performance depend on several factors, implying that linear regression analysis is not sufficient to verify or falsify H10. Hence, H10 has to be investigated further in the discussion of results deriving from the path analyses.

While a correlation analysis did not get significant results for the level of immersion and the students' post-test performances, H11: *A higher level of immersion predicts a better post-test performance* was investigated further by comparing the non-immersive setting laptop with the most immersive setting HTC Vive. The mixed results lead to further investigation using an ANOVA analysis, including all levels of immersion. A small, non-significant effect of the level of immersion on post-test

Table 5.19

*Results of the Hypotheses Tests (H10-H14)*

Hypothesis	Relation		$\beta$	Supported?
Post-Test Performance				
H10	$\uparrow$ Presence	$\longrightarrow$	$\uparrow$ Perf <sub>post</sub>	.19** Yes
H11	$\uparrow$ Immersion	$\longrightarrow$	$\uparrow$ Perf <sub>pre</sub>	.08 No
H12 <sub>a</sub>	$\uparrow$ Perf <sub>pre</sub>	$\longrightarrow$	$\uparrow$ Perf <sub>post</sub>	.35*** Yes
H13 <sub>a</sub>	$\uparrow$ German	$\longrightarrow$	$\uparrow$ Perf <sub>post</sub>	.32*** No
H13 <sub>b</sub>	$\uparrow$ Maths	$\longrightarrow$	$\uparrow$ Perf <sub>post</sub>	-.28*** Yes
H14 <sub>a</sub>	$\uparrow$ Mot <sub>int</sub>	$\longrightarrow$	$\uparrow$ Perf <sub>post</sub>	(.17) No
H14 <sub>b</sub>	$\uparrow$ Mot <sub>id</sub>	$\longrightarrow$	$\uparrow$ Perf <sub>post</sub>	(.09) No
H14 <sub>c</sub>	$\uparrow$ Mot <sub>ij</sub>	$\longrightarrow$	$\downarrow$ Perf <sub>post</sub>	(-.09) No
H14 <sub>d</sub>	$\uparrow$ Mot <sub>ext</sub>	$\longrightarrow$	$\downarrow$ Perf <sub>post</sub>	(-.08) No

*Note.*  $\uparrow$ A  $\longrightarrow$   $\uparrow$ B: A has a positive effect on B;  $\uparrow$ A  $\longrightarrow$   $\downarrow$ B: A has a negative effect on B; \*\* $p < .01$ ; \*\*\* $p < .001$ . Coefficients presented derive from the overall analysis.  $\beta$  values in brackets show excluded simple linear regression coefficients.

results was found [ $F(2, 208) = .72, p > .05, \eta_p^2 = .01$ ]. It can be concluded that the level of immersion is not a predictor for performance. While this contradicts the results from section 3.3.5, the findings go along with the key idea of the EFiL and the deriving research framework: A possible small effect of immersion on learning outcomes can be explained through the enhanced level of presence induced by the higher level of immersion, but immersion is not a key factor in the learning process.

H12: *A higher score in the pre-test predicts a better post-test performance* can be maintained: Linear regression analysis (see Tab. 5.19) showed that the students' pre-test performances predicted their post-test performances for the overall measures ( $\beta = .35; p < .001$ ), the *components of a computer* topic ( $\beta = .38; p < .01$ ), and the *asymmetric encryption* topic ( $\beta = .50; p < .001$ ). While predictive effect of pre-test performance on post-test performance for the *finite state machines* topic was not significant ( $\beta = .21; p > .05, n.s.$ ), the poor scale reliability has to be kept in mind (see section 5.3.2.5).

Regarding H13: *Higher previous scholastic performance predicts a better post-test performance (a: German, b: Maths)*, both subjects showed significant correlations with the overall post-test performance. Both, scholastic performance German ( $\beta = .32$ ;  $p < .001$ ) and scholastic performance Maths ( $\beta = -.28$ ) were included as the post-test performance's predictors in the linear regression analysis (see Tab. 5.19). As a lower grade indicates better scholastic performance in the particular subject, the effect of Maths on post-test performance was compliant to H8 while the subject German was not. The effect of Maths was significant for the *asymmetric encryption* topic ( $\beta = -.27$ ;  $p < .05$ ) and for the *finite state machines* topic ( $\beta = -.44$ ;  $p < .01$ ); the effect of German was significant for the topics *components of a computer* ( $\beta = .32$ ;  $p < .05$ ), *asymmetric encryption* ( $\beta = .29$ ;  $p < .05$ ) and *finite state machines* ( $\beta = .33$ ;  $p < .05$ ). Thus, H13<sub>b</sub> can be maintained; H13<sub>a</sub> has to be discarded. The positive effects of the scholastic performance in Maths can be explained with the assumptions of section 2.2 implying that increased cognitive benefits (roughly represented with scholastic performance) result in better spatial mental skills. There are two possible ideas connected with the negative effect of scholastic performance in German on post-test performance: 1) Students who are talented in linguistic tasks and skills might have less interest in the more conceptual and technological perspectives of CS; 2) Students with good grades in the subject German might have a strong interest in narratives, focusing more on the story and the characteristics of the VE than on the learning contents. Both are ideas without empirical evidence and need further investigation. But the significant negative effects of the scholastic performance in German on post-test performance for all topics is interesting and has to be considered in further analyses as well: There seems to be an interesting effect of cognitive capabilities or underlying interests on learning processes.

H14: *The student's motivation towards learning CS predicts the post-test performance (a: intrinsic motivation increases post-test performance; b: identified motivation increases post-test performance; c: introjected motivation decreases post-test performance; d: external regulation decreases post-test performance)* assumed relations between the post-test performance and the motivational constructs. While there was a significant correlation between the overall post-test performance and intrinsic motivation ( $r = .17$ ;  $p < .05$ ), motivational factors were not included as predictors for post-test performance in the linear regression analysis (see Tab. 5.19). Thus, H14 has to be discarded for all sub-hypotheses H14<sub>a</sub>, H14<sub>b</sub>, H14<sub>c</sub>, and H14<sub>d</sub>. These results are not compliant with the EFiL and the research model. A possible reason why motivational traits did not affect learning outcomes could lie in the concept of CS

Replugged, which provides engaging and motivating environments that might not be associated with CS by the students (similar to H5).

H15: *Presence mediates the effect of immersion on post-test performance* has to be discarded as H6 had to be rejected as well. There was no significant effect of immersion on post-test performance. As both, the effect of immersion on presence and the effect of presence on learning outcomes, were positive, a negative mediation effect could be excluded as well.

To further investigate the research model presented in section 3.4, observed variable path analyses were conducted to test the hypotheses deriving from the research model as well as from the results of bivariate analyses and the multiple linear regression analyses (see section 5.3.5.7). Table 5.20 shows the results of the path analysis hypotheses tests for the overall model.

H1: *Intrinsic motivation correlates negatively with external regulation* can be maintained. There was a significant negative correlation found between the two factors. This result is compliant to the theoretical and empirical findings of motivational theories.

Regarding the hypotheses focusing scholastic performance and its predictors, H2<sub>a</sub>: *Scholastic performance German is predicted by a) external regulation (decrease) and b) intrinsic motivation (increase)*, H2<sub>b</sub>: *Scholastic performance Maths is predicted by external regulation (decrease) and intrinsic motivation (increase)*, and H2<sub>c</sub>: *Scholastic performance German correlates positively with scholastic performance Maths* have to be regarded separately. While there was a significant positive correlation between the scholastic performance in German and in Maths, only the predictive effect of external regulation on Maths was significant, but not in the predicted direction. Thus, H2<sub>a</sub> and H2<sub>b</sub> have to be rejected; H2<sub>c</sub> can be maintained. The directions of the predictive effects of motivational traits on scholastic performances were surprising as well. While it was assumed that intrinsic motivation would predict a higher scholastic performance while external regulation would predict a lower scholastic performance (which was the case in terms of the subject Math), intrinsic motivation showed a negative effect on the scholastic performance in the subject German. This, again, could derive from different interests and talents as the questionnaire measuring intrinsic and external regulation asked precisely for the motivational traits to learn in the subject of CS.

The academic emotions were assumed to depend on the scholastic performances. H3<sub>a</sub>: *Positive academic emotions are predicted by a) scholastic performance German (decrease) and b) scholastic performance Maths (increase)* can be maintained, the

Table 5.20

*Results of the Path Analysis Hypotheses Tests*

Hypothesis	Relation		Path Coefficient	Supported?
Motivation				
H1	$\uparrow\text{Mot}_{\text{int}}$	$\longleftrightarrow$ $\uparrow\text{Mot}_{\text{ext}}$	-.40***	Yes
Scholastic Performance				
H2 <sub>aa</sub>	$\uparrow\text{Mot}_{\text{int}}$	$\longrightarrow$ $\uparrow\text{Maths}$	-.08	No
H2 <sub>ab</sub>	$\uparrow\text{Mot}_{\text{ext}}$	$\longrightarrow$ $\downarrow\text{Maths}$	.12	No
H2 <sub>ba</sub>	$\uparrow\text{Mot}_{\text{int}}$	$\longrightarrow$ $\uparrow\text{German}$	.12	No
H2 <sub>bb</sub>	$\uparrow\text{Mot}_{\text{ext}}$	$\longrightarrow$ $\downarrow\text{German}$	.23**	Yes
H2 <sub>c</sub>	$\uparrow\text{German}$	$\longleftrightarrow$ $\uparrow\text{Maths}$	.51***	Yes
Emotional State				
H3 <sub>aa</sub>	$\uparrow\text{German}$	$\longrightarrow$ $\uparrow\text{Emo}_{\text{po}}$	.37*	Yes
H3 <sub>ab</sub>	$\uparrow\text{Maths}$	$\longrightarrow$ $\uparrow\text{Emo}_{\text{po}}$	-.26*	Yes
H3 <sub>ba</sub>	$\uparrow\text{German}$	$\longrightarrow$ $\downarrow\text{Emo}_{\text{ne}}$	-.27*	Yes
H3 <sub>bb</sub>	$\uparrow\text{Maths}$	$\longrightarrow$ $\downarrow\text{Emo}_{\text{ne}}$	.07	No
H3 <sub>c</sub>	$\uparrow\text{Emo}_{\text{po}}$	$\longleftrightarrow$ $\downarrow\text{Emo}_{\text{ne}}$	.07	No
Pre-Test Performance				
H4 <sub>a</sub>	$\uparrow\text{Mot}_{\text{int}}$	$\longrightarrow$ $\uparrow\text{Perf}_{\text{pre}}$	.16*	Yes
H4 <sub>b</sub>	$\uparrow\text{Mot}_{\text{ext}}$	$\longrightarrow$ $\downarrow\text{Perf}_{\text{pre}}$	.20**	Yes
Presence				
H5 <sub>a</sub>	$\uparrow\text{Imm}$	$\longrightarrow$ $\uparrow\text{Pres}$	.49***	Yes
H5 <sub>ba</sub>	$\uparrow\text{Emo}_{\text{po}}$	$\longrightarrow$ $\uparrow\text{Pres}$	.15*	Yes
H5 <sub>bb</sub>	$\uparrow\text{Emo}_{\text{ne}}$	$\longrightarrow$ $\downarrow\text{Pres}$	-.08	No
Post-Test Performance				
H6 <sub>a</sub>	$\uparrow\text{Pres}$	$\longrightarrow$ $\uparrow\text{Perf}_{\text{post}}$	.16**	Yes
H6 <sub>b</sub>	$\uparrow\text{Perf}_{\text{pre}}$	$\longrightarrow$ $\uparrow\text{Perf}_{\text{post}}$	.34***	Yes
H6 <sub>c</sub>	$\uparrow\text{German}$	$\longrightarrow$ $\uparrow\text{Perf}_{\text{post}}$	.26***	Yes
H6 <sub>d</sub>	$\uparrow\text{Maths}$	$\longrightarrow$ $\downarrow\text{Perf}_{\text{post}}$	-.29***	Yes

*Note.* A  $\longleftrightarrow$  B: A and B are correlated;  $\uparrow\text{A} \longrightarrow \uparrow\text{B}$ : A has a positive effect on B;  $\uparrow\text{A} \longrightarrow \downarrow\text{B}$ : A has a negative effect on B; \* $p < .05$ ; \*\* $p < .01$ ; \*\*\* $p < .001$ . Coefficients presented derive from the overall analysis.

effects of the scholastic performance in the subjects German and Math were significant and their direction were compliant to the hypotheses. Regarding H3<sub>b</sub>: *Negative academic emotions are predicted by scholastic performance German (increase) and scholastic performance Maths (decrease)*, the directions were compliant to the theory but only the effect of the subject German was significant. H3<sub>c</sub>: *Positive academic emotions are correlated negatively with negative academic emotions* can be maintained, as a significant correlation was found. Even though H3<sub>b</sub> could not be maintained, there are indicators that all hypotheses of H3 are valid; larger sample sizes might prove this.

H4 assumed that *Pre-test performance is predicted by a) external regulation (decrease) and b) intrinsic motivation (increase)*. The hypotheses can be maintained for the overall measure as the effects of intrinsic motivation and external regulation on pre-test performance were significant and affected the pre-test performance in the hypothesized directions. H4 could also be maintained for the *components of a computer* topic ( $\beta = .30$ ;  $p < .01$  for intrinsic motivation;  $\beta = -.35$ ;  $p < .01$  for external regulation). The effects for the *asymmetric encryption* topic and the *finite state machines* topic pointed in the hypothesized directions but were not significant ( $p > .05$ , n.s.). Larger sample sizes could help verifying these relations. But the poor scale reliability of the *finite state machines* performance test has to be considered as well as an explanation for the non-significance of the effects.

H5 hypothesized that *Presence is predicted by a) immersion (increase), b) positive emotions (increase), and c) negative emotions (decrease)*. Immersion had a significant effect in the overall measure, the *components of a computer* EVE ( $\beta = .41$ ,  $p < .01$ ), the *asymmetric encryption* EVE ( $\beta = .61$ ,  $p < .001$ ), and the *finite state machines* EVE ( $\beta = .46$ ,  $p < .001$ ). The effect of positive emotions on presence was only significant ( $p < .05$ ) for the overall measure ( $\beta = .15$ ) and for the *finite state machines* EVE ( $\beta = .22$ ). The effect of negative emotions on presence was insignificant ( $p > .05$ , n.s.) for all measures/EVEs though it was pointed in the hypothesized direction. Again, larger sample sizes could lead to significant results for effects in the hypothesized direction. As before, the questionable scale reliability of the negative emotions scale has to be kept in mind.

For the overall model, H6: *Post-test performance is predicted by a) presence (increase), b) pre-test performance (increase), c) scholastic performance German (decrease), and d) scholastic performance Maths (increase)* can be maintained. The model showed significant effects of the pre-test performance, presence, and the scholastic performances in German and in Math. While pre-test performance was a predictor

for post-test performance regarding the *components of a computer* topic ( $\beta = .45$ ;  $p < .001$ ) and the *asymmetric encryption* topic ( $\beta = .47$ ;  $p < .001$ ), its effect was insignificant ( $p > .05$ , n.s.) for the *finite state machines* topic. Scholastic performances in German and Maths predicted the post-test performance significantly in the *asymmetric encryptions* topic ( $\beta = .28$ ;  $p < .05$  for German;  $\beta = -.27$ ;  $p < .05$  for Maths) and in the *finite state machines* topic ( $\beta = .29$ ;  $p < .05$  for German;  $\beta = -.41$ ;  $p < .01$  for Maths). Presence was a significant predictor for post-test performance in the *asymmetric encryption* topic ( $\beta = .21$ ;  $p < .05$ ). All insignificant effects pointed in the hypothesized direction. Thus, H6<sub>a</sub> can be maintained.

### Summary 8: Results and Discussion

The findings show that learning outcomes in educational virtual environments can be predicted by

- presence (influenced by the level of immersion, the student's emotional state, and his/her contextual motivation for learning),
- previous scholastic performance (influenced by gender and the student's contextual motivation for learning), and
- previous knowledge about the topic (which can be, for a given unfamiliar topic of a subject, predicted by the student's motivation for learning in the subject).

While different levels of immersion can induce different levels of presence, the technological supply is not the key characteristic of an educational virtual environment that activates learning processes. It is the emerging level of presence, which is also influenced by other factors, that contributes to learning processes. Presence has a small effect on learning, but factors like the previous scholastic performance and the previous knowledge about the topic are more effective predictors. Variance explanations for the post-test performance between 20 % and 34 % indicate that there are still many more factors that have an impact on learning processes in educational virtual environments. As it was not possible to 1) include all factors suggested by the Educational Framework for Immersive Learning, and, 2) within the included factors, display only small, particular ideas of the underlying theoretical constructs, further studies are required to contribute to a deeper understanding of immersive learning processes.





# Chapter 6

## Conclusions

This thesis took different perspectives on learning in immersive EVEs. The theoretical ideas and models of experiencing immersive VEs were explored from a general, educational perspective. These ideas were then put into practice, focusing on didactical questions of CSE. The results of the conducted study were discussed on the basis of the theoretical assumptions and their limitations were displayed.

In chapter one and two, a perspective from the Educational Sciences was taken in order to determine what factors, in theory, contribute to immersive learning processes leading to learning outcomes. Therefore, we first took a more general look into the variables defining experiences in VEs: immersion and presence. We separated these characteristics so that the level of immersion consists of the objective components of the experience on a technological level while presence explains the induced feeling of non-mediation regarding physical, social, and self-related aspects. Along this way, this thesis contributed a conceptual model of objective and subjective factors influencing presence, extending existing approaches of Steuer (1992) and Slater (2003). On the basis of these relations, chapter three pursued educational approaches and ideas related to immersive learning from Whitelock et al. (1996); Hedberg and Alexander (1994); Dalgarno and Lee (2010); Fowler (2015); and Slater (2017). Immersion and presence were localized in the supply-use framework of Helmke (2014), suggesting that the level of immersion is part of the instructional supply while presence adds to the perceptual processes inside the learner and, thus, contributes to the use side of the framework. The deriving Educational Framework for Immersive Learning (EFiL) suggests a general explanation of scholastic learning in educational VEs. Some particular theoretical ideas and findings behind the supply-use framework of Helmke, both, related to general learning processes and related to learning in VEs in particular, were explored further. By connecting them to the conceptual model explaining presence, a research model for the investigation of immersive learning processes was proposed.

The research model assessed the relations and effects between the learner-specific variables (presence, motivation, cognition, and emotion), the supplied level of immersion, and learning outcomes. The model presented an approach in which presence, influenced by immersion, cognitive abilities, and achievement emotions, predicted learning outcomes together with the mutually correlated factors context motivation and cognitive abilities, both also influencing the learner's achievement emotions.

Chapter four then selected the CS Unplugged approach as an idea to create engaging activities for learning CS. By introducing the idea of CS Replugged, this thesis tried to pursue and foster existing ideas for learning about the topics *components of a computer*, *asymmetric encryption*, and *finite state machines*. By following the idea of including narratives that are supposed to engage and encourage the learner, the CS Replugged approach takes immersive technology to give the learner opportunities to interact with concepts and ideas of CSE in VEs while perceiving the VEs as non-mediated (or, at least, as less mediated than a non-immersive version).

In chapter five, two studies were designed on the basis of the research model. Three EVEs (*Bill's Computer Workshop*, *Fluxi's Cryptic Potions*, and *Pengu's Treasure Hunt*) were developed as treatments. The EVEs could be used with different devices in order to provide learning experiences at various levels of immersion. The results were reported and discussed: All environments were effective in terms of learning outcomes indicating that the CS Replugged approach is an effective method to teach CS contents (even though it is, by now, not possible to say if it is more effective than any other method). The study delivered indicators that the research model is applicable to some of the EVEs, but might not fit all immersive learning scenarios. While there were indicators that a higher immersion was related to higher learning outcomes, significant predictive effects were found between presence and the learning outcomes. Even though a hypothesized, mediating influence of presence on the effect of immersion on learning outcomes could not be verified, the result indicates that the theoretical assumptions of the EFIL might be right: The immersive EVE is an instructional supply that has to be perceived (in terms of feeling present inside the environment) and interpreted by the learner's mind first. The perception process, as well as the learning processes, were supposed to be influenced by the person-specific variables context motivation, achievement emotions, and cognitive abilities. These relations could be reproduced partly in the bi- and multivariate analyses. A path analysis of the standardized overall results, which was similar to the research model, showed good model fit values and could be applied to two of the CS Replugged EVEs

as well. A weak spot of the study is that some of the tests showed questionable or poor scale reliabilities, which has to be eradicated in further studies.

This chapter will now provide some insights into the implications and conclusions coming along with the theoretical, practical, and empirical results from this thesis. While the path towards this point of the thesis followed a top-down approach (suggesting a theoretical framework, deducing a research model, developing immersive experiences, carrying out a study testing the immersive experiences), the conclusions move along a bottom-up approach: First, an impression of the CS Replugged approach by reflecting on the learning experiences and outcomes will be provided. Then, study's results are discussed with regards to the general localization of VE characteristics in the supply-use-framework from an educational view.

## 6.1 Conclusions from a Perspective of Computer Science Education

In a world where mediation is omnipresent, CSE needs to be a central part of preparing children for their later professional and everyday life. Teaching the fundamental ideas and concepts of CS via engaging activities and first-hand experiences can foster children's understanding. As many concepts in CS are rather abstract, the use of metaphors and analogies can help in designing such activities. CS Unplugged already introduced several concepts teaching such ideas. The idea of CS Replugged, providing mediated activities for learning and teaching CS while the learner experiences the feeling of non-mediation, can

- refine (some particular) existing activities so that the technology provides additional value and
- create new activities by realizing metaphor and analogies that are difficult or impossible to carry out in reality.

The EVE *Bill's Computer Workshop* presented an interactive game that let the learner explore the inside of a computer by repairing (in terms of finding/replacing) several components of it. While it does not use a metaphor or analogy, it is still an engaging hands-on activity that is physically impossible in reality. In this case, the immersive technology enables the CS Replugged activity, which delivers good learning results on a remembering level (the student is able to name the components of a computer, their relations, and their functions). The results of the study show that the EVE is effective, especially in immersive settings. From the experiences

during the study, the students had fun playing the game<sup>1</sup>, but environment can still be refined. As it includes much turning and teleporting, the current application is not suitable for mobile VR. Doing so, it is recommended to use a professional HMD or a non-immersive laptop setting for the current version of *Bill's Computer Workshop*. It would be interesting to compare this gamified approach with an approach of building or repairing a computers in the classroom in reality.

*Fluxi's Cryptic Potions* introduces a new idea of visualizing the idea behind asymmetric encryption without approaching mathematical backgrounds or computational complexity. By taking up an established approach of mixing colors, the narrative of encrypting and decrypting letters using public and private magic potions in a medieval fantasy setting generates an exciting experience for students of a younger age. Like the EVE for the components of the computer topic, *Fluxi's Cryptic Potions* was effective in terms of learning outcomes regarding asymmetric encryption understanding skills. While the EVE lacks the charm of understanding the mathematical backgrounds of one-way functions, relying on complex problems, it can introduce the basic idea by using the metaphor. Here, immersive settings were beneficial for the learning experience as the used potions were memorized better. It can be assumed that the creation of a mental model (which potion has to be used for what reason) was supported this way. Still, the experience could be made even more immersive by enhancing the interactive aspects. Another approach could be to integrate multiple users or even the whole class in a network that can communicate via their carrier dragons and their magic potions.

The original CS Unplugged activity *Treasure Hunt* was simulated in the EVE *Pengu's Treasure Hunt* by adding an automatically generated map and the task to collect all key parts (to find all routes/transition functions) before opening the treasure chest on the treasure island (the final state). Here, the immersive experience was supposed to add additional features to the real-life activity. Again, the learning outcomes were significantly higher after completing the activity, indicating that the approach is effective. But, as for all EVEs, it is questionable if the virtual experience really provides a better learning experience than the original CS Unplugged activity (keeping in mind that they might serve distinct purposes/stages in the learning process). While the visualizations of the islands were highly motivating, the immersive settings entice the students to get distracted from the task and rather explore the islands than completing the map. A possible fix for this might be to integrate the CS

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<sup>1</sup>In many cases, the investigators could tell when a student was teleported inside the computer for the first time by him/her exclaiming "Wow!", looking around the tall hardware structure.

Replugged idea into an AR that is visualized as an overlay for the original activity. But it is questionable if it is worth the effort of providing the AR devices in order to just display supplemental information.

The three environments only present a small part of what is possible with the idea of CS Replugged. By using metaphorical and non-metaphorical approaches and by focusing on different cognitive levels, the presented EVEs are thought of to be examples for a variety of further ideas. It becomes clear that using AR and VR is not the solution for every topic but rather a new idea to enhance learning and teaching CS in particular aspects. First, the activity must be suitable for the use of immersive technology and second, the teacher also plays a crucial role in the process of learning. He/she has to include the immersive activity at the right point during the learning process so that the students can benefit from this. Furthermore, if the activities include metaphors and analogies, it is the teacher who has to explain the connections to CS before or after the activity. When following the argumentation that presence enhances learning, it can be argued that the aim of CS Replugged is not to introduce VR games as a substitute for CS Unplugged activities, as the sense of presence will always be higher in real activities, especially when they are fun<sup>2</sup> and engaging. The idea of CS Replugged, therefore, tries to improve existing approaches (where improvement is needed and where it can be beneficial for learning) through augmentation or modification (in terms of the SAMR model, Puentedura, 2006) or to enable new activities (redefining a task, Puentedura, 2006) rather than simply substituting technology for existing activities. The EVEs have to be considered as prototypes: In order to engage the students into the activities, they can be enhanced by adding more possibilities for exploration. Bell et al. (2012) note that Unplugged activities

“can largely be seen as a desire to rescue children from becoming only users<sup>3</sup>, that is, becoming addicted to whatever technologies are inflicted on them, rather than being given the wherewithal to create systems that work for them; to choose between what is good and what is harmful; and to discern what will improve their quality of life, and what will improve someone else’s quality of life at their expense” (p. 438).

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<sup>2</sup>Of course, the discussions on how emotional factors like enjoyment can contribute to presence as presented in section 2.2.4.4 might also be applicable for real world activities.

<sup>3</sup>Here, Bell, Rosamond, and Casey reference to a quote attributed to Edward R. Tufte: “Only two industries refer to their customers as ‘users’: computer design and drug dealing” (Bell et al., 2012, p. 438).

To empower children to do this, activities, real or virtual, have to provide opportunities to explore. Right now, all EVEs provide closed storylines with only few room for exploring and experimenting. The further development of the EVEs can benefit from the possibilities of immersive technology: Including the possibility to walk around, to grab, raise, turn, and throw things, and to interact with other students in the same VE. The presented EVEs could give a small insight of what is possible, but a lot more opportunities await for the idea of CS Replugged.

As a note on the side, it can be argued that VR and AR pose an interesting topic for CS Education on their own. Similar to the representation of information, which poses a fundamental idea of CS, different levels of immersion can result in a topic concerned with the representation of sensory stimuli. By combining these questions on how perceptual cues can be represented virtually with questions regarding immersion and presence, as well as by taking into account social and critical questions regarding a virtual information and media literacy, Virtuality Literacy was suggested as a transdisciplinary Computational Thinking skill (Dengel, 2018c).

## 6.2 Conclusions from a Perspective of the Educational Sciences

How does learning in immersive EVEs work? How are learning processes induced through the learner's sense of presence? What role does the technology regarding the provided level of immersion play? In order to answer these questions, this thesis used established approaches for the explanation of scholastic learning and combined the technological and person-specific characteristics of immersive and non-immersive EVEs with theories and empirical findings related to technology-enhanced learning. The supply-use-framework of Helmke (2014) provided a solid theoretical basis for localizing these 'new' factors<sup>4</sup>. The resulting Educational Framework for Immersive Learning can be used for a variety of questions and hypotheses concerned with technology-enhanced learning, especially with a focus on VR and AR. Splitting VE characteristics into objective, technological features and subjective, person-specific features allows distinct investigations of the instructional supply (level of immersion regarding hardware and software) and the perceptual processes (in terms of feeling physically, socially, and self-present) regarding learning processes and outcomes.

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<sup>4</sup>In fact, both factors existed before: Every medium has a certain level of immersion and every activity induces a certain level of presence in the real, the imaginary, or a virtual world. It is now that they gain prominence as immersive technology can provide levels of presence that are at least comparable to what we experience in the real world.

As the supply-use-framework includes many theoretical and empirical results for explaining scholastic performance on a general level, it is necessary to derive particular object-theories and research models that explain and investigate effect chains in detail. By investigating a research model on how immersion, as well as the subjective factors context motivation, cognitive abilities, achievement emotions, and presence interact regarding learning processes and outcomes, a small part of the EFiL was put into concrete terms. This process of deriving hypotheses from the EFiL as well as from particular theories has the potential to explain the involved variables and their relations to other factors. It is unlikely that one model can display all relations in the EFiL, including all different types of research questions. This is why future studies have to focus on particular areas and effects. For example, this study did not focus on questions regarding the teacher, the context variables, gender, and the individual background of the learner. Including such factors into research models can highlight more relationships that determine learning success in EVEs.

It has to be noted that there were some weak spots in the study: Some poor scale instruments were used and there was no control group without any treatment. No crossed-lagged-panel design was used for controlling the stability of the trait variable motivation and the cognitive abilities can only roughly be displayed using grades. Further, the groups were not completely randomized due to class allocations. Still, the investigation of partial relationships in the EFiL using the EVEs for CSE revealed that many of the underlying assumptions seem to be true, while some had to be rejected. In particular, it is interesting that some results were contrary to the underlying assumptions: Especially the opposite effects of the scholastic performance in the subject German on emotions and of the motivational traits towards learning CS on the scholastic performance in the subject German raises new questions about how different motivations, interests, and skills in particular subjects can contribute to learning in another subject. A key result from the study is that presence has a significant effect on learning outcomes, adding to the question whether the provided technology itself or the interpretation and perception of the displayed contents matters in terms of learning.

The results show further that it is not useful to separate questions concerning general educational issues from didactical intricacies. While the obtained results show relations for the presented EVEs, the underlying didactical concepts, in this case, CS Replugged, seems to be a crucial factor influencing all theoretical relationships. For example, the research model hypothesized relations between the motivational traits

and the learning outcomes implying that more self-regulated forms of context motivations (towards learning CS) would increase learning outcomes while less self-regulated forms of context motivation would decrease learning outcomes. The initial approach of the didactical concept CS Replugged approaches ideas that teach CS without focusing on computers as a tool and by using metaphorical and non-metaphorical narratives that are supposed to be fun and engaging. Doing so, learners might not even relate the EVEs to learning contents of CS, explaining the lack of predictive effects of the assessed motivational traits for these particular learning outcomes. It can be concluded that the educational perspective cannot be investigated while blanking out the didactical perspective of the subject. Not only do the didactical contents and approaches seem to moderate the strength of apparent relationships between the person-specific variables, but they also seem to determine whether these relations are relevant at all.

Media Learning, immersive or not, is always connected to the setting in which the instructional medium is used. Future studies might not only focus on the medium and its content and technological characteristics, but also on the surrounding setting. This includes the phase of teaching, in which the EVE is used: An instructional medium can be used, for example, as an introduction to a new topic/problem (*phase of task definition*), for acquiring knowledge related to the problem (*phase of working out fundamentals for solving the task*) or in the *phase of task solution* (Tulodziecki, Grafe, & Herzig, 2019). In addition to embedding the medium in the larger teaching sequence, other factors like the procedure, the composition of the class (individual experience, collaborative experience), and technical support are part of the setting-related considerations. As noted before, the learning process framed by the setting does not necessarily have to be intentional, as there are various unintentional learning situations as well.

This thesis tried to represent a variety of key aspects relevant for Immersive Learning research. It becomes clear that research regarding questions of Immersive Learning cannot think in disciplines. While the presented ideas are not universal, they are thought of as sparks for exciting discussions between and above the disciplines contributing their perspectives to Immersive Learning.



## Chapter 7

# Epilogue: Future Teaching and Learning in Immersive Educational Virtual Environments

It has been noted at several points of this thesis, that research regarding teaching and learning in immersive EVEs unites inter- and transdisciplinary questions. It has also been noted, that, despite the encouraging results of the studies included in the thesis and the opportunities given by VR and AR media, it is still a long way until immersive technology finds its way into the everyday classroom. The technology is still new and only few educational applications exist. For now, theoretical, empirical, and technological developments may not be sufficient to bring VR and AR into the traditional educational system. When technological basics regarding the use of VR and AR are lacking, teachers' support of using immersive teaching and learning media will stay scarce.

According to Mishra and Koehler (2014), digital technologies tend to have inherent properties that make it difficult to apply them in a straightforward way<sup>1</sup>. Doing so, teaching with technology becomes a 'wicked problem' involving multiple, mutually interacting factors. To tackle this problem, they introduced the *technological pedagogical content knowledge* (TPCK) as a framework for teacher knowledge with a focus on technology-enhanced learning. The knowledge areas concern the integration of technology in the classroom (Fig. 7.1).

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<sup>1</sup>While traditional pedagogical technologies are often characterized by specificity (e.g. a pencil is for writing only), stability (e.g. chalkboards in the classroom have been around for centuries), and transparency of function (the inner working of a pencil is simple), digital technologies tend to be unstable in many different ways, e.g. regarding their rapid change or regarding their inner working, which is hidden from the user (Koehler & Mishra, 2014).

By extending Shulman's concept of *pedagogical content knowledge* (PCK) (Shulman, 1986), Mishra and Koehler (2014) conceptualized seven knowledge domains:

- *Content Knowledge (CK)*: knowledge about the actual subject matter that the students are supposed to learn about
- *Pedagogical Knowledge (PK)*: knowledge about the processes, practices, and strategies concerned with teaching and learning
- *Technological Knowledge (TK)*: knowledge about operating digital technologies
- *Pedagogical Content Knowledge (PCK)*: the interaction between the knowledge domains CK and PK
- *Technological Content Knowledge (TCK)*: the interaction between the knowledge domains CK and TK
- *Technological Pedagogical Knowledge (TPK)*: the interaction between the knowledge domains TK and PK
- *Technological Pedagogical Content Knowledge (TPACK<sup>2</sup>)*: the interaction between the knowledge domains PCK, TCK, and TPK (Angeli, Valanides, & Christodoulou, 2016).

While PCK consists of the knowledge to represent specific content areas and making them more accessible to learners by following pedagogical reasoning in general, TPK refers to pedagogical ways to use technology without referring to a specific learning content (Angeli et al., 2016). TCK refers to knowledge concerned with topic-specific representations regarding a certain content domain by utilizing emerging technologies (Cox & Graham, 2009). TPACK is described as a form of knowledge that is brought to play by expert teachers anytime they teach:

“TPCK is the basis of good teaching with technology and requires an understanding of the representation of concepts using technologies; pedagogical techniques that use technologies in constructive ways to teach content; knowledge of what makes concepts difficult or easy to learn and how technology can help redress some of the problems that students face; knowledge of students' prior knowledge and theories of epistemology; and knowledge of how technologies can be used to build on existing knowledge and to develop new epistemologies or strengthen old ones.” (Mishra & Koehler, 2006, p. 1029)

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<sup>2</sup>The additional A was added later as it was easier to pronounce and to remember (A. Thompson & Mishra, 2007).

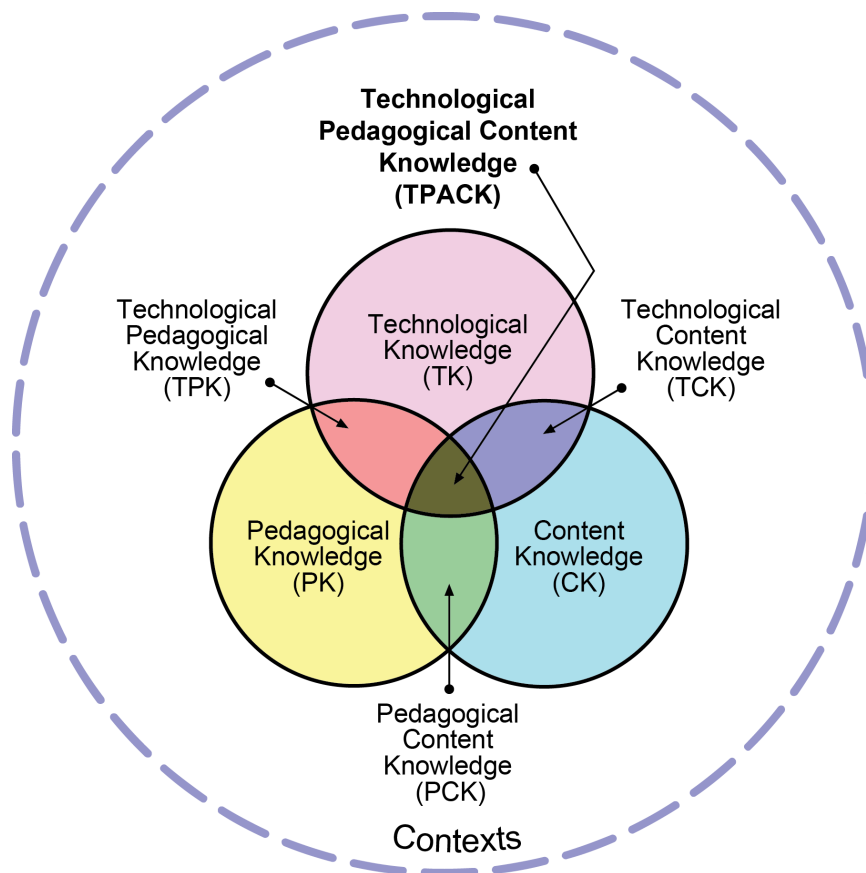


Figure 7.1. Technological Pedagogical Content Knowledge Framework by Koehler & Mishra (Reproduced by Permission of tpack.org, ©2012)

The TPACK framework can be used as a reference to what has to be done regarding Teacher Education to foster the use of immersive media in the classroom. Here, VR and AR can be regarded as the ‘new’ technologies that teachers are unfamiliar with.

In order to investigate the current attitude of becoming teachers towards the application of VR in early education, a survey among 277 primary school preservice-teachers assessed their experiences with VR, their interest in experimenting with VR and their perceived benefit of the use of VR technologies in primary school education. While only 63,6 % of the students showed at least some interest (*slightly interested* or *very interested*) in experimenting with VR, 77,3% were at least *slightly interested* in exploring the didactical possibilities of VR in primary school education. The most prominent educational topics that could, according to the participants, benefit from immersive media were: Local History and Geography, Arts, Handicrafts, and Mathematics. A moderately strong relationship ( $r = .45, p < .001$ ) between the students’

personal interest in VR technology and their perception of a possible benefit of VR technology in primary school regarding teaching and learning processes was found. Of course, the students were not professionals that could give a profound insight to the possibilities of VR in primary school education. But it can be argued that, in order to bring VR into the classroom, it is not sufficient to prove the effectiveness of VR in terms of teaching and learning: Professional teachers and preservice-teachers have to be convinced that VR can be a motivating and engaging tool that has to be used at the right point. The current lack of professional EVEs for educational purposes leaves a gap of unfulfilled didactical and pedagogical demands. Both issues could be addressed by integrating the development of immersive EVEs into Teacher Education, hence fostering technological, didactical, and pedagogical skills (Dengel, 2018b).

Immersive Teaching “as a set of skills enabling a teacher to evaluate and select existing immersive learning environments with regards to their prospective educational benefits for a given target group” (Dengel & Bucher, 2019, p. 1) shows merit to become a new topic in Teacher Education. The evaluation of a seminar investigating the benefits of implementing immersive teaching and learning into Teacher Education by designing immersive experiences with preservice-teachers showed that working with and developing immersive EVEs can foster technological, pedagogical, and content knowledge. Best practices for involving preservice-teachers in a seminar in order to develop immersive educational experiences were named *engagement by design* (practice-oriented teaching), *immersion* (hands-on experiences in VEs/augmented environments), and *innovation* (designing EVEs with specific learning contents/research questions) (Dengel & Bucher, 2019). Integrating these practices into Teacher Education could contribute to future teachers’ confidence to use immersive technology in the classroom.

So what is left to do? Immersive media shows potential to be the next big step regarding technology-enhanced education. This thesis tried to discuss this step from various perspectives, including theoretical, practical, and empirical approaches. As almost every thesis, this work concludes with the notion that future work has to investigate the introduced ideas further. But it also concludes with an appeal to educational researchers working with immersive technology: Immersive Teaching and Learning is not a sterile future science that should happen curtained in laboratories. It is an approach for enhancing education in a truly immersive and engaging way. Not everywhere, not always, but powerful and effective when used at the right time and with the right tools.

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# Appendices

## A Motivation Questionnaire



CODE:

## Warum arbeitest und lernst du im Fach Informatik?

Verwende die unten stehende Tabelle, um für jeden der angegebenen Gründe anzugeben, wie stark dieser auf einer Skala von 1 (stimmt überhaupt nicht) bis 5 (stimmt völlig) zutrifft.

<b>Ich arbeite und lerne im Fach Informatik...</b>	stimme überhaupt nicht zu			stimme voll und ganz zu	
	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>
... weil es mir Spaß macht.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
... um später eine bestimmte Ausbildung machen zu können (z.B. Schule, Lehre oder Studium).	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
... weil ich damit mehr Möglichkeiten bei der späteren Berufswahl habe.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
... weil ich möchte, dass meiner Lehrerin/meinem Lehrer denkt, ich bin ein/e gute/r Schüler/in.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
... weil ich neue Dinge lernen möchte.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
... weil ich von meiner Lehrerin/meinem Lehrer ein Lob bekommen möchte.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
... weil ich sonst von zu Hause Druck bekomme.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
... weil ich ein schlechtes Gewissen hätte, wenn ich wenig tun würde.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
... weil ich sonst Ärger mit meiner Lehrerin/meinem Lehrer bekomme.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
... weil ich mit dem Wissen im Fach später einen besseren Job bekommen kann.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
... weil ich es genieße, mich mit dem Fach auseinanderzusetzen.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
... weil ich gerne Aufgaben aus dem Fach löse.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
... weil ich sonst schlechte Noten bekomme.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
... weil ich möchte, dass die anderen Schüler/innen von mir denken, dass ich ziemlich gut bin.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
... weil ich die Sachen, die ich hier lerne, später gut gebrauchen kann.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
... weil ich gerne über Dinge des Faches nachdenke.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
... weil ich es einfach lernen muss.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
... weil ich in den Prüfungen besser abschneiden möchte als meine Mitschüler/innen.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
... weil ich mich vor mir selbst schämen würde, wenn ich es nicht tun würde.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

## B Emotion Questionnaire



## C Presence Questionnaires







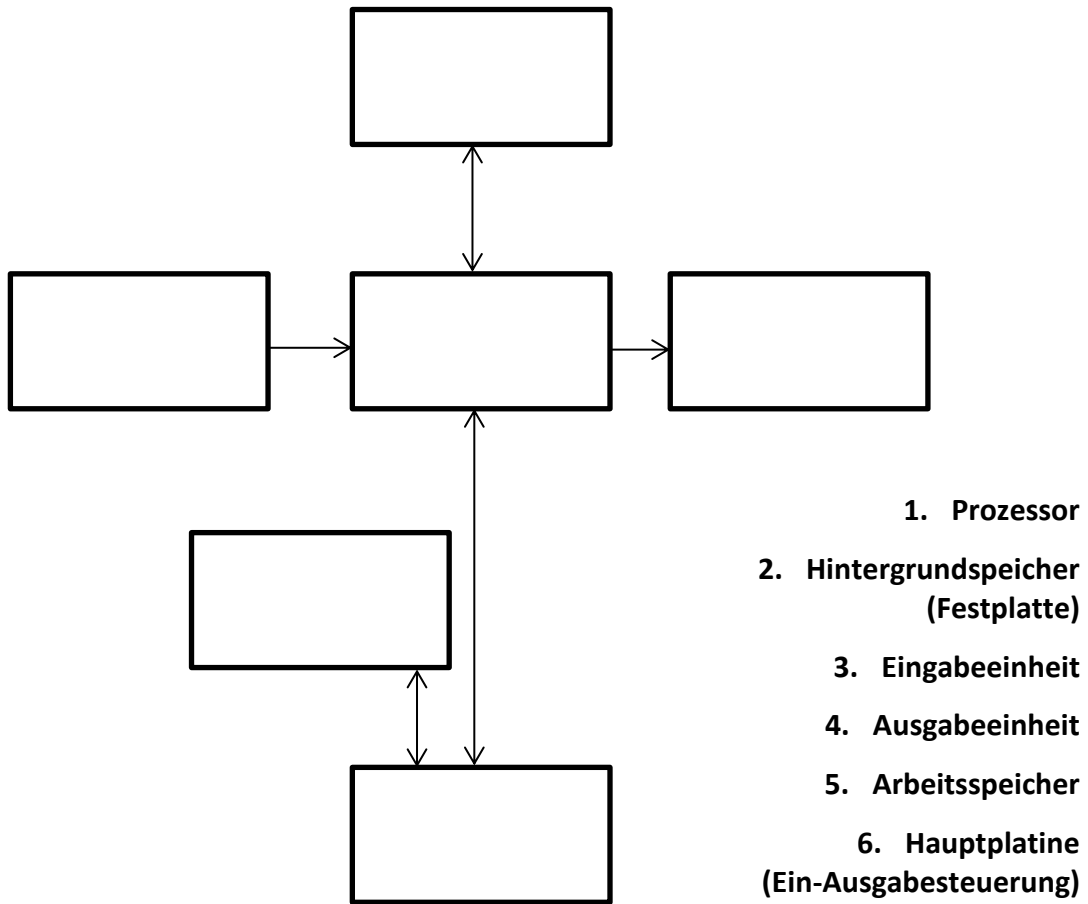
## D Pre and Post Performance Tests



CODE:

### Aufgabe 1

Ordne die Komponenten richtig in das untenstehende prinzipielle Schema eines Computersystems ein.



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## Aufgabe 2

Zu den Aufgaben der oben genannten Bestandteile: Setze nun nacheinander die vorher zugeordneten Begriffe in die Lücken ein und beschreibe jeweils kurz die Aufgabe der jeweiligen Rechnerkomponente.

- a. Die Aufgabe des **Prozessors** ist:

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- b. Die Aufgabe des **Hintergrundspeichers (Festplatte)** ist:

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- c. Die Aufgabe des **Arbeitsspeichers** ist:

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CODE:

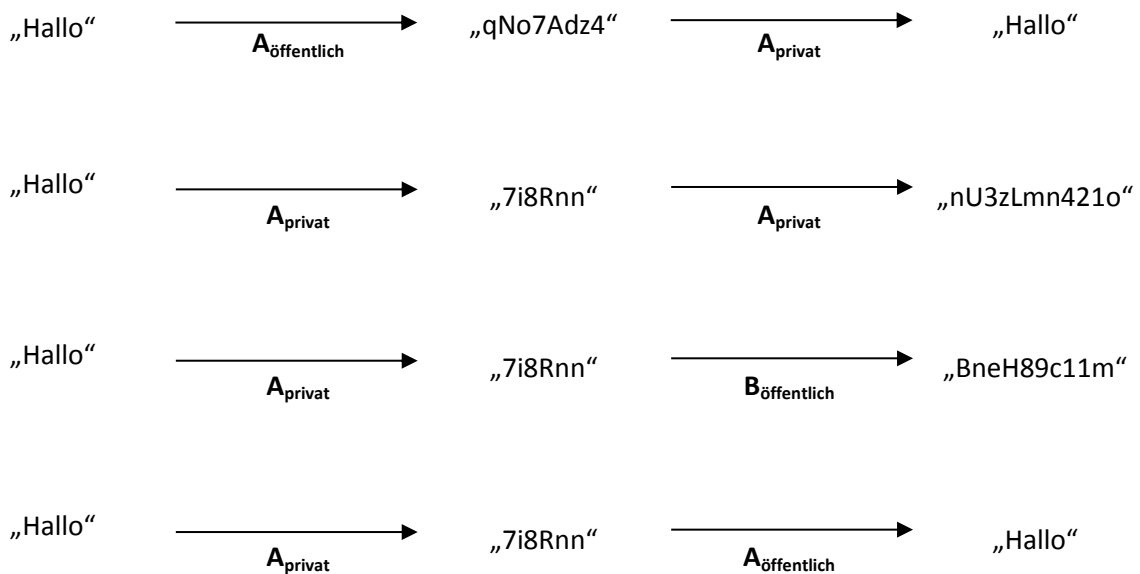
Bei dem Verschlüsselungsverfahren **asymmetrische Verschlüsselung** gibt es für jeden Teilnehmer ein sogenanntes **Schlüsselpaar**. Dieses Schlüsselpaar besteht aus zwei Schlüsseln: einem **öffentlichen Schlüssel** und einem **privaten Schlüssel**. Diese „Schlüssel“ kann man sich als mathematische Funktionen vorstellen, welche einen Buchstaben, ein Wort oder einen ganzen Text verschlüsseln. Beide Schlüssel, also der öffentliche und der private Schlüssel, heben sich gegenseitig auf.

Beispiel:

Alice hat ein Schlüsselpaar:  $A_{\text{öffentlich}}$  und  $A_{\text{privat}}$

Bob hat auch ein Schlüsselpaar:  $B_{\text{öffentlich}}$  und  $B_{\text{privat}}$

Verschlüsselt man nun das Wort „Hallo“ mit  $A_{\text{öffentlich}}$ , dann kann man es nur mit  $A_{\text{privat}}$  wieder entschlüsseln. Würde man „Hallo“ beispielsweise mit  $B_{\text{privat}}$  verschlüsseln, bräuchte man  $B_{\text{öffentlich}}$ , um es wieder zu entschlüsseln.



Der **öffentliche Schlüssel** eines Schlüsselpaares ist für jeden Teilnehmer frei zugänglich.

Den **privaten Schlüssel** eines Schlüsselpaares kennt nur der Teilnehmer, dem das Schlüsselpaar gehört.

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## Aufgabe 1

Erkläre folgende Prozesse in eigenen Worten:

- a) Alice möchte Bob eine geheime Nachricht schicken, die niemand außer Bob lesen kann. Deswegen verschlüsselt Alice die Nachricht mit **B<sub>öffentlich</sub>**. Warum?

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- b) Wenn Alice Bob eine Nachricht schickt, die zwar jeder entschlüsseln könnte, von der aber jeder eindeutig sehen kann, dass sie von Alice kommt, verschlüsselt sie die Nachricht mit **A<sub>privat</sub>**. Warum?

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## Aufgabe 2

Ergänze die fehlenden Schlüssel, um die Nachrichten wieder entschlüsseln zu können:

„Hallo Bob“  $\xrightarrow{\text{B}_{\text{öffentlich}}}$  „qNasdG  
nz4mn7b“  $\xrightarrow{\quad}$  „Hallo Bob“

\_\_\_\_\_

„Hallo Alice! Ich  
bins, Bob!“  $\xrightarrow{\text{B}_{\text{privat}}}$  „7injasZ12Ms3  
dasnbvjhv“  $\xrightarrow{\quad}$  „Hallo Alice! Ich  
bins, Bob!“

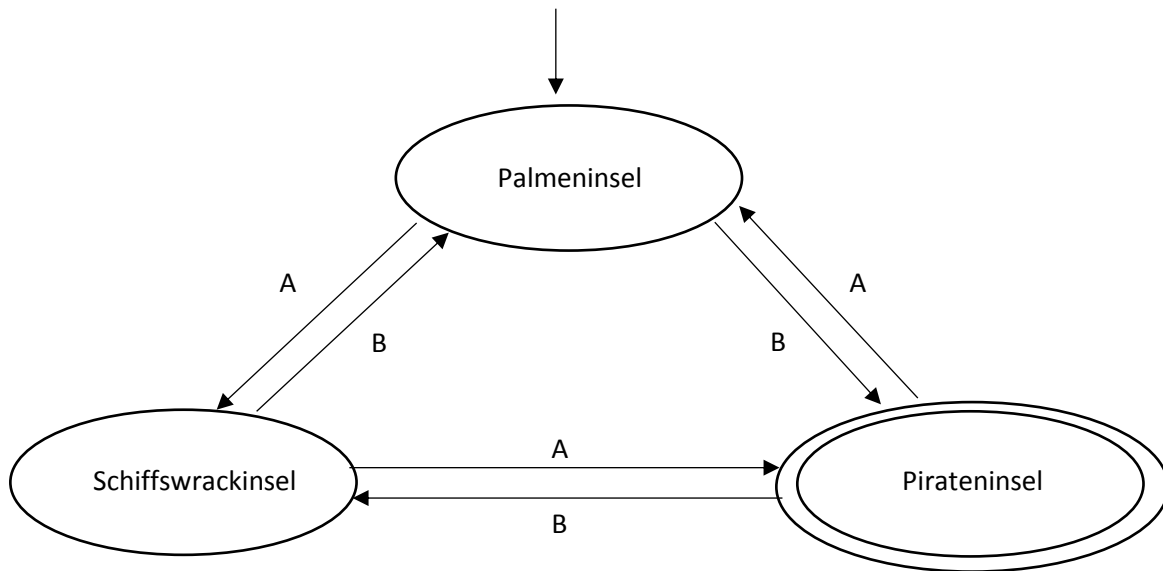
\_\_\_\_\_

„Super!“  $\xrightarrow{\text{B}_{\text{öffentlich}}}$  „Amk5s7“  $\xrightarrow{\text{A}_{\text{privat}}}$  „SAbi\$67“  $\xrightarrow{\quad}$  „Amk5s7“  $\xrightarrow{\quad}$  „Super!“

\_\_\_\_\_

CODE:

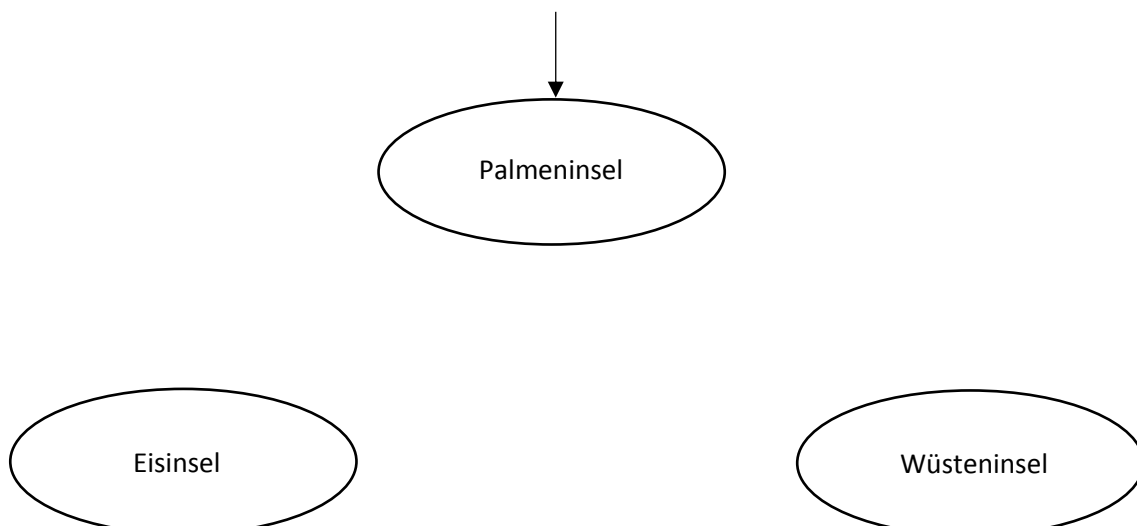
Hier siehst du ein Beispiel für eine Schatzkarte mit ausgefüllten Schiffsrouten.  
Die Palmeninsel ist durch den obigen Pfeil als Startinsel festgelegt.  
Durch die doppelte Einkreisung sieht man, dass der Schatz auf der Pirateninsel vergraben ist.  
Von jeder Insel gehen Schiffsrouten aus, die dich von einer Insel zur nächsten bringen. Hier kommt man beispielsweise von der Palmeninsel aus mit dem **A**pfelboot (abgekürzt mit A) zur Schiffswrackinsel, das **B**irnenboot (abgekürzt mit B) führt zur Pirateninsel.



### Aufgabe 1

Unten siehst du eine Inselkarte mit drei Inseln. Deine Aufgabe ist es, die Inselkarte zu einer Schatzkarte mit Schiffsrouten zu erweitern. Zu deiner Verfügung stehen die beiden Boote Apfelboot (abgekürzt mit A) und Birnenboot (abgekürzt mit B). Zeichne folgende Routen in die Karte ein:

- Von der Palmeninsel aus kannst du mit A zur Wüsteninsel fahren und mit B zur Palmeninsel
- Von der Wüsteninsel aus kannst du mit A zur Palmeninsel fahren und mit B zur Eisinsel
- Von der Eisinsel aus kannst du mit A zur Palmeninsel fahren und mit B zur Wüsteninsel
- Die Eisinsel ist die Insel, auf der sich der Schatz befindet, markiere sie entsprechend.



## Aufgabe 2

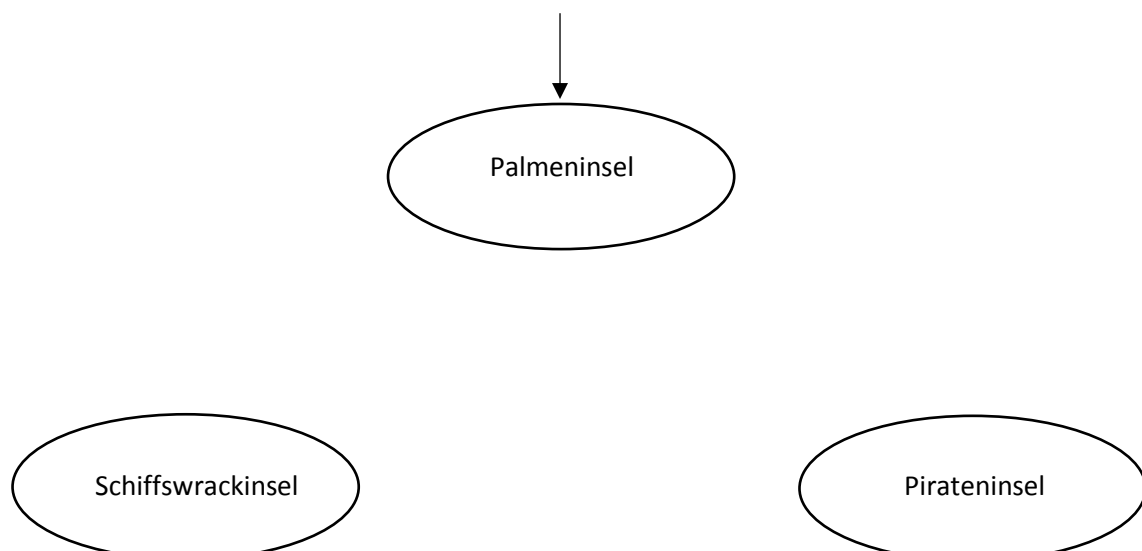
Unten siehst du die Schifffahrtsrouten in Lückentexten beschrieben.

Diesmal ist die Pirateninsel die Startinsel und die Palmeninsel die Insel, auf der der Schatz vergraben ist. Bitte ergänze die Tabelle so, dass von jeder Insel ein Boot A und ein Boot B wegfährt. Von jeder Insel führt allerdings nur ein Boot zur nächsten Insel, das andere Boot bringt einen zur gleichen Insel zurück. Jede Insel soll erreichbar sein. Du kannst den Platz unter dem Lückentext für Notizen oder das Aufzeichnen einer Karte nutzen.

Von der	<b>Pirateninsel</b>	führt das	<b>Apfelboot (A)</b>	zur	<b>Palmeninsel.</b>
Von der	<b>Pirateninsel</b>	führt das	<b>Birnenboot (B)</b>	zur	_____
Von der	<b>Schiffswrackinsel</b>	führt das	<b>Apfelboot (A)</b>	zur	_____
Von der	_____	führt das	<b>Birnenboot(B)</b>	zur	<b>Pirateninsel.</b>
Von der	<b>Palmeninsel</b>	führt das	_____	zur	<b>Schiffswrackinsel.</b>
Von der	_____	führt das	_____	zur	_____

## Aufgabe 3

In dieser Aufgabe darfst du nun selbst eine Schatzkarte mit den Schiffrouten entwerfen. Zeichne die Karte vollständig, das heißt, dass von jeder Insel jeweils eine Route mit Boot A und eine mit Boot B weggeht. Die Startinsel ist die Palmeninsel. Der Schatz ist auf der Pirateninsel vergraben, markiere diese entsprechend. Zeichne die Schiffrouten so, dass der Schatz nur dann gefunden wird, wenn die letzten beiden gewählten Boote jeweils Boot B sind.





## E Self Efficacy Questionnaire



CODE:

**Inwieweit glaubst du, die folgenden Aufgaben selbstständig lösen zu können?**

(Bitte in jeder Zeile eine Antwort auswählen)

	das wäre einfach für mich	ich könnte das mit ein bisschen Mühe schaffen	es würde mir schwer fallen, das allein zu schaffen	das könnte ich nicht
... die Bestandteile eines Computers aufzählen.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
... den Unterschied zwischen symmetrischer und asymmetrischer Verschlüsselung erklären.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
... einen endlichen Automaten zu einer gegebenen Aufgabenstellung (z.B. ein Kaffeeautomat) zeichnen.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
... die Rolle von öffentlichem und privatem Schlüssel im Verschlüsselungsprozess erklären.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
... die Funktionsweise eines endlichen Automaten an einem selbst gewählten Beispiel zeigen.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
... die Funktionen der Komponenten innerhalb eines Computers beschreiben.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>



## **F AdvanceAnalyses**

Table 1  
*Associations Between Gender And Model Variables*

	<i>gender</i>
<i>motivation</i>	
intrinsic motivation	female: $M = 2.65$ , $SD = .86$ ; male: $M = 3.53$ , $SD = .99$ ; $t(71) = -4.06$ , $p < .0005$
identified motivation	n.s.
introjected motivation	female: $Mdn = 42.51$ ; male: $Mdn = 32.64$ ; $U = 467.50$ , $p < .05$
external regulation	female: $Mdn = 43.82$ ; male: $Mdn = 30.36$ ; $U = 420.50$ , $p < .01$
<i>scholastic performance</i>	
Math	n.s.
German	female: $Mdn = 28.97$ ; male: $Mdn = 40.53$ ; $U = 395.00$ , $p < .05$
<i>emotion</i>	
positive emotions	female: $M = 2.52$ , $SD = .92$ ; male: $M = 3.18$ , $SD = .87$ ; $t(68) = -3.05$ , $p < .01$
negative emotions	n.s.
<i>presence</i>	
Bill's Computer Workshop	n.s.
Fluxi's Cryptic Potions	n.s.
Pengu's Treasure Hunt	n.s.
<i>pre-test</i>	
Components of a Computer	female: $M = 2.31$ , $SD = 1.69$ ; male: $M = 4.22$ , $SD = 1.91$ ; $t(69) = -4.44$ , $p < .0005$
Asymmetric Encryption	n.s.
Finite State Machines	n.s.
<i>post-test</i>	
Components of a Computer	[female: $Mdn = 26.87$ ; male: $Mdn = 40.89$ ; $U = 337.00$ , $p < .01$
Asymmetric Encryption	n.s.
Finite State Machines	n.s.

Table 2

*Associations Between Age And Model Variables*

	<i>age</i>
<i>motivation</i>	
intrinsic motivation	n.s.
identified motivation	n.s.
introjected motivation	n.s.
external regulation	n.s.
<i>scholastic performance</i>	
Math	n.s.
German	n.s.
<i>emotion</i>	
positive emotions	n.s.
negative emotions	n.s.
<i>presence</i>	
Bill's Computer Workshop	$r = -.27, p < .05$
Fluxi's Cryptic Potions	n.s.
Pengu's Treasure Hunt	$r = -.35, p < .01$
<i>pre-test</i>	
Components of a Computer	n.s.
Asymmetric Encryption	n.s.
Finite State Machines	n.s.
<i>post-test</i>	
Components of a Computer	n.s.
Asymmetric Encryption	n.s.
Finite State Machines	n.s.

Table 3

*Associations Between Class And Model Variables*

	<i>class</i>
<i>motivation</i>	
intrinsic motivation	n.s.
identified motivation	n.s.
introjected motivation	n.s.
external regulation	n.s.
<i>scholastic performance</i>	
Math	n.s.
German	n.s.
<i>emotion</i>	
positive emotions	n.s.
negative emotions	n.s.
<i>presence</i>	
Bill's Computer Workshop	n.s.
Fluxi's Cryptic Potions	n.s.
Pengu's Treasure Hunt	n.s.
<i>pre-test</i>	
Components of a Computer	n.s.
Asymmetric Encryption	n.s.
Finite State Machines	n.s.
<i>post-test</i>	
Components of a Computer	n.s.
Asymmetric Encryption	n.s.
Finite State Machines	n.s.

Table 4

*Associations Between Experience And Model Variables*

	<i>experience</i>
<i>motivation</i>	
intrinsic motivation	$r = .34, p < .01$
identified motivation	n.s.
introjected motivation	n.s.
external regulation	n.s.
<i>scholastic performance</i>	
Math	n.s.
German	n.s.
<i>emotion</i>	
positive emotions	n.s.
negative emotions	$(r = -.27, p < .05)$
<i>presence</i>	
Bill's Computer Workshop	n.s.
Fluxi's Cryptic Potions	n.s.
Pengu's Treasure Hunt	n.s.
<i>pre-test</i>	
Components of a Computer	n.s.
Asymmetric Encryption	n.s.
Finite State Machines	n.s.
<i>post-test</i>	
Components of a Computer	$r = .33, p < .01$
Asymmetric Encryption	n.s.
Finite State Machines	n.s.





## **G Statutory Declaration**

## **Versicherung (gem. § 4 Abs. 3 Satz 1 Nr. 5 PromO):**

Ich versichere hiermit

- an Eides statt, dass ich die Dissertation selbständig angefertigt, außer den im Schriftenverzeichnis sowie den Anmerkungen genannten Hilfsmitteln keine weiteren benutzt und die Herkunft der Stellen, die wörtlich oder sinngemäß aus anderen Werken übernommen sind, bezeichnet habe,
- dass ich die Dissertation nicht bereits in derselben oder einer ähnlichen Fassung an einer anderen Fakultät oder einer anderen Hochschule zur Erlangung eines akademischen Grades eingereicht habe.

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(Unterschrift)

## **Statutory Declaration:**

I declare that I have authored this thesis independently, that I have not used other than the declared sources / resources, and that I have explicitly marked all material which has been quoted either literally or by content from the used sources.

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(signature)