Using Immersive Virtual Reality in Education

The Construction of the Didactics for Immersive Learning Framework

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Acknowledgements

The current dissertation is the result of a year of work, marking the end of my Master's program in Human-Technology Interaction. What started as being inspired by my technically-handy grandpa as a child will now move to a new exciting chapter as I finalize my studies at the Eindhoven University of Technology.

Ever since my bachelor's, I have had my eye on doing my thesis on immersive Virtual Reality (iVR). I have always been fascinated by its ability to transport you to completely different places. My hope was that I would be able to contribute to iVR research and further its potential to help people. My ambitions ranged from helping students learn better and have fun while doing so to assisting valued healthcare workers in training and performing their jobs. As my study years passed, I was fortunate to be inspired by Wijnand IJsselsteijn's research on iVR and embodiment. I made sure to inquire about his supervision of my thesis project already at the start of my Master's, to which he enthusiastically agreed.

During the course of this project, I was fortunate to have two highly qualified supervisors. I would first like to thank Wijnand IJsselsteijn, who provided me with valuable in-depth feedback about all topics related to iVR, from suggesting relevant articles to correcting my usage of terminology. He provided valuable feedback to lift my thesis to the next level, even in the final stretch. Secondly, I would like to thank Peter Ruijten. Your academic knowledge and intensive feedback during the project contributed significantly to the result. Additionally, you helped me out immensely when Wijnand, as the first supervisor, happened to be unavailable. I know how busy both of you are, so your time for our regular meetings and reading my report is highly valued!

My supervisors had to pull hard to limit my ambitions and prevent me from transforming this master thesis on this topic I am passionate about into a full-blown Ph.D. project. I appreciate their efforts enormously. My enthusiasm could have tempered more in hindsight, but I am excited about what the project has become.

Finally, I would like to thank my parents, friends, and girlfriend for their support throughout this project. You have helped me on many occasions by giving feedback on my work and supporting my mental health. Things did not always go according to plan, among others, due to the COVID-19 pandemic. However, your support kept me grounded and motivated to keep working hard. Without your help, this thesis would not have been the project I am proud to present today!

Abstract

Immersive virtual reality (iVR) meets increasing popularity for educational purposes. However, little research has been conducted on the context in which the medium is the best educational choice with most didactical benefits. Performed studies also frequently did not consider teacher experience, therefore lacking a connection to real-world teaching practices. This thesis aims to construct a framework with didactical guidelines enriched with teacher experiences to help educators use iVR.

Towards this goal, a literature review of didactical theories was combined with a thematic analysis of interviews with educators who had experience with iVR. Based on the results, the didactics for immersive learning (DIL) framework was constructed. After, the framework was verified for practicality and comprehensibility in a second interview round with teachers who had no experience with iVR.

The results suggest that the DIL framework cannot only be used for designing iVR-LEs, but also for assessing iVR readiness of teachers/organizations, applying iVR in classrooms, training teachers, and gathering support from educational boards. However, this thesis also raises the question of how external factors can best facilitate teachers in this process. Even with didactical guidance by the DIL framework and facilitation by external factors, intuitional teaching practice will continue to play a role since some teachers will stick with familiar methods due to personal factors. Additionally, a degree of intuitional teaching practice will remain vital for teachers to adapt their learning contents to the dynamic setting of daily lessons. On this basis, teachers and educational boards could consider using the DIL framework for pedagogically beneficial iVR development and implementation while paying particular attention to the influence of external factors and intuition. The newly developed DIL framework is directly applicable to motivate and improve iVR use in education.

Keywords

Immersive virtual reality, immersive virtual learning environment, immersive virtual reality learning environment, instructional design, media didactics, teacher experience, education, multimedia learning, VR, iVR, VLE, iVLE, iVRLE, ISD.

Contents

1. Introduction

The technology of immersive virtual reality (iVR) meets increasing popularity in applications varying from leisure to business and education. In particular educative uses of iVR are on the rise, with 60% of primary and secondary school teachers in the USA being interested in making this technology part of their lessons (Samsung Electronics America, 2016) to improve learning outcomes by facilitating concept understanding, collaboration, and motivation. School-based educational settings utilize iVR in topics such as engineering (Halabi, 2020), biology (E. Johnston et al., 2018; Parong & Mayer, 2018), and history (Bowen, 2018; Rosa-Jiménez & Ventura-Blanch, 2020). Corporations also use iVR for educative purposes in fields such as industrial (Boud et al., 1999; Seth et al., 2011), healthcare (Ahlberg et al., 2007; Dang et al., 2018), and aerospace training (Aoki et al., 2008; Bowling et al., 2008).

While meeting increasing popularity, little research has been conducted on the assumed learning benefits and requirements of using iVR-based learning environments (iVRLEs) for education. The studies conducted were small, short, and lacked a clear comparison of using the technology over other methods. Research has primarily focused on learning outcomes for specific topics, presenting anecdotal evidence that is hard to generalize beyond the context of the studies (Dalgarno & Lee, 2010).

A minority of these studies investigate more generalized design principles that are beneficial for designing and using iVRLEs, yet still lack integration into a holistic didactical selection and usage process. Didactics is the scientific discipline focused on teaching in professional institutions (e.g., schools or sports institutions) and can be understood at a variety of abstraction levels (Kerres, 2018).

At the highest abstraction level, general didactics represent the overarching theory of teaching and learning processes. General didactics is part of the field of pedagogy (all factors related to the upbringing of a child), the holistic process and environments in which a person is educated and acquires the tools to educate themselves (van Manen, 2006). More levels of didactics can be distinguished, but these are beyond the scope of this thesis (see Kerres (2018, p. 53) for an overview). Even though singular acts of teaching and learning depend on a multitude of didactical levels, the focus of this thesis is placed on general didactics. This focus is chosen to construct a subject-independent foundation that is usable for and can be further refined by future research towards a wide array of educational levels and topics.

With the introduction of technology-based instruction methods, general didactics is further tailored to media-specific didactics. Media didactics deal with the influence of media in learning processes and explore which media are most suitable for these processes. Additionally, it aims to guide the use of media to activate learning processes to attain learning goals (Bendel & Hauske, 2004). Due to the multi-disciplinary nature of technological media, media didactics is at the disciplinary intersections of, amongst others, psychology, computer science, information science, media science, and communication science (Kerres, 2018). Hence, it is necessary to conduct a comprehensive analysis and use a diverse project team to design or implement iVRLEs. To date, this analysis proves to be difficult given the limited availability of didactically-sound research on iVRLEs.

To guide the didactically-grounded use of iVRLEs, this medium is investigated from a pedagogical perspective. This thesis focuses on interdisciplinary didactical guidelines in order to construct a universal framework with general goals and methods of instruction concerning iVRLEs, and thus exists on the abstraction level of general didactics. The overarching research questions of this thesis are “Which didactical guidelines can aid educators in using iVRLEs in a pedagogically beneficial manner?” and “How can teacher iVR-experience be integrated with the didactics for immersive learning?” Towards this goal, a review of relevant didactic theories is combined with a thematic analysis of interviews with educators.

1.1. What is Immersive Virtual Reality?

Before exploring the didactical background of iVR, the term is first defined to support a clear understanding of the thesis' context. The definition is then backed with a theoretical model based on two main technical dimensions that make up the foundation of iVR as a medium.

In current times, iVR is widely known as a technology that completely immerses the user inside a computer-generated environment, creating the illusion that the user has stepped into an artificial world (Furht, 2008). This immersion can be achieved by using a Head-Mounted Display (HMD) or multiple projections in a cave (Buttussi & Chittaro, 2018). The most common method of iVR is using an HMD to project video in front of the eyes, thereby allowing the user to focus on the display without distraction from the outside world (Furht, 2008). This HMD can be a mobile phone in a casing or a specialized product with the sole use of accessing iVR environments (e.g., the Oculus Quest 2, Pico Neo 2, or HTC Vive).

To define how the term iVR is used in this thesis and to explore the differences with other representations (e.g., 2D computer screen-based environments), the iVR taxonomy by Steuer (1992) is used (see Figure 1). A key element of iVR is the feeling of being in a digital environment, which Steuer (1992) defined as the feeling of presence and was also grounded in later research (Milgram & Kishino, 1994; Skarbez et al., 2021). Telepresence would be the scientifically correct term since it involves a mediated environment different from the physical environment. However, due to the widespread scientific use of the term 'presence,' this thesis adopts this terminology. Two technical variables influence the presence that a user experiences, namely the vividness and the interactivity of the virtual environment (Steuer, 1992). The technical variables are moderated by subjective differences such as an individual's background and situational factors (see Figure 1).

1.1.1. Vividness

Vividness is defined as the sensory richness of a mediated environment (Steuer, 1992). This definition is similar to the concept of (sensory) immersion (Mikropoulos & Natsis, 2011; Slater & Wilbur, 1997), physical fidelity (Alexander et al., 2005) or reproduction fidelity (Dalgarno & Lee, 2010; Milgram & Kishino, 1994). Two variables make up the vividness of iVR, namely the sensory breadth and depth (see Figure 1).

The breadth refers to the number of sensory dimensions simultaneously presented, while the depth denotes the resolution of each perceptual channel (Steuer, 1992). It follows that the vividness of iVR allows for a greater breadth (e.g., visual, locomotion, or tactile) and depth (e.g., higher visual freedom and higher resolution of visuals) of perceptual channels than 2D computer screen-based environments. Similarly, specialized iVR HMDs facilitate vividness to a higher degree than mobile-phone-based iVR due to the lack of functionalities in current-day mobile phones.

1.1.2. Interactivity

Interactivity is defined as the degree to which users can modify the form and content of a mediated environment in real-time (Steuer, 1992). This definition is related to the concepts of intuitive interaction (Mikropoulos & Natsis, 2011) and learner interaction (Dalgarno & Lee, 2010). When interactivity is well-mapped to the content, iVR environments can lead to embodiment (Johnson-Glenberg, 2018). Following the taxonomy by Steuer (1992), the concept of interactivity is used in this thesis. Interactivity is further supported by, amongst others, speed, range, and mapping (see Figure 1).

Speed refers to the system's response time, range refers to the number of possibilities for action, and mapping refers to the predictability and naturality of the physical controls to influence the mediated environment. Mapping is similar to the concept of coherence from Skarbez et al. (2021). The range of actions can change a user's perception of the environment (e.g., moving, looking around) or change the environment itself (e.g., throwing a rock, opening a door). It follows that iVR allows greater interactivity than 2D computer screen-based virtual worlds. Similarly, specialized HMDs facilitate interactivity to a higher degree than current-day mobile-phone-based VR.

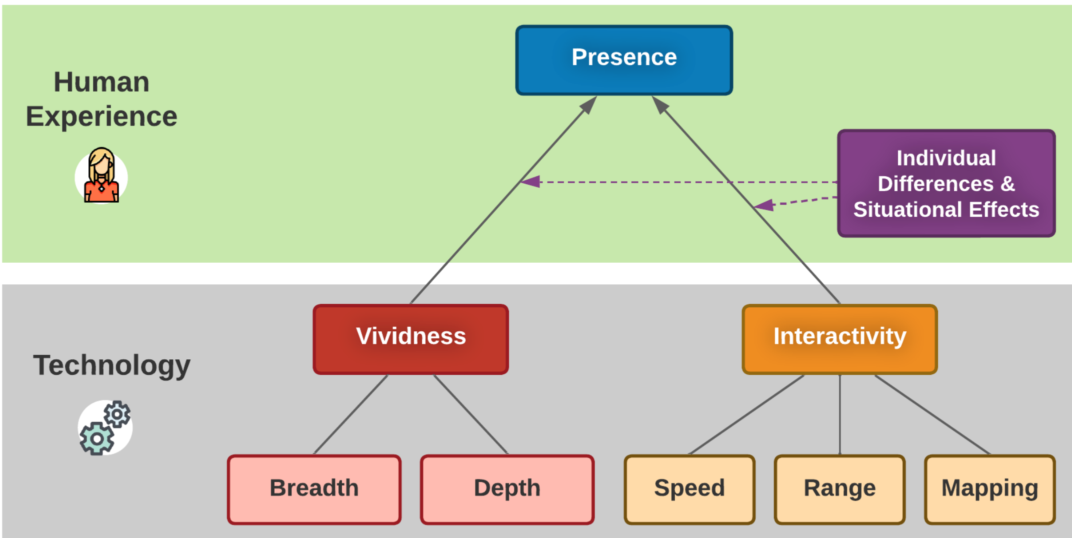

Figure 1. The emergence of presence results from the technical aspects of vividness and interactivity. Personal background and situational effects modulate the emergence. Adapted from Steuer, J. (1992). Defining virtual reality: Dimensions determining telepresence. *Journal of Communication*, *42*(4), 73–93. Copyright by Oxford University Press.

It should be noted that interactivity and vividness are interconnected concepts. Studies show that a high degree of interactivity is related to users treating the avatars as their natural bodies, even if objective realism (vividness) entails notable differences (Maister et al., 2015). This effect of embodiment is well studied in both iVR and non-iVR environments, such as the classic rubber hand illusion (IJsselsteijn et al., 2006). This experiment by IJsselsteijn et al. is a prime example of how an individual's body image is a plastic, temporary construct that can be influenced within a short time span.

The experienced vividness and interactivity can vary significantly between users, situations, and points in time. Subjective differences such as an individual's background and situational factors influence the perception of the technical characteristics of iVR (see Figure 1). The personal nature of presence is broadly supported in the scientific field (IJsselsteijn, 2003; Kuo & Feng, 2013; Shin, 2017; Shin et al., 2016; Weibel et al., 2010). An example of an individual's background are the experiences and expectations a user has regarding the virtual medium, also known as their media schemata (IJsselsteijn, 2003). IJsselsteijn (2003) described that users' media schemata may attenuate their initial response to respond to the iVR as they would to unmediated stimuli. While the media schemata adapt to new media form factors, users still tend to respond to media as they would to reality (Reeves & Nass, 1996). Kuo and Feng (2013) find that personal engagement factors depend on users' intentions and individual traits. Similarly, Weibel et al. (2010) find that extraversion, innovativeness, openness to explore, and willingness to try are positively related to the tendency of feeling immersed in iVR. Shin (2017) adds that the personal background is a fluid and reflective concept instead of a fixed and isolated construct since a users' processing of the content, system, and context can vary over time. Following its dynamic nature, it is vital to consider presence with a contextual and procedural view that highlights the dynamic nature of users' perception of experience (Shin, 2017).

To specify the boundaries of the term iVR in this thesis, another distinction should be made with augmented reality (AR) and augmented virtuality (AV) devices, where the user interacts with the digital and physical environments simultaneously. Although vividness and interactivity can also be substantially present in AR and AV, differences exist with iVR. In AR, the user experiences an enhanced physical environment, while in AV, real-world objects are merged in a virtual environment. AR and AV differ from iVR, where the user exclusively experiences the virtual environment. To distinguish between the different technologies, Milgram and Kishino (1994) constructed a taxonomy that consists of a reality-virtuality continuum, which describes the transition from natural to virtual environments (see Figure 2). Moving from left to right on the continuum increases the share of the environment that consists of virtual elements.

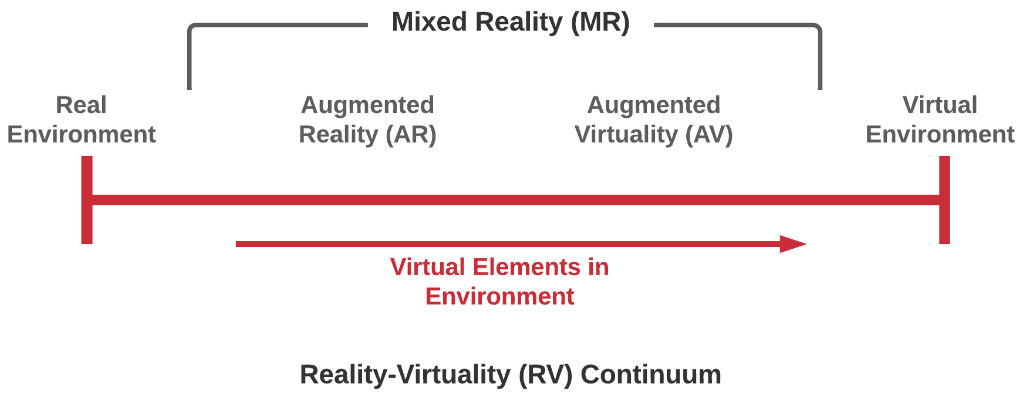

Figure 2. Milgram and Kishino's simplified reality-virtuality continuum. Adapted from Milgram, P., & Kishino, F. (1994). A taxonomy of mixed reality visual displays. *IEICE Transactions on Information and Systems*, *77*, 1321–1329. Copyright by the Society of Photo-Optical Instrumentation Engineers.

In essence, the vividness and interactivity of a virtual environment influence the experience of presence by the user. iVR differs from other technologies such as AR because it is an entirely virtual environment. In light of currently available technologies to mediate virtual environments, the term iVR will refer to "virtual immersive three-dimensional environments that are accessed with an HMD, in which a user experiences presence." The focus is placed on specialized iVR HMDs because of the increased control of the experimental environment and the improved vividness and interactivity compared to mobile-phone-based HMDs.

1.2. Conceptual Research Aims

Teachers and educators struggle with using iVRLEs in a didactically-grounded manner. Next to external factors, an important cause is the absence of established didactical guidance on the selection and application of immersive media. This thesis aims to aid educators in this process by providing guidance for the didactically-grounded application of iVRLEs. A conceptual evaluation is conducted of established didactics relevant to iVR learning to lay the foundation for immersive learning didactics. Therefore, the question this literature review aims to answer is "Which didactical guidelines can aid educators in using iVRLEs in a pedagogically beneficial manner?"

2. Conceptual Literature Review

It is crucial to consider iVRLEs as a part of the educational process to ensure their effective and didactically-grounded use. To pursue this goal, the consolidation of iVRLEs in the context of instructional design is investigated. As a sub-discipline of general didactics, instructional design is concerned with the overarching process of the conception and development of learning offerings based on teaching-learning research (Kerres, 2018; "What is instructional design?" n.d.).

Situated instructional design knowledge must be explored and integrated into a design theory to guide pedagogically beneficial integration of iVRLEs in the teaching process. Based on the work by Gregor and Hevner (2013), Lähtevänoja et al. (2020) developed a model where instructional design knowledge for iVRLEs is categorized on its completeness and maturation (see Figure 3). The first level only provides limited and less mature design knowledge. For iVRLEs, Lähtevänoja et al. (2020) give examples of the effect on singular direct learning outcomes such as learning about cells in biology (A. P. Johnston et al., 2018) or about building computers (Teranishi & Yamagishi, 2018). For singular indirect learning outcomes Lähtevänoja et al. (2020) give examples of motivation and engagement.

The second level provides more complete, mature, and abstract design knowledge. For iVRLEs, Lähtevänoja et al. (2020) state this as an investigation of the circumstances of successful first-level iVRLE studies. Examples are the comparison between different technologies (Agrawal et al., 2018; Holopainen et al., 2020; Krokos et al., 2019; Papachristos et al., 2017), or executing a longitudinal study to determine long-term learning effects (W. Huang, 2020).

The third-level design knowledge involves overarching didactical frameworks to guide the didactical use of iVRLEs as part of a holistic learning path, which includes its positioning in relation to other didactical methods and media (e.g., in a university or high-school course).

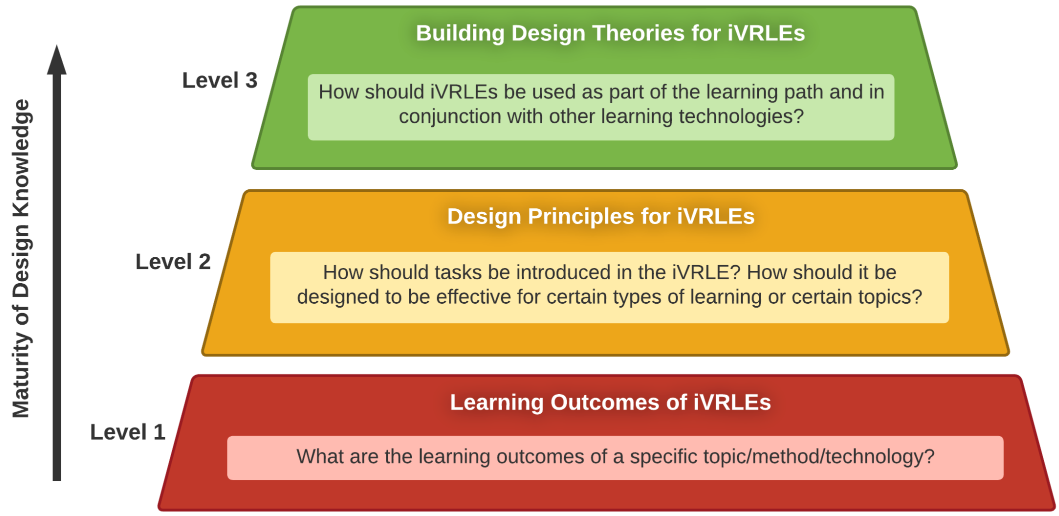

Figure 3. Three design knowledge levels for immersive Virtual Reality learning environments. Adapted from Lähtevänoja, A., Holopainen, J., Vesisenaho, M., & Häkkinen, P. (2020). Developing design knowledge and a conceptual model for virtual reality learning environments. *Designing, deploying, and evaluating virtual and augmented reality in education* (pp. 100–123). IGI Global. https://doi.org/10.4018/978-1-7998-5043-4.ch005. Based on the work of Gregor and Hevner (2013). Copyright by IGI Global.

To date, only first and second-level design knowledge is available for iVRLEs. There is a pressing need for third-level design knowledge in order to guide the use of VRLEs by teachers and establish it as a didactically-grounded medium. This thesis attempts to construct a pedagogical foundation to guide the decision to use iVR supplementary to other tools in the teacher's toolbox of didactical methods and provide recommendations for using iVR when this tool is considered the best fit for the situation. Next to pedagogical theories, it is essential to consider the context of the learning situation in this media selection process (K. Nielsen & Miraglia, 2017; Wong et al., 2010).

Since the first and second design knowledge levels are integrated into the third-level design theory, the thesis structure follows the same upwards sequence through the design levels to create an overarching didactic framework. First, studies concerning the first-level design knowledge are summarized, concerning the affordances of the technology and the qualitative and quantitative outcomes. Next, the second-level design knowledge is discussed, involving design principles and other situated theories on iVR application. Finally, the third level didactical framework for iVR is constructed, starting from established general instructional design theories. It incorporates both the first and second design knowledge levels.

2.1. Level 1: Affordances and Learning Outcomes

First-level design knowledge of iVRLEs refers to their singular direct learning outcomes or singular indirect learning outcomes. Examples of direct learning outcomes are, e.g., learning about cells in biology (A. P. Johnston et al., 2018) or about building computers (Teranishi & Yamagishi, 2018), while examples for indirect learning outcomes are motivation or engagement (Cheng et al., 2015). Before exploring these learning outcomes, the aspects of iVRLEs that facilitate these learning outcomes are discussed.

2.1.1. Affordances of iVRLEs

The aspects of iVRLEs that facilitate learning outcomes are referred to as learning affordances (Dalgarno & Lee, 2010) or educational affordances (Kirschner, 2002; Kirschner et al., 2004). First, the terminology of affordances is discussed to clarify how technology gives rise to affordances and how educational affordances can facilitate learning.

Initially coined by Gibson (1979), affordances are the functionality of an environment or technology in relation to the user. Kirschner et al. (2004) defines three main categories of affordances for educational technologies: social, educational, and technological affordances (see Figure 4).

To decide on the didactical method and medium, the learning task's required affordances are compared with the provided affordances of the available methods and media. By matching the required and provided affordances, the educators ensure that the most effective learning facilitation method is used. This thesis investigates iVRLEs as an educational technology. Thus, following Kirschner et al. (2004), iVR functionalities are explored based on its social, educational, and technological affordances. Besides the affordances, J. Nielsen (1994) describes other factors that also affect the overall acceptability of iVRLEs, such as costs, compatibility, and reliability. However, these factors fall outside of the scope of this thesis. Only the functionality is discussed based on the social, educational, and technological affordances.

Social affordances denote the use, or utility, that the technology facilitates for social purposes (J. Nielsen, 1994). Social affordances encompass the relationships between the social properties of a technology and the social characteristics of the learners, which enable certain kinds of interaction (Kirschner, 2002; Kirschner et al., 2004). Objects in the learning environment that possess social affordance properties encourage learners to engage in social interaction by accommodating the social intentions of users as they come up and motivating users to initiate communication (Kreijns et al., 2002). Cooperation contributes to learning from four perspectives: motivational, social cohesion (students want to help the group members succeed), cognitive development (learning from each other since they are likely in the same zone of proximal development (Vygotsky, 1978)), and cognitive elaboration (explaining things to group members) (Johnson & Johnson, 1995; Johnson-Glenberg, Birchfield, et al., 2014).

Educational affordances denote the use, or utility, that the technology facilitates for educational purposes (Kirschner et al., 2004). Educational affordances are the relationships between the properties of an educational intervention and the characteristics of the learners, which enable certain kinds of learning (Kirschner, 2002; Kirschner et al., 2004). In the same way as social affordances, educational affordances of the environment must fulfill the learning intentions of students as they come up and must motivate the student to make use of a learning intervention. Besides design attributes, the salience of the educational affordances of an environment may also depend on factors like students' attention, expectations, or prior experiences (Hattie & Yates, 2014; Kirschner et al., 2004).

Technological affordances facilitate the usability of a technology and are based on how well users can utilize elements of a system. To obtain good usability, the system should be easy to learn, efficient to use, easy to remember how to use, low in system error rate, and satisfying to use (J. Nielsen, 1994; Preece et al., 1994). In educational tools, bad usability is often caused by a blind desire to use the technological tool instead of seeing it as a method to improve the learning process. As a result, these educational tools ignore the needs and abilities of the users of the technology (Kirschner et al., 2004; Norman, 1992).

It is important to note that learning tasks and environments consist of different interacting parts and affordances, resulting in emerging learning properties that exceed the sum of the properties of the individual affordances (Kirschner et al., 2004). Dalgarno and Lee (2010) add that "technologies themselves do not directly cause learning to occur but can afford specific learning tasks that themselves *may* result in learning or give rise to certain learning benefits." Therefore, it is of great importance to refrain from assuming that iVRLEs *always* lead to an improvement of learning and to carefully consider the context in which educators will use the technology.

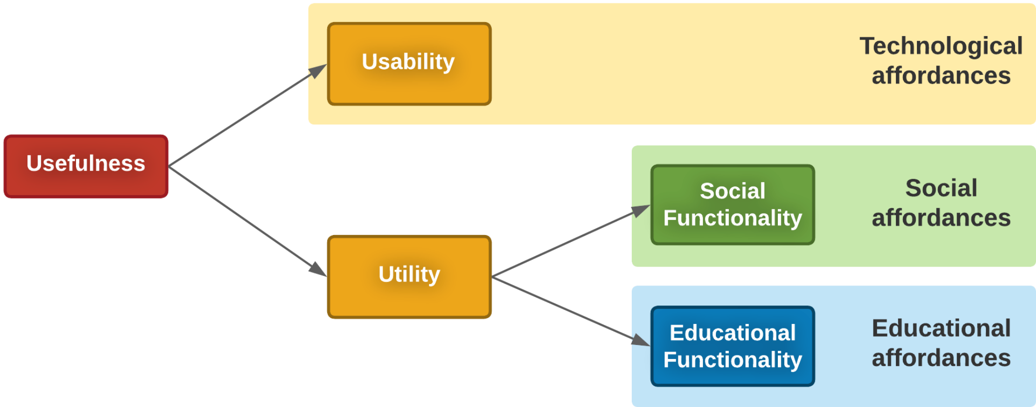

Figure 4. The usefulness of a learning environment is determined by a combination of educational, social, and technological affordances. Adapted from Kirschner, P. A., Strijbos, J. W., Kreijns, K., & Beers, P. J. (2004). Designing electronic collaborative learning environments. *Educational Technology Research and Development*, *52*(3), 47–66. https://doi.org/10.1007/BF02504675; based on work by Nielsen, J. (1994). *Usability engineering* (1st ed.). Morgan Kaufmann Publishers. Copyright by Springer Nature.

Educational and Social Affordances of iVRLEs. The technical affordances denote the usability that mediates the social and educational affordances of iVRLEs. These affordances are the social and learning tasks that an iVRLE facilitates. To create an overview of the different educational and social affordances, they are integrated with the AR - VR affordance framework by Steffen et al. (2019), which is adapted to only entail the affordances of iVRLEs. Four overarching affordances indicate how the learning process can benefit from iVRLEs: (a) recreating aspects of the physical world, (b) enhancing aspects of the physical world, (c) creating aspects that do not exist in the physical world, and (d) diminishing aspects of the physical worlds. Steffen et al. (2019) stress that physical reality is more vivid than iVR, which raises the question of which situations benefit from letting go of the sensory vividness of the physical world in exchange for the benefits that an iVRLE brings.

Affordance 1: Recreate Aspects of the Physical World. Recreating aspects of the physical world denotes situations where iVRLEs do not significantly change the learning task but make certain learning situations easier or more accessible. The vividness and interactivity of iVRLEs facilitate learning tasks that lead to the development of enhanced spatial knowledge representation of the explored domain (Dalgarno & Lee, 2010; W. Huang, 2020; Xu et al., 2021).

Dalgarno and Lee (2010) also state that iVRLEs facilitate learning tasks that lead to improved transfer of knowledge and skills to real situations through the contextualization of learning. Notably, not all contextual information is of equal value as information can differ in relevance and usefulness for the particular learning task.

Contextual learning also allows a more integrated and natural evaluation of learning (Johnson-Glenberg, 2018). Furthermore, Ke et al. (2020) state the real-world contextual goal of preparing students to use iVR in their future professional careers.

Replacing physical situations with iVRLEs can reduce financial (e.g., visiting Machu Pichu with the whole class) or effort-related resource costs (e.g., organizing a trip to a prison with a class of hundreds of students; Bagiati et al., 2020; Bailenson, 2018; Xu et al., 2021).

When used as a replacement or addition to real-world practice activities, it can also aid in providing more practice opportunities without social or time pressure (Jensen & Konradsen, 2018; Steffen et al., 2019).

Affordance 2: Enhance Aspects of the Physical World. Enhancing aspects of the physical world refers to learning situations where the tasks in iVRLEs are substantially different from the physical world.

An iVRLE supports various sub-affordances based on emotion like increasing empathy (Shin, 2017; Steffen et al., 2019) and increasing intrinsic motivation and engagement due to personalization and game/narrative-based approaches (Dalgarno & Lee, 2010). The high degree of vividness and interactivity could also increase the likelihood of learners experiencing the feeling of flow and engagement as they become psychologically immersed in the iVRLE (Dalgarno & Lee, 2010). Ke et al. (2020) state that the ability to switch perspective between virtual actors and viewpoints inside iVRLEs can aid learning (e.g., by supporting empathy or spatial knowledge).

Engagement and learning can also be facilitated by the richer and more effective collaborative learning possible in iVRLEs compared to 2D alternatives (Dalgarno & Lee, 2010). Educators can realize cooperative learning in iVRLEs in creative ways (e.g., through role-plays and mentoring) with a greater degree of immersion (De Freitas & Veletsianos, 2010) compared to other technologies and methods. As a result, immersed cooperation can improve distance learning (where the learner is not physically present at school, e.g., during a pandemic lockdown, difficult weather situation, or public transport strike). Compared to other technologies, iVRLEs also facilitate collaborative and individual distance learning well (Kavanagh et al., 2017). De Freitas and Veletsianos (2010) also mention an additional educational sub-affordance of providing broader capabilities for learner-led activity such as problem-based and inquiry-based learning. Similar to learner-led is the ability to let students create their own virtual worlds to enable mastery of content and to project their understanding of what they have learned to the teacher and other students (Ausburn & Ausburn, 2004).

Steffen et al. (2019) and identify the additional sub-affordances of facilitating additional information and filtered information (supported by Okechukwu and Udoka, 2011), and expanding physical capabilities.

Another educational argument for iVRLEs is that it affords the simulation of one-to-one teaching. One-to-one teaching has been shown to significantly improve the learning of around 80% of the students in a class, as demonstrated by Bloom (1984) and Walberg (1984).

Affordance 3: Create Aspects That Do Not Exist in the Physical World. Creating aspects that do not exist in the physical world opens a whole new setting where the learning process can take place. One sub-affordance is that abstract concepts can be communicated more clearly in iVRLEs than in physical reality. Mikropoulos and Natsis (2011) support the sub-affordance of abstract concepts and state two additional educational sub-affordances in their review of virtual educational environments: reification and transduction.

Reification is the practice of transforming abstract concepts into perceptible representations (Southgate, 2020), such as presenting the user with objective speech characteristics for presentations (Bonner & Reinders, 2018; Van Ginkel et al., 2020) or therapeutic intake conversations (Van den Berg, n.d.).

Transduction extends the user's capability to perceive data that would ordinarily be beyond the ability of their senses, such as simulating the migration paths of whales to allow the learner to follow the paths of different species around the world (example from Southgate, 2020) or making infra-red light visible to the learner in the iVRLE.

Normally impossible (experiential) learning activities can be facilitated by breaking the laws of nature, such as overcoming space-time linearity (e.g., traveling back to a historical site) (Abdul Rahim et al., 2012; Bagiati et al., 2020; Dalgarno & Lee, 2010; Freina & Ott, 2015; Roussou, 2004; Steffen et al., 2019), scaling up or down (e.g., taking a tour of the digestive system or perceiving a single photon) (Bailenson, 2018; Dalgarno & Lee, 2010; Kontogeorgiou et al., 2008), or depicting the nonexistent (e.g., hypothetical biological lifeforms, or fantasy creatures for stage design in theatre education) (Southgate, 2020). By allowing learners to experience these normally impossible activities in iVRLEs, they create a deeper and more immersive mental model of the learning content.

Affordance 4: Diminish Aspects of the Physical Worlds. Diminishing aspects of the physical world allows learners to partake in learning tasks without worrying (as much) about related risks. The risks can either involve the learners themselves or their environment. For the learner, the physical risk is reduced (e.g., in practicing with heavy machinery) (Bagiati et al., 2020; Bailenson, 2018; Lapointe & Robert, 2000; Pantelidis, 2010) as well as the emotional or mental risks (Steffen et al., 2019).

Regarding the environment, an iVRLE allows learners to observe the impact of their actions without any real-world consequences or environmental damage (e.g., cutting down an entire forest to teach about environmental effects of deforestation) (Bagiati et al., 2020; Bailenson, 2018; Okechukwu & Udoka, 2011).

The summarized educational and social affordances (see Figure 5) give preliminary guidance on iVRLE usage in education. Different educational and social sub-affordances can be combined to create learning tasks. An example is the article by Rosa-Jiménez and Ventura-Blanch (2020), which states that the educational affordances of iVRLEs for architectural educations are a combination of motivation, perspective switching, experiential learning (based on vividness and interactivity), and spatial knowledge representation.

Technical Affordances of iVRLEs. Similar to other educational technologies, iVRLEs give rise to technical affordances. The technical affordances of an iVRLEs work together with the social and educational affordances to facilitate learning outcomes. As previously mentioned, two main dimensions of technological affordances can be determined in iVRLEs: Vividness and Interactivity (Steuer, 1992).

These dimensions interact and form the concept of presence, the individual experience of feeling like being in a virtual environment. Before exploring learning outcomes of iVRLEs, a didactical perspective is taken on the technical dimensions of vividness and

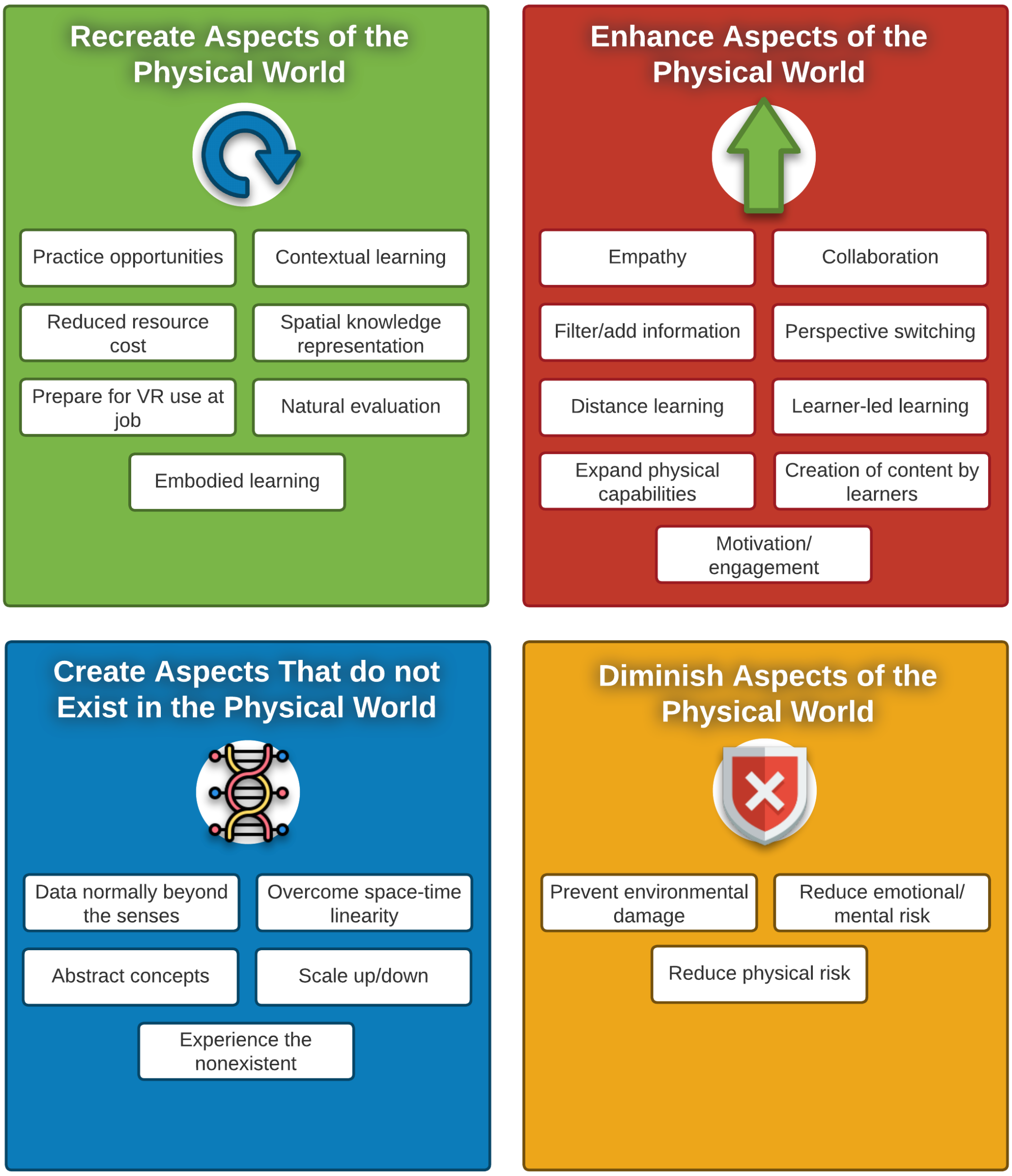

Figure 5. Educational and social sub-affordances of immersive Virtual Reality learning environments, model adapted from Steffen, J. H., Gaskin, J. E., Meservy, T. O., Jenkins, J. L., & Wolman, I. (2019). Framework of affordances for virtual reality and augmented reality. *Journal of Management Information Systems*, *36*(3), 683–729. https://doi.org/10.1080/07421222.2019.1628877. Sub-affordances included from Abdul Rahim et al. (2012), Ausburn and Ausburn (2004), Bagiati et al. (2020), Bailenson (2018), Dalgarno and Lee (2010), De Freitas and Veletsianos (2010), Freina and Ott (2015), W. Huang (2020), Johnson-Glenberg (2018), Ke et al. (2020), Mikropoulos and Natsis (2011), Okechukwu and Udoka (2011), Pantelidis (2010), Roussou (2004), Shin (2017), Steffen et al. (2019), Southgate (2020), and Xu et al. (2021).

interactivity.

Vividness. Vividness is supported by iVR's ability to simulate a wide array of sensory information (e.g., tactile, visual, audio, or locomotion). With this multi-sensory feedback, iVR may help learners develop more accurate mental models, enhancing learning (Roberts & Roberts, 2014; Sanfilippo et al., 2022). Sensory vividness, as a result of the vividness of an iVRLE, has been shown to predict affective learning (C. L. Huang et al., 2020).

Vivid environmental stimuli (e.g., of novel or intense nature) can stimulate situational interest (Hidi & Ann Renninger, 2006; Renninger et al., 2008). Situational interest is shown to promote learning by increasing learners' attention and engagement (Harackiewicz et al., 2016).

However, increased vividness in terms of breadth or depth can increase extraneous cognitive load and decrease learning because learners have to focus more to find relevant content, especially when irrelevant details are included that are not necessary for learning (C. L. Huang et al., 2020; Makransky et al., 2020).

Interactivity. Interactivity is supported by iVR's ability to simulate motor action in the brain, which is indicated to aid learning by strengthening memory traces (Bailenson, 2018; Broaders et al., 2007; Congdon et al., 2017; Goldin-Meadow, 2011; Hostetter & Alibali, 2008; Johnson-Glenberg, 2018; Kerres et al., 2021; Lindgren et al., 2016; Ruiter et al., 2015) and by giving learners a sense of agency (Johnson-Glenberg, 2018).

Additionally, it can aid learning by decreasing germane cognitive load (mental effort required to process information) (Kirsh & Maglio, 1994; Skulmowski et al., 2016) and by allowing learners to use their body to create a richer representation of the problem by grounding it in physical metaphors (Alibali & Nathan, 2012; Hostetter & Alibali, 2008; Kerres et al., 2021; Nathan et al., 2014). Physical engagement can facilitate active learning, which has been shown to increase STEM (science, technology, engineering, and mathematics) grades by up to 20% (Waldrop, 2015). Hand and arm gestures are especially suitable motor actions for iVRLEs, considering the limited physical space required. Embodiment in the iVRLE can be high even if the congruence of the motion to the content is only moderate due to the use of controllers instead of full-body tracking. Such high embodiment is due to the influences of sensory immersion and the magnitude of the gesture (Johnson-Glenberg, 2018).

Besides being a modality that can benefit learning, the motor action of using hands to control a digital action can also attenuate cybersickness (Stanney & Hash, 1998), driven primarily by sensory integration processes (Weech et al., 2019). Cybersickness is a form of motion sickness that can occur due to exposure to iVRLEs, varying from a slight headache to nausea (Stanney et al., 2021). The amount of users experiencing cybersickness depends on the content and interactivity (Stanney et al., 2021). Sickness in iVR can be minimized by users having active task-focused control instead of being passive observers (Stanney et al., 2021).

Motor action is not suited for every educational situation since the motor action is more likely to facilitate learning if it is meaningfully integrated into the didactical intervention (Johnson-Glenberg, Birchfield, et al., 2014; Mavilidi et al., 2015; Skulmowski & Rey, 2018) compared to motor action that is unrelated to the learning content. However, even with meaningful integration, high bodily engagement can lead to learning gains (Johnson-Glenberg et al., 2016; Lindgren et al., 2016) as well as impaired learning to cognitive overload (Mullen & Davidenko, 2021; Post et al., 2013; Ruiter et al., 2015; Skulmowski et al., 2016; Song et al., 2014). Especially novice learners are easily cognitively overwhelmed (Kirschner et al., 2020; Post et al., 2013). In line with benefits for lower cognitive load, there are studies where lower levels of bodily engagement lead to successful outcomes, such as observing movements (Brucker et al., 2015) or performing minor gestures (De Nooijer et al., 2013).

2.1.2. Learning Outcomes of iVRLEs

The technological, educational, and social affordances of iVRLEs interact to facilitate learning tasks. Next, the first-level design knowledge of iVRLEs is discussed. To this category belong the singular direct and the indirect learning outcomes.

Two side notes are essential to emphasize in the discussion of learning outcomes. Firstly, since iVR is a relatively novel technology, it is possible that (part of) the learning outcomes are the result of the novelty effect (Bagiati et al., 2020; R. E. Clark, 1983; Kirschner et al., 2020). Students (and possibly teachers) might get excited about the usage of this new and "cool" technology and, as a result, be temporarily more engaged and eager to learn. It is crucial to investigate long-term effects to establish sustained learning outcomes. One early study on the novelty effect in iVRLEs found that the increased engagement and motivation linked to the novelty of the technology only attenuated slowly (W. Huang, 2020). In addition, W. Huang states that: "novelty does not necessarily increase learning achievement. (p.162)" The fit between the learning content and the learning method is considerably more important than the motivation and engagement that the novel technology of iVR brings about.

Secondly, it should be stressed that media are difficult to compare in scientific studies. For scientific robustness, it is essential that only one variable (the medium) is changed in a study (R. E. Clark, 1983; Kirschner et al., 2020) and that other variables (e.g., instructional method) are kept the same. Changing only one variable is problematic since didactical media are not neutral tools, meaning that the compared media likely have a distinct specific instructional method that works best for it (R. E. Clark, 1983; Kirschner et al., 2020; Neelen & Kirschner, 2020). Despite being required for scientific robustness, a skewed result of (possible) learning benefits of media is likely to be obtained by not changing the instructional method to utilize the medium's potential entirely. Additionally, positive outcomes can result from teachers and researchers expecting better performance from the students when using iVRLEs. Known as the Pygmalion effect, expectations affect reality and create self-fulfilling prophecies (Rosenthal & Jacobson, 1968; Szumski & Karwowski, 2019; Thorndike et al., 1968). This Pygmalion effect complicates the clarity of the study's results. To fully understand learning benefits, there is a need for more research that focuses on the necessary characteristics of instructional methods and the situational and personal contextual variables (R. E. Clark, 1983; Kirschner et al., 2020). Only by considering this context is it possible to explore the educational potential of the attributes of iVRLEs (Kozma, 1994).

Despite the influences of the novelty effect and the complexity in comparing instructional methods, it is worth investigating the results of studies conducted in the field. These studies nonetheless provide valuable preliminary indications of possible learning outcomes for iVRLEs.

Direct Learning Outcomes. The technology of iVR is still relatively novel to the educational scene, and only a limited number of studies have been conducted on the topic of direct learning. One of the reasons why the number of studies has been limited is because much work remains to be done in developing validated metrics for evaluating the impact of iVRLEs, from pedagogical, research, and institutional perspectives (Cook et al., 2019). The few studies that have been performed (and were published) report moderately positive results. Some studies find no effect for direct learning outcomes (Bailenson, 2018; Moreno & Mayer, 2002; Xu et al., 2021; Ylinen et al., 2020), sometimes caused by a high cognitive load (Xu et al., 2021). Nevertheless, a substantial number of studies report positive effects.

Positive learning effects using iVRLEs are found for procedural knowledge such as operating construction machines (Sulbaran & Baker, 2000), interpersonal skills (Theelen, van den Beemt, et al., 2020), interactive teaching and demonstrative instruction (Ke et al., 2020; Theelen, Willems, et al., 2020; Theelen et al., 2019, 2020), memorizing and drawing a virtualized 3D model of the inner ear (Jang et al., 2017), and simulated surgical exams (Logishetty et al., 2019; Xu et al., 2021).

Learning outcomes are also reported for factual and conceptual knowledge-based topics such as writing, language acquisition, and physics. When participants interact with marine ecosystems in an iVRLE before writing an informative letter, they are more engaged and show improved writing outcomes (Lamb, 2021). The researchers state that the experiential component of iVRLEs promotes interaction between long-term memory systems and working memory systems due to increased activation of procedural and episodic memory systems. This interaction is said to improve memory, critical thinking, and inferential thinking. For language sciences, initial studies show that iVRLEs affect learner behaviors in terms of linguistic complexity, accuracy, and correct feedback (Lin & Lan, 2015). Peeters (2019) states that this is the result of the combination of experimental control, ecological validity, and reproducibility facilitated by iVRLEs. Moreover, iVRLEs are successfully applied in sub-fields of the language sciences as diverse as indirect speech processing, syntactic priming, predictive language processing, multilingualism, and gesture studies (Peeters, 2019). Physics topics such as astronomy and centripetal force are shown to benefit from (mixed reality) solutions where students learn about dynamic concepts with learning tasks that include full-body movements (Johnson-Glenberg et al., 2016; Lindgren et al., 2016). This learning benefit is supported by brain imaging (fMRI) research which shows that activity in the motor regions significantly predicts content knowledge test performance (Kontra et al., 2015).

Furthermore, the diverse learning outcomes which iVRLEs can facilitate also extend to students with various disabilities, for whom learning outcomes are found across a wide range of skills (e.g., academic, behavioral, social, and vocational) (Kellems et al., 2021).

Indirect Learning Outcomes. Indirect learning outcomes are not task specific but instead refer to general mental effects deemed beneficial to learning (Lähtevänoja et al., 2020). More studies have been conducted on the topic of indirect learning outcomes with mostly positive (published) results. Positive effects are found regarding using iVRLEs for attitude changes (Bailenson, 2018), engagement (Bailenson, 2018; Filsecker & Kerres, 2014; Kaufmann et al., 2000; Lischer-Katz et al., 2018; Sulbaran & Baker, 2000), enjoyment and motivation (Crosier et al., 2000; Häfner et al., 2013; Mantovani et al., 2003; Oigara, 2019; Xu et al., 2021; Ylinen et al., 2020), reflection (Ranieri et al., 2020; Schott & Marshall, 2018), reduced anxiety (Theelen, Willems, et al., 2020), and self-efficacy in acquired knowledge (Xu et al., 2021) for spatial analytic tasks (Lischer-Katz et al., 2018) and interpersonal skills (Theelen et al., 2019).

Indirect learning outcomes seem straightforward at first glance but require a more detailed explanation to be practically usable. Engagement, for instance, is not a one-dimensional concept. Student engagement is a multi-dimensional construct that can refer to cognitive, behavioral, affective, or motivational indicators (Filsecker & Kerres, 2014). Cognitive indicators can entail the depth of cognitive processing of learning content. In contrast, behavioral indicators are factors such as participation, login frequency and duration, time on task, persistence and intensity of task completion, feedback (retention), or termination (drop-out). Affective indicators refer to the inner involvement or enthusiasm for the learning offering, and motivational or volitional indicators express the interest and the intent to deal with a learning offering and regulate one's own learning process.

At the same time, some studies also show no difference between iVR and non-iVR environments in terms of presence and usability (Çoban, 2021). It should be noted that participants only experienced the iVRLE for a limited time (5-7 minutes) and that some participants experienced the iVR HMD (an HTC Vive) for the first time. Nevertheless, it is wise to abstain from the assumption that iVRLEs always creates presence but instead consider presence an interplay of factors such as the content, didactical method, learner specifics, and iVR technology. More research on the process of presence and its influencing factors is necessary for well-grounded understanding and effective use of iVRLEs (Weech et al., 2019).

The indirect learning outcomes *can* facilitate learning in a multitude of ways, but this is not an automatic or causal relationship. Learning can be facilitated by engagement and motivation as part of a state of flow (Csikszentmihalyi, 2014). In a state of flow, the activity is so intrinsically motivating that a person pursues it in their own interest instead of for any external rewards. Some studies and educational arguments for iVRLEs assume that motivation automatically leads to learning, as a result of this losing sight on didactical methods and at times even impairing learning (Hirsch Jr, 1996; Kirschner et al., 2020; Nuthall, 2007). Nuthall adds that while motivation and interest in novelty are not predicted to maintain long-term academic learning, it can still help students get started.

2.1.3. Conclusion - Learning Outcomes

An iVRLE facilitates learning based on the interaction between its social, educational, and technological affordances. The social and educational affordances can focus on four degrees of technology integration: (a) enhancing positive aspects of the physical world, (b) creating aspects that do not exist in the physical world, (c) recreating positive of the physical world or, (d) diminishing negative aspects of the physical world. Technological affordances refer to the usability of the environment.

Learning tasks based on combinations of affordances and degrees of technology integration have been reviewed. These studies show that iVRLEs can facilitate both procedural and cognitive direct learning and indirect learning outcomes. Several studies report adverse or absent effects and signify the importance of considering iVRLEs as part of a holistic instructional method that incorporates context (e.g., learner characteristics and familiarity with iVR).

2.2. Level 2: Design Principles

From the first-level design knowledge overview, it emerges that both direct and indirect learning outcomes can be facilitated by the educational, social, and technological affordances of iVRLEs. At the same time, the mixed scientific results signify the importance of considering iVRLEs as part of a holistic instructional method, which also incorporates context (e.g., learner characteristics and familiarity with iVR).

The second-level design knowledge for iVRLEs builds upon the outcomes of the first-level design knowledge and involves more overarching design principles for iVRLEs (Lähtevänoja et al., 2020). The design principles combine the circumstances of successful first-level iVRLE studies with established didactical principles relevant to iVRLEs.

This section investigates the design principles that conduce a didactically effective environment in iVR. Utilizing specific design guidelines can promote technological, social, and educational affordances. In line with the three affordance categories, social, educational, and technological design principles are investigated. As stressed before, this is solely the facilitation of learning since the learning process is neither linear nor automatic.

2.2.1. Social Design Principles

Social design principles build upon the concept of the social affordances of an educational technology (Kirschner et al., 2004; Kreijns et al., 2002). Learning in a social setting can promote deep, meaningful learning (Kerres, 2018). Social learning tasks have to be deliberately designed, since merely placing students in groups and assigning them a learning task does not promote cooperation (Johnson & Johnson, 1995). For iVRLEs, this could be done by including a preprogrammed non-player character (NPC), having a not-in-headset partner interact with them (e.g., via speech or a 2D computer screen), or by designing sequential tasks that require discussion in an asynchronous manner (e.g., giving students different roles) (Johnson & Johnson, 1995).

2.2.2. Educational Design Principles

Educational design principles build upon the concept of the educational affordances of an educational technology (Kirschner et al., 2004; J. Nielsen, 1994). These design principles are categorized into active learning, scaffolding, reflection, guided exploration, building on pre-existing knowledge, and inclusive development of iVRLEs.

Active Semantic Learning. Active semantic learning denotes active processing, both physically and mentally, which can facilitate learning (Craik & Lockhart, 1972;

Kerres, 2018; Mayer, 2014). Since learning is an active process of knowledge construction, even the usage of the most impressive iVRLEs does not facilitate learning if learners do not actively engage in the learning activities (Mulders et al., 2020). How material is processed proves to be even more important than the student's intention to learn (similar to concepts of engagement and enjoyment), even if a student deliberately prepares for a test (Craik & Tulving, 1975; Marsh & Butler, 2013).

Motor action can aid learning, as discussed in the Technical Affordances of Immersive Virtual Learning Environments (p.13). Gestures are not suited for every learning process since they must be meaningfully integrated and not cause cognitive overload (Post et al., 2013). To ensure gestures benefit the learning process, they are advised to focus on learning-relevant interaction (Mulders et al., 2020). The interaction should be part of the learning task (e.g., interaction with the chemistry setup students are learning about, instead of with irrelevant surroundings) and be coherent with the context of the learning task (e.g., students perform actual motions of surgery instead of pressing a button). Additionally, provide pre-training for learners to get used to the interaction tools in iVRLEs (Mulders et al., 2020).

Besides physical interaction, active mental interaction with the learning content is also essential to generate semantic learning (Krokos et al., 2019; Mulders et al., 2020; Parong & Mayer, 2018). Educators can encourage active mental processing with various techniques.

- Educators can stimulate students to think about how the new learning content is related to and distinct from other, already known concepts, known as elaborative encoding (Craik & Lockhart, 1972; Kirschner et al., 2020). Teachers can aid learners in this process by actively linking the new information to pre-existing knowledge to help them retain and recall information better (Craik & Lockhart, 1972; Kirschner et al., 2020). This is closely related to considering pre-existing knowledge and scaffolding, the second and third educational design principle (see below, p.19 and p.20).
- Educators can include activities that focus on the application of the material in different situations (Craik & Lockhart, 1972; Kirschner et al., 2020), for instance, with problem-based tasks either inside or outside of the iVRLE (Kerres, 2018; Mulders et al., 2020).
- Educators can have students rework the new material in their own words (e.g., summarizing, paraphrasing, making mind-maps, or discussing with peers) (Craik & Lockhart, 1972; Kerres et al., 2021; Kirschner et al., 2020).
- Teachers can actively relate the learning content to the student's personal experience (Craik & Lockhart, 1972; Kirschner et al., 2020).
- Educators can use transfer appropriate processing and make sure the student processes the information in the same way it will be used or tested (Craik & Lockhart, 1972; Kirschner et al., 2020). Educators should prompt students to imagine what they are expected to do with what they have learned.
- Educators can educate learning strategies to learners (e.g., mental palaces (Krokos et al., 2019)).
- Repeated testing can aid active, deep processing (Karpicke & Roediger, 2008). Testing can be done formative (during the learning process) and summative (after

the learning process), possibly with gestures as a more natural method of testing (Johnson-Glenberg & Megowan-Romanowicz, 2017).
- Educators can use prompting techniques prior to, during, or after the engagement with a learning activity (e.g., adjunct questions before or after an iVR experience) to stimulate processing (Kirschner et al., 2020; Popova et al., 2014; Rothkopf, 1970).

By ensuring that learners take a mentally and physically active approach in processing the content, the learning content is processed on a deeper level, and learning is facilitated.

Build on Pre-Existing Knowledge. Building on pre-existing knowledge denotes the need to balance the content in iVRLEs with learners' prior knowledge to prevent over- or under-stimulation (S. Y. Chen & Huang, 2013; H. M. Huang et al., 2010; Kerres, 2018; Mulders et al., 2020) and to help learners integrate new information into their existing cognitive structures (Ausubel, 1960, 1963, 1968; Craik & Lockhart, 1972; Kirschner et al., 2020; Piaget, 1952; Wadsworth, 1996). Support systems help facilitate learning for novice learners but can hinder more knowledgeable learners by making the learning content too easy and causing mental under-stimulation. This duality is known as the expertise reversal effect (Chi et al., 1981; Kalyuga, 2009; Kirschner et al., 2020; Sweller et al., 2003) and is also valid in iVRLEs (Armougum et al., 2020; Johnson-Glenberg, 2018).

To accommodate for learners' different experience levels, educators should adapt the content's difficulty and support based on the learner. For experienced learners, they can balance the stimulation by increasing the difficulty, removing support (Van Merriënboer & Kirschner, 2018), or letting them aid novice learners. Methods to improve learning for experts by increasing difficulty and removing support include using more problem- and inquiry-based learning. Problem-based learning is not suited for novice learners since they first need prerequisite knowledge and exposure to situations that need similar strategies to solve (Sweller, 1988). Instead, educators can aid novice learners by preventing cognitive overload (Mayer & Pilegard, 2014) with the support of knowledge-based preparation before going into the iVRLE. This preparation can be done with techniques such as exposition (overview of the new knowledge, usually for new learners), narration (novel information is introduced in a story format), skimming (giving an overview of the new learning material), or graphic organizers (e.g., concept maps or Venn diagrams).

Once inside the iVRLE, novice learners benefit from a structured approach (Kerres, 2018; Kirschner et al., 2020; Mulders et al., 2020; Sweller et al., 2003; Van Merriënboer & Kirschner, 2018) to aid in derivate subsumption (linking new things to already-known concepts) and correlative learning (adding new details to what the learner already knows). The structured approach also aids in subordinate subsumption (introducing a new higher-level concept into which existing categories can be integrated) and combinatorial subsumption (ideas are linked between higher-level concepts) (Ausubel, 1968; Kirschner et al., 2020). Examples of effective structured approaches are worked examples and tutorials (Kalyuga, 2009).

For both novice and expert learners, it is recommended to structure the content from simple to complex, general to detailed, or from concrete to abstract to help learners integrate the knowledge into existing schemata (Ausubel, 1960, 1963, 1968; Reigeluth, 1983). An iVRLE can aid in concrete examples that could otherwise not be feasible and make abstract concepts more tangible. By matching the level of challenge with learners' skills (together with other flow conditions), a state of flow can be achieved, which increases technology acceptance and engagement (Hamari et al., 2016; Liu et al., 2009; Sanchez-Franco, 2010) and can mediate learning (Hamari et al., 2016).

It is recommended to test learners' knowledge to adjust the iVRLE appropriately. The outcome of this test might also signify that the iVRLE should only be used at a later point in the learning path after a more extensive knowledge foundation is created by learners. Most mentioned design principles can take place inside and outside of the iVRLE. By matching the new learning content with pre-existing knowledge, learners are less prone to cognitive overload and able to more easily integrate the novel knowledge, thereby facilitating knowledge acquisition and recall.

Scaffolding. Scaffolding refers to the degree to which the learning content is matched to the student. Ideally, the content matches, or is a little beyond, the individual student's skill level (also known as the zone of proximal development)(Vygotsky, 1978). Incorporating scaffolding in iVRLEs is complex since the timing and manner of providing and taking away support is crucial. The ultimate goal is to show the learner the discrepancies between where they are in their learning journey and the problem at hand (Kirschner et al., 2020; Wood et al., 1976). As a result, the content should initially have low stakes for errors, becoming gradually more difficult as learners adept. Specifically, mistakes which are made with confidence by the learner and are then appropriately corrected are beneficial for learning (Metcalfe, 2017). Adaptive difficulty and scaffolding are seen as one of the most effective practices in education (Hattie & Yates, 2014; Kalyuga, 2009), but are still relatively expensive to develop for iVRLEs. For scaffolding, design principles are to keep lessons short when introducing new concepts and to demonstrate what learners need to do, with the inclusion of thought processes during the demonstration (Kirschner et al., 2020).

Scaffolding also applies to content in iVRLEs which can be complex and overwhelming for learners, leading to an overload of extraneous cognitive load. Extraneous cognitive load is the mental effort related to using a medium and can hinder learning (Dede, 2009). To prevent cognitive overload and focus the mental resources on learning, educators are advised to scaffold by limiting the options and breaking up complex tasks into smaller, more manageable tasks (Mulders et al., 2020; Van Merriënboer & Kirschner, 2018; Vygotsky, 1978). By scaffolding, the educator ensures that the learning content is at the right challenge level for the learner and that the learner is in charge of their learning process, thereby facilitating learning.

Reflection and Feedback. Reflection and feedback refer to supported self-reflection of students and the feedback supplied to them to aid in their reflection. It is vital to incorporate reflection moments to allow learning to solidify (Di Stefano et al., 2014; Johnson-Glenberg & Megowan-Romanowicz, 2017). Reflection moments can be integrated inside or outside the iVR headset depending on the context (e.g., the necessity to maintain immersion). Inside the iVR headset, (congruently mapped) gestures can be used to help learners to reflect on embodied representations of their ideas (Lindgren & Johnson-Glenberg, 2013).

Supplying feedback depends on the context (e.g., situation, person) but should, in general, be unobtrusive, immediate, and actionable (Kerres et al., 2021; Shute, 2008). Feedback should not be constant since the integration into the learner's mental model takes time. Formative feedback (during learning) should additionally focus on being specific, supportive, and non-evaluative (Shute, 2008). By using reflection and feedback, the educator promotes semantic learning and ensures that correct information is solidified in the mental representation of the learners, hence facilitating future usage of the learned knowledge.

Guided Exploration. Guided exploration involves the didactical method of purposefully guiding a student's learning environment to facilitate learning. Regarding the environment, free exploration can incite curiosity and help users accommodate in iVRLEs. However, guidance of the learner is needed to aid learning (Johnson-Glenberg, 2018; Kirschner et al., 2006). Since iVRLEs increase cognitive load, especially for novices, it is recommended to provide guidance inside the learning environment to prevent cognitive overload (Mulders et al., 2020), increase self-efficacy (individual's belief in their innate ability to achieve goals) (Kirschner et al., 2020; Zimmerman, 1989) and help students construct perceptual models and knowledge structures (Megowan, 2007).

Guided exploration can be facilitated by highlighting (e.g., blinking objects, lights, or signs) or virtual pedagogical agents (also known as non-playable characters). Guidance is likely to be less necessary when learners gain more experience (Bandura, 1986; Kirschner et al., 2006) and can be phased out as a form of scaffolding, where it is crucial to still give learners the chance to call for help if needed (Zender et al., 2020). By using guided exploration, the educator ensures that the learners are in the optimal state of mental stimulation (neither bored nor stressed), with this facilitating knowledge acquisition.

Inclusive Development of iVRLEs. Inclusive development of iVRLEs stresses the need for the inclusive design of iVRLEs to assure the iVRLE matches learners' and teachers' diversity in individual differences (e.g., ability, needs, cultural background) and situational effects. Therefore, there is a need to co-design with teachers and students and frequently playtest with novice and expert end-users. Co-designing ensures that the content is appropriately contextualized (Dalgarno & Lee, 2010) and that it has relevance to and is generalizable to the real world once users are out of the iVR headset (Johnson-Glenberg, 2018). It is crucial to playtest with age-appropriate learners for feedback, which is substantially different from playtesting with developers since they have a different physiological response compared to the end-users. The developers' brains adapt to discomfort, and their movement becomes more efficient over time due to practice (Oculus, n.d.). As stated by Mulders et al. (2020), it is vital to prioritize learning over presence (which they define as mental and physical immersion) when designing or using iVRLEs. Even though iVRLEs can provide learning through realistic contexts and tasks, other methods and media might fit the learning process better. If the higher degree of presence is not relevant for the learning objective, iVRLEs can instead hinder learning since these unnecessarily increase the extraneous cognitive load (Mulders et al., 2020). By inclusively developing iVRLEs, the content and usage fit best to the pedagogical context, thereby ensuring that the pedagogical potential is realized and that the educators and learners are able and motivated to use the medium.

2.2.3. Technological Design Principles

Technological design principles build upon the concept of the technological affordances of an educational technology (Kirschner et al., 2004; J. Nielsen, 1994; Norman, 1992; Preece et al., 1994), also known as the usability. Following the definition of usability from J. Nielsen (1994), these design principles are categorized in the learnability, efficiency, memorability, errors, and satisfaction of the iVRLE.

Learnability. Learnability denotes that iVRLE should be easy to learn. Given the relative novelty of iVR technology, it is advisable to assume that every learner is new to it. Novices need more support to facilitate learning (Chi et al., 1981; Johnson-Glenberg, 2018; Kirschner et al., 2020). Educators should be lenient to learners by allowing them to acclimate to the virtual space before starting the learning process. Additionally, they should declutter the user interface (UI) as much as possible, especially at the beginning of the learning process (Johnson-Glenberg, 2018; Johnson-Glenberg, Savio-Ramos, et al., 2014). Essential elements in the iVRLE should be placed close to each other, and learning tasks should go easy on the learners' proprioceptive system (which perceives where the body is in space). A segment of students will easily learn their way around iVR (Timmermans, 2021), so it should be possible for experienced learners to skip the introduction or adjust the difficulty (Johnson-Glenberg, 2018). Some students also need more support and time to get acclimated due to their lower spatial abilities (Jang et al., 2017).

Efficiency. Efficiency entails that iVRLEs should be efficient to use once the student or teacher has learned how to operate the system. A factor related to efficiency that has previously been discussed is the educational design principle of inclusive development of iVRLEs. After all, by including educators and learners in the development process, they can detect points of improvement and ensure the iVRLE is suited to their needs and expectations. Besides the inclusive development, several general efficiency guidelines can assist in designing and using iVRLEs by considering the mental effort required to operate them.

To efficiently stimulate mathemagenic behaviors (behaviors that give rise to learning) in learners, both the teacher and teaching material should focus and retain students' attention on the learning material without distractions. Technology such as laptops, phones, and thus also iVR should not be available when these are not necessary for the learning process (Kirschner et al., 2020; Rothkopf, 1970).

One way to retain attention and improve efficiency in iVRLEs is to minimize text reading. It is best to rely on informative graphics or mini-animations whenever possible since prolonged text reading in iVR headsets causes strain on the eyes (Hoffman et al., 2008; Johnson-Glenberg, 2018). A voice-over can be included with the animations to engage both the visual and verbal processing systems. The engagement of both processing systems is at the core of dual-coding theory (Mayer, 2014) and is shown to improve learning (J. M. Clark & Paivio, 1991; Makransky & Petersen, 2021; Mayer, 2014; Taylor et al., 2007).

While the virtual environment can improve learning by supplying context and experience, it is crucial to find a balance between distracting factors that increase cognitive load and the educational narrative of the lesson (Bailenson, 2018). Both the pictorial and verbal channels have a limited capacity for processing, and a cognitive overload of either channel due to the iVRLE would impair learning since (Mayer, 2014). Especially novice learners are vulnerable to this cognitive overload (Kirschner et al., 2020; Post et al., 2013). Solutions to this are to separate the engaging experiences from the presentation of learning materials (alternate between telling and doing), to create experiences that do not require the presentation of facts (Bailenson, 2018) or to provide proper guidance through the experience (Johnson-Glenberg, 2018; Kirschner et al., 2006). For more information on guidance, see 2.3.2. Educational Design Principles - Guided exploration.

Memorability. Memorability stresses that iVRLEs should be easy to remember so students and teachers do not have to relearn how to interact with them. A simple UI does not only make the iVRLE easy to learn but also helps the user to return without effort after not using the iVRLE for a period of time (J. Nielsen, 1994). Naturally, the perception of what defines an easy-to-remember UI differs between target groups, stressing the need to include the target learner group in the development of iVRLEs.

Errors. Errors concerning the use of the iVRLE should be kept to a minimum, and if errors do occur, they should be easy to recover from. These errors only refer to the usage of the systems and are substantially different from purposeful errors that a student makes while in the learning process (e.g., exercises or assessments). To help a learner when they make an error, they should be able to backtrack to the former step in a learning task effortlessly. Additionally, it is wise to include a positional reset option in case learners get stuck in the environment.

Satisfaction. Satisfaction of using the iVRLE should be high so that teachers and students enjoy using it and are motivated to use it frequently. Satisfaction can facilitate learning but should not be the primary goal of the iVRLE since motivation alone does not lead to learning (Hirsch Jr, 1996; Kirschner et al., 2020; Nuthall, 2007). A method to increase positive attitudes is to ensure that users feel that they have control over the virtual environment (Kay, 1989). Satisfaction is subjective to the target group of learners, providing an additional argument to include the target learner group in the development of iVRLEs.

Additionally, the users' satisfaction is related to the experienced difficulty of the system. However, not all difficulties and satisfying experiences are weighed similar. In particular, the experienced peak and end level impact the users' retrospective evaluation (Cordes, 1993; Do et al., 2008; Kahneman et al., 1993). Therefore, it is recommended to aim for a steady difficulty level without sharp peaks, to end with an easier task, and to include pleasurable events near the end.

2.2.4. Conclusion - Design Principles

Several design principles for iVRLEs are discussed. Social design principles revolve around facilitating and motivating cooperation. Educational design principles involve active learning, scaffolding, reflection, guided exploration, building on existing knowledge, and inclusive development of iVRLEs. Technological design principles that benefit the usability of iVRLEs consider the learnability, efficiency, memorability, errors, and satisfaction related to using iVRLEs.

Since most design principles were based on established didactics, an overview is given of design challenges and opportunities specific to iVR. First, the challenges are discussed. A design challenge for iVRLEs is preventing cognitive overload because this would impair learning. This overload can be prevented by using learning-relevant interactions, using iVR problem-based learning when learners have sufficient prior knowledge, and balancing pictorial and verbal cognitive channels. Next, since iVRLEs are technologically complex, it can be difficult and expensive to provide appropriate differentiation in difficulty (e.g., scaffolding, support systems, highlighting) for learners' expertise levels. As a result of iVRLEs' complexity, a more diverse team is also required to develop it compared to other educational media. In developing iVRLEs, infographics, animations, or voice-overs should be used since prolonged text reading in iVR headsets causes strain on the eyes. When iVRLEs are used in the classroom, educators should give students enough time to acclimate to the new medium. Additionally, they should only make iVR headsets available when strictly needed because otherwise, it is likely to distract learners.

Nevertheless, sufficient opportunities exist to make using iVRLEs worthwhile. Some opportunities will be discussed in addition or supplementation to the previously discussed affordances of iVRLEs (see p.9). With iVRLEs, educators can aid students' comprehension with concrete and immersive examples. After the knowledge acquisition, educators have access to a wide array of immersive activities that focus on applying the material in different situations. As part of the application, relevant motor action can aid semantic learning. Through the immersive and interactive practice, students can process information in the same way it will be tested or used vocationally. The tests can use more natural methods based on simulated real-life tasks to further knowledge transfer between education and vocational application.

2.3. Level 3: Theory-based Application

Previous sections determined multiple social, educational, and technological design principles for iVRLEs. While these design principles aid in developing and using iVRLEs, they remain situated. More research is needed on the development and evaluation of educational scenarios in which affordances of iVRLEs support pedagogically meaningful goals (Dalgarno & Lee, 2010; Fowler, 2015; Herzig, 2014; Hu Au & Lee, 2017; Mikropoulos & Natsis, 2011). Consequently, there is a need to construct a holistic design theory around the educational use of iVRLEs. In this section, the question by Lähtevänoja et al. (2020) of "how iVRLEs should be used as part of the learning path and with other technologies" is explored. The section builds upon the learning outcomes and design principles of iVRLEs but approaches the use from a didactical perspective.

First, the absence of, and need for, didactics in iVRLEs use is discussed. Subsequently, relevant theories on didactical media selection are explored, including a few first attempts at iVR media selection models. Since this thesis aims to construct a framework on the selection and usage of iVRLEs as a didactic medium that can genuinely aid educators in practice, it is also essential to evaluate any differences between practice and theory. The section concludes with the need for more research into the differences between the limited amount of available theory and the practical usage of iVRLEs in education.

2.3.1. Absence of Didactics in iVRLEs

For first-level design knowledge, some studies prove helpful by reporting positive learning outcomes yet remain predominantly situated without exploring their usage conditions: when and how iVRLEs work best and for whom. Additionally, topics and research design often appear to be based on researchers' common-sense (Dalgarno & Lee, 2010) or tenure and promotion portfolios (Cook et al., 2019) instead of didactic theories. As Kirschner et al. (2020) note, "[t]he content and learning goals should determine the choice of media, not the other way around. Technology for the sake of technology is bad practice" (p. 292).

For second-level design knowledge, some researchers have attempted to provide valuable guidelines on types of activities in iVRLEs that can benefit the learning process based on the social and educational affordances of the medium (Dalgarno & Lee, 2010; Steffen et al., 2019). However, these design guidelines only specify possible activities. They do not establish when to use iVRLEs over other media or when to use iVRLEs in the learning process. No single method works well under all conditions, so it is essential to consider why and when specific (iVR-based) methods support learning and why other methods do not (Atkinson, 2000; Berliner, 2002; Commissie Parlementair Onderzoek Onderwijsvernieuwingen, 2008; Cook et al., 2019; "Immersive technology," 2020; Kirschner & van Merriënboer, 2013; Van Merriënboer & Kirschner, 2018). Other methods such as videos or 3D models can, in some instances, achieve the same learning goal at lower effort and costs (Cook et al., 2019; "Immersive technology," 2020). Even "old school" learning by lecturing can be more effective depending on the learning content (Kirschner et al., 2020; Schwartz & Bransford, 1998).

For third-level design knowledge, no studies yet consider the entire learning path around iVRLEs (Lähtevänoja et al., 2020). Similarly, Cook et al. (2019) state the need to "[d]evelop replicable workflows that can be implemented by a variety of stakeholders." Even though the novelty of accessible iVR and the expensiveness of iVR HMDs are good reasons for the absence of holistic iVRLE models, there is a need for research to unite the iVR and education communities (Cook et al., 2019; Dalgarno & Lee, 2010; De Freitas, 2006; Fowler, 2015; "Immersive technology," 2020; Steffen et al., 2019).

2.3.2. Didactics for iVRLEs

This section discusses the link between didactical methods and media, the situational and personal context of learning, and the selection process of a didactical medium. Since an analysis of all available didactical media would be overly extensive, the didactics concentrate on the medium of iVR.

Media as Non-Neutral Didactical Tools. It is a widely shared view in the field of media didactics that a medium does not lead to learning by itself and that manner of application matters substantially (R. E. Clark, 1983; Herzig, 2014; Kirschner et al., 2020; Neelen & Kirschner, 2020). To a degree, didactical methods (e.g., lecture or project work) can be implemented in different media (e.g., face-to-face, online, mobile, iVRLEs) without differences in effectiveness (R. E. Clark, 1983; Kerres, 2018; Kirschner et al., 2020; Peterßen, 2000). However, a medium can be better suited for certain methods, and it is, therefore, essential to carefully consider if the usage of the specific medium improves the efficiency, effectiveness, or enjoyability of the learning process of both the students and teachers (Commissie Parlementair Onderzoek Onderwijsvernieuwingen, 2008; Herzig, 2014; Kirschner et al., 2020). For iVRLEs, the intrinsic characteristics (interactivity and vividness; see p.2) and following affordances (see p.9) define how well it suits with didactical methods.

Besides the fact that a medium can be better suited for a specific instructional method, media (such as iVRLEs) should also not be conceived as neutral learning tools since learning applications have a pedagogical 'intent' baked into them during designing (De Freitas et al., 2010; Southgate, 2020). This non-neutrality is particularly the case for iVRLEs since they allow the design of not just learning tasks but learning experiences as a whole (De Freitas et al., 2010; Southgate, 2020). As Southgate (2020) states: "[iVR applications] are created with a particular vision of the learner and learning process even if, in some cases, this is not overtly explicated or adequately informed by didactical theory." Educators can still use iVR and iVRLE applications in ways contrary to the designed pedagogical intent, but it is vital that they critically evaluate the pedagogical underpinnings (Southgate, 2020).

Situational and Individual Context. Next to evaluating the match of the pedagogical foundation of an iVRLE, educators should evaluate the match between the iVRLE and the context in which it is to be used. Context denotes the system, practical setting, group characteristics, and the personal characteristics (Dengel et al., 2021; Scutt, 2018; Stefanini & Griffiths, 2020). The context is indicated to impact learning effects of media (Commissie Parlementair Onderzoek Onderwijsvernieuwingen, 2008; Herzig, 2014; Lee et al., 2021). Cultural influences, for example, can determine the effectiveness of iVRLEs such as virtual agents (Lee et al., 2021). Regarding individual context, cognitive differences should be assessed based on objective abilities rather than preferred learning styles (e.g., visual, auditory, or kinaesthetic) because abilities are better predictors of how a person learns most effectively (R. E. Clark, 1982; Hattie & Yates, 2014; Kirschner, 2017; Kirschner & van Merriënboer, 2013; Pashler et al., 2009).

Selection Process of a Didactical Medium. Even in a specific educational setting where iVRLEs have a pedagogical benefit, it is essential to follow a holistic selection process to ensure an iVRLE is the best fit. Not using such an inclusive process paves the way for neglecting contextual factors or other didactical media, which would be a better fit for the situation. To ensure that the iVRLE is chosen as the best solution, theories on the design and selection of didactic media are considered.

To ensure the usefulness and usability of educational technology, Kirschner (2002) proposes a design process grounded in user-centered instructional design research. It focuses on the learner's perspective and the influences of physical and cultural constraints of the learner, learning situation, and environment. An example of a constraint of the learning situation is that new courses must consider conventions or learning methods the students are used to. Otherwise, learning a new method poses an extra load on the learner, impairing the learning of the subject content. After constructing a new course or set of materials, the educator should evaluate how learners experience the support, how learners actually use the provided support, and learning outcomes in terms of effectiveness, efficiency, and satisfaction of students and teachers. While being a good design process to ensure the desired learner experience and to consider constraints of the learner, learning situation, and environment, embedding in didactical methods is missing.

To ensure the use of media is based on didactics, Kerres (2018) constructed a number of didactics-based questions to be used in the selection process. The framework suggests that educators consider the educational goals of the situation, applicable learning principles, and characteristics of principles integrated into proven successful instructional methods. To guarantee that the learning method fits into the school and course context, the educators should evaluate the curriculum (supported by (E. A. Johnston et al., 2018)), the structure of the subject, how knowledge will be used vocationally (in later occupation), and the added value of the specific educational medium. The ratio of costs and benefits of the iVRLEs must also be considered. Despite considerable learning benefits, the costs of using iVRLEs can still be too high. While the questions are valuable in assuring that evidence-based didactics are considered within the local context, they do not provide much guidance on the selection criteria or time-related media placement in the learning path.

Specifically for iVRLEs, Southgate (2020) proposed the actionable pedagogy for immersive learning (APIL) framework to help educators take informed action in choosing, using, and reviewing iVR applications. The framework discusses several questions to determine if iVR is indeed the best choice in the educational situation, as well as activities to consider in preparation of and inside of the iVRLE. It is subdivided into a teacher, learner, and technical realm (see Table 1). While being a good checklist and having some good recommendations, advice on how iVRLEs are advised to be positioned in the learning path is missing.

Similar to Southgate (2020), Mulders et al. (2020) created a framework for meaningful iVR use. Valuable design principles that ensure that iVR contributes to learning are provided. These principles have previously been mentioned in this thesis (see p.17). They are (a) learning first, immersion second, (b) providing learning relevant information, (c) segmenting complex tasks in smaller units, (d) guiding immersive learning, (e) building on existing knowledge, and (f) providing constructive learning activities. While the framework by Mulders et al. (2020) provides valuable considerations, it needs support from other models to provide the integration in the didactical process (e.g., when and why to apply it, how to support it).

To determine if iVRLEs should be used instead of other methods, the affordance framework from Bower (2008) is considered. Bower starts with the identification of educational goals based on which suitable learning tasks are created. The required affordances of the learning tasks are then compared to the affordances of the available methods. While providing a solid process to select a medium based on the required affordances and to limit the influence of prejudices, the model needs support from other models to guide the entire instructional design process. Even if a medium suits the affordances best, contextual influences might still limit its practical applicability and effectiveness.

Teacher realm

- Clarify why the iVRLE should be used instead of other technologies or methods (e.g. based on learning affordances and objectives).
- Map out how the iVRLE aligns with the curriculum objectives, scope, and sequence.
- Ascertain whether the iVRLE is used as an experience, tool, a form of media for content creation, or as a total learning environment.
- Assess the imbued pedagogical assumptions in existing iVRLE applications and if these are appropriate for the type of learning you want to enable.
- Reflect on how iVRLEs can help with signature pedagogies (favored ways of teaching in a specific discipline, e.g., field trips for geoscience)

Learner realm

- Consider student familiarity with iVR for leisure and learning.
- Involve students in developing iVRLEs (also to mitigate risks)
- Allow students time to play in the iVRLE to familiarize themselves.
- Guide students through the learning affordances of the iVRLEs and explain how it can enable them to learn.
- Use integrated activities that incorporate student autonomy, collaboration, problem-solving, and creative skills both inside and outside of the iVRLEs. Provide comparable activities for students that do not like or cannot use iVR.

Technical realm

- Consider health and safety information of hardware and appropriateness of software.
- Consider the developmental stage(s) of learners (e.g., in selecting hardware and software).
- Determine spatial, network, and bandwidth requirements of the hardware and software.
- Consider what appropriate social interaction is, and how this can be moderated in the iVRLE application.
- Ascertain if the iVRLE application has useful, accessible learning analytics.

Table 1. Condensed overview of the Actioned Pedagogy for Immersive Learning (APIL) framework by Southgate, E. (2020). *Virtual reality in curriculum and pedagogy: Evidence from secondary classrooms* (1st ed.). Routledge. https://doi.org/https://doi.org/10.4324/9780429291982. Copyright by Routledge.

Similar to Bower (2008) but more holistic is the instructional design model by Tacgin and Dalgarno (2021), which guides appropriate learning strategies facilitated by iVRLEs. Building on the models by Dalgarno and Lee (2010) and Tacgin (2018), they link the technical affordances of iVRLEs with the educational affordances. They support the need for specifications of the target learners, intended learning outcomes, and instructional approach. Valuable connotations are the need to consider the restriction of functionalities depending on the selected iVR hardware and software and use experts from different fields to design iVRLEs. Examples of recommended areas of expertise are instructional designers, graphical designers, educational subject experts, coders, designers, prop creators, sound effects people skilled in hardware integration, and audio/video engineers (Tacgin & Dalgarno, 2021). While supporting the need for thorough analysis before choosing or designing an iVRLE, advice on how it is to be positioned in the learning path is missing.

To guide the placement of iVRLEs in a course sequence, the elaboration framework by Reigeluth (1983) is used. Previously discussed in 2.3.2 Educational Design Principles, it states that both for novice and expert learners, it is recommended to structure the content from simple to complex, general to detailed, or from concrete to abstract to help learners integrate the knowledge into existing knowledge structures (Ausubel, 1960, 1963, 1968; Kirschner et al., 2020; Reigeluth, 1983). By first determining which structure the course uses, appropriate learning tasks can be constructed. The affordances of the learning tasks can then be compared to iVRLEs and other didactical methods to determine the most suitable option. iVRLEs can facilitate learning through simple, concrete examples that could otherwise not be feasible and by making abstract concepts more tangible or practicing a complex skill. Therefore, the placement of an iVRLE in a course sequence depends on its structure and appropriate learning tasks. When a goal of the course is to train learners in a procedure (e.g., to teach or to use a chemistry lab), iVRLEs can be a safe practice environment between theory and the real-life application of the procedure (Kerres, 2018).

Besides basing the placement on the structure and appropriate learning tasks, it is also essential to consider the balance between technology-based and non-technology-based lessons. Even though an iVRLE can function as a total learning environment (Southgate, 2020), it provides a more considerable learning benefit when provided in addition to traditional lessons in line with other computer-based media (Kerres, 2018; Kulik et al., 1986; Tamim et al., 2011; Theelen et al., 2019). The exact balance and integration of iVRLEs in the course depends on the content, context, and required affordances of learning tasks.

The didactical guidelines of the models are integrated with the ADDIE model, an instructional design (ISD) model which helps guide the complete learning path (Gagne et al., 2004, p.21). It is similar to other ISD models (such as (Dick et al., 2015), Smith and Ragan (2004), C. J. Chen (2009), and Seels and Glasgow (1998)), but more streamlined in comparison. The ADDIE model consists of five different phases: (a) analysis, (b) design, (c) development, (d) implementation, and (e) evaluation. Goodwin et al. (2015) applied the ADDIE phases to guide the design, development, and application of iVRLEs. The analysis phase describes the need to determine the instructional context, learning objectives, methods used for the learning experience (tools, technologies, and settings), and how concepts can be grounded in embodied action. The design phase specifies designing the learning experience by integrating environment, context, and instructional aspects and motivating learner interaction with the learning content. For the implementation phase, they suggest to motivate students to actively engage with the iVRLE and its action possibilities to promote learning. Finally, for the evaluation phase, they describe qualitative and quantitative learning assessments, and the modification of the instructional method to address issues or changing needs.

The ADDIE model is frequently used to successfully guide learning facilitated by technology (Alajmi, 2009; Muruganantham, 2015; Patel et al., 2018) and by iVRLEs in specific (Edwards et al., 2019; Fudholi et al., 2020; Hanson & Shelton, 2016; Ramansyah et al., 2020; Yu et al., 2021). However, it should be noted that the developmental process of course material and the accompanied selection of didactical media is not linear. Like all instructional design processes, it is iterative and stages might be skipped, revisited, or conducted in a different order. However, for simplicity in communication and applicability of the framework, the process is described with a linear visualization in the didactics for immersive learning (DIL) framework (see Figure 6).

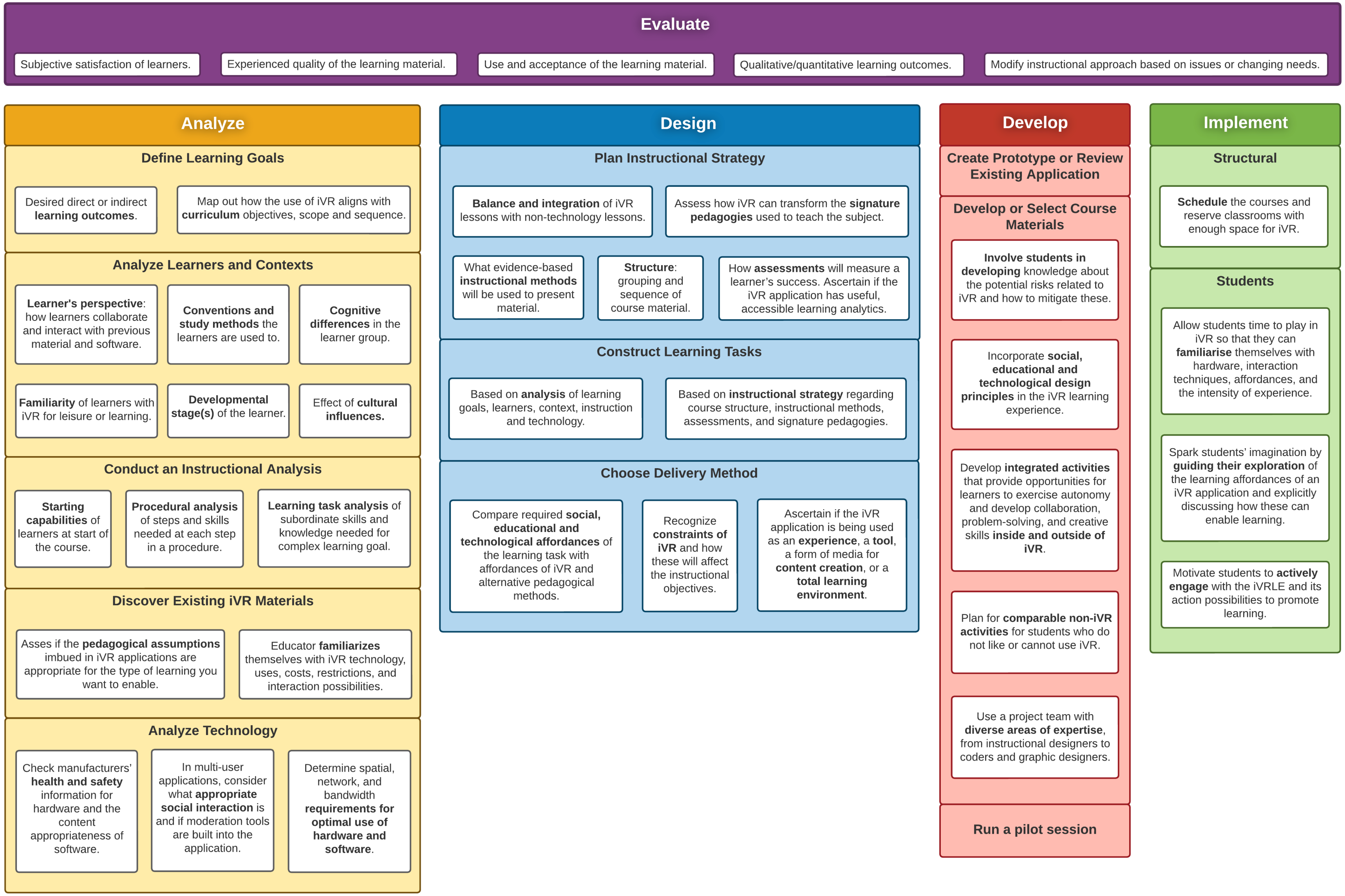

Figure 6. The Didactics for Immersive Learning (DIL) framework guides the decision process and use of iVRLEs as a didactical medium. Based on the ADDIE instructional design model from Gagne et al. (2004) and Goodwin et al. (2015). Didactical theories included from Mulders et al. (2020), Bower (2008), Kirschner et al. (2004), Kirschner and van Merriënboer (2013), Kirschner (2002), Lähtevänoja et al. (2020), Kerres (2018), Reigeluth (1983), Southgate (2020), Stefanini and Griffiths (2020), Hanson and Shelton (2016), Van Merriënboer and Kirschner (2018), Tacgin and Dalgarno (2021), Goodwin et al. (2015) and Lee et al. (2021).

2.3.3. Gap in Research: Teacher Experience

The literature review on didactic media selection provides a number of valuable theories which are combined in the comprehensive DIL framework to guide "*how* iVRLEs should be used as part of the learning path and with other technologies" (see Figure 6). One crucial consideration not included in the framework is the disparity between scientific theories and the daily practice of teaching. After all, a learning theory can have outstanding theoretical performance features, but the didactic benefit remains minimal if learners and teachers do not accept it or do not use it according to its design (Gerstenmaier, 2002; Kerres, 2018; Nuthall, 2007). For the DIL framework to guide evidence-informed practice in a practically applicable and valuable way, the element of teacher experience is essential. Teacher experience is the third and final pillar of evidence-informed practice, next to evidence from scientific research and the context (see Figure 7). The teacher experience is discussed in terms of the adoption time of new theories and media, teaching based on intuition, and increasing complexity of didactical models.

Figure 7. Evidence-informed teaching is based on: (a) the best available evidence from research, (b) the content - system, setting, group, and individual (learner experience and background), and (c) teacher experience, expertise and professional judgement. Since the visualisation is focused on teaching, the Adapted from Stefanini, L., & Griffiths, J. (2020). Addressing the challenges of using evidence in education. *Impact. Journal of the Chartered College of Teaching*, (10). https://impact.chartered.college/article/addressing-the-challenges-using-evidence-education/. Copyright by The Chartered College of Teaching.

Educators' understanding of learning, teaching, and accompanied didactic methods is known to only change slowly over the years (Bischof et al., 2016). Educators progress through phases of awareness, acceptance, and adoption of an innovation (such as iVRLEs) based on intra- and extra-personal factors (Leoste et al., 2021). A portion of the iVRLE adoption insights is summarized, but the holistic process of iVRLE adoption is outside of the scope of this thesis. There is a need for teachers to be provided with resources and support to adapt lesson plans to their classroom specifics (Leoste et al., 2021), and information to help them perceive the educational value of iVRLEs (Leoste et al., 2021; Timmermans, 2021). Educators are more inclined to perceive the educational value if the iVRLE is appropriately aligned with the target group, pedagogical needs and requirements, teaching contents and objectives, as well as learning situation and organization (Commissie Parlementair Onderzoek Onderwijsvernieuwingen, 2008; Kerres, 2018; Timmermans, 2021). This alignment can also be improved by including developers of learning material in the creation of iVRLEs (Timmermans, 2021). The medium of iVR must demonstrate the added value of the media-supported learning offering compared to other established didactical methods, as well as the additional effort associated with the media-supported method. Finally, the efficiency of the proposed solution must be demonstrated by weighing the ratio of costs and benefits of different variants against each other (Kerres, 2018; Leoste et al., 2021; Timmermans, 2021). To conclude, proper conditions are required to both facilitate a learning benefit from the use of iVRLEs, as well as to gather acceptance and adoption by educators.

While differing between teachers, considerable parts of lessons are constructed based on an "intuitional" experiential basis instead of didactic theories. Didactical theories tend to view pedagogical interventions as simple 'input' and 'output' with a focus on effectiveness and tend to neglect the value of pedagogical professionals' judgement about what is educationally desirable in particular situations (Biesta, 2007). As a result, didactics provide valuable interpretative knowledge for teaching processes but do not provide easy-to-use solutions for dealing with specific problems (Reinartz, 2003). Consequently, Reinartz states that didactics should not be expected to influence the practical action of teachers directly. Even if teachers use specific instructional methods, they adapt and modify them for usage in the classroom. As a result, teachers who believe they are using different methods may be doing essentially the same things, and teachers who believe they are using the same method may be doing different things (Nuthall, 2007, p. 32-33). Therefore, it is vital to investigate how educators (would) use the DIL framework in practice and consider inter-teacher variability in teaching style.

Compared to other instructional methods (e.g., face-to-face), digital learning methods can be even more challenging to apply to specific problems since they require more precise planning and allow less flexibility to compensate mistakes or make changes in planning (Kerres, 2018). An educator likely feels less pressured by the need for flexibility when an iVRLE has inbuilt personalization. Additionally, it is recommended to clearly define the role which the iVRLE has in the learning path (e.g., experience, a tool to practice a skill, or method of content creation) and allow the educator a degree of freedom in the use of methods. If circumstances require a change in planning, the explicit role definition helps the educator more easily switch or substitute the iVRLE with other methods that can achieve a similar goal.

In trying to be the best didactic method, existing models of didactic design are becoming more and more complex, making it also increasingly more difficult to implement and to evaluate whether the effort for many analysis steps is actually worthwhile (Kerres, 2018). A large number of analysis steps can cause a cognitive overload for the educator and prevent the realization of learning benefits from the model. As a result, the question is not only whether a theory is true or false, but mainly what pragmatic contribution it can have to the educational problem in the learning path. Given the absence of didactics in iVR, it is likely that DIL framework will aid in guiding the didactical decision and usage of iVR. However, practical research with educators is required to ensure that the model is not too complex.

2.4. Empirical Research Aims

The DIL framework identified and merged diverse instructional design models and didactic theories. It includes the earlier established affordances, learning outcomes, and design principles. While providing scientifically well-grounded guidance on how iVRLEs should be used as part of the learning path and in relation to other technologies, the aspect of teacher experience is still missing. It is necessary to include educators' experience, expertise, and professional judgment to improve the DIL framework to be a valuable and accessible guide to evidence-informed teaching practice. As such, the research question (RQ) is:

RQ: How can teacher iVR-experience be integrated with didactics for immersive learning?

Based on the research question, the following sub-questions (SQs) are identified regarding the current educational use of iVRLEs in practice and educators' evaluation of the DIL framework.

SQ1: What guides the decision of educators to use iVRLEs in education?
SQ2: How do educators integrate iVRLEs in their educational practices?
SQ3: How do educators perceive the complexity of the DIL framework?
SQ4: How would educators put the DIL framework into practice?
SQ5: What could be improved about the DIL framework according to educators?

Based on the literature review of the preliminary iVRLE studies and the established didactical theories, the decision process and the application of iVRLEs are expected to be frequently based on intuitional practice. In this thesis, intuition-based teaching practice is defined as educational practices not based on explicit didactical and contextual analysis. Intuition includes educators' implicit and explicit knowledge gathered through teaching experience. The term thus encompasses more than the tendency of people to "do it as it always has been done." Expected intuitional teaching practice examples are educators using iVR based on methods of other media or educators sticking with habits and not using iVR altogether.

Additionally, the DIL framework is expected to be appreciated for the visual overview of the process, but a portion of educators may see it as too complex. As a result, this would hinder the use of the model in practice. Naturally, a trade-off exists between the applicability and completeness of the model. Therefore, it is of great interest to investigate what teachers think could be improved about the framework. Concretely, the following hypotheses are formulated for the sub-questions.

- H1: Most educators base the decision to use iVRLEs in education on intuition rather than on didactical theories.
- H2: Most educators apply iVRLEs in education based on intuition rather than on didactical theories.
- H3: Most educators appreciate the visual overview of the DIL framework, but some are overwhelmed by the number of elements of the model.
- H4: Educators would use the DIL framework in varying ways, affected by external factors (e.g., school environment) and established habits of using intuitional methods.
- H5: Few educators prefer a more simplified DIL framework that includes examples.

To answer the research question and sub-questions, interviews are conducted with educators who have experience with iVRLEs. The interviews are split into two studies, where the first iteration investigates the experiences of educators who have used iVRLEs in education (sub-questions 1-2), and the second iteration verifies the DIL framework (sub-questions 3-5). A thematic analysis is carried out on the investigation and validation interview studies.

3. Methodology

3.1. Design

Two interview studies were conducted with educators to determine how an instructional design model can be instrumental to educators in the didactically-grounded selection and use of iVRLEs. A qualitative approach was chosen on two grounds, the importance of context and detailed inter-educator variability, and the novelty of the constructed DIL framework. Both interview studies were of a semi-structured nature (Galletta & Cross, 2013), signifying they consisted of open questions at the start and targeted theoretical questions at the end.

The first interview study investigated the sub-questions 1-2: how experienced educators choose and use iVRLEs and how they experience the (flexibility of) use. Interviews were analyzed using a content analysis (Bernard, 2013) which aimed to distill codes of the interview data into overarching themes.

The second interview study investigated the sub-questions 3-5: how educators view (complexity of) the DIL framework, how they would use it, and what could be improved. The DIL framework was constructed based on the literature review and the results of the first interview study. Similar to the first interview study, a content analysis was used for analysis.

After the first and second interview study, the interviews were used to revise and finalize the DIL framework (see Figure 8 for the complete research timeline).

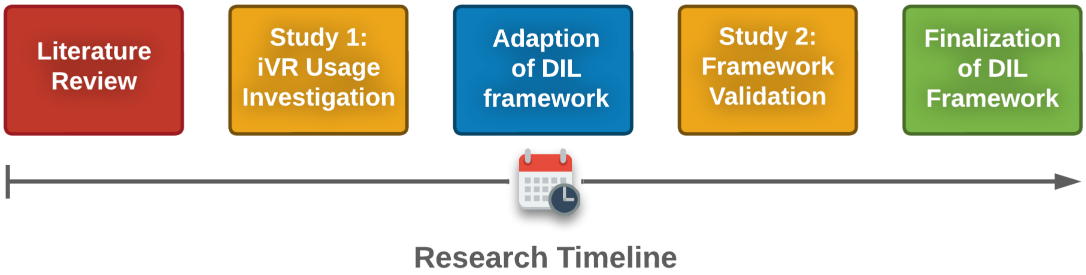

Figure 8. The research timeline of this thesis.

3.2. Participants

Study 1

After receiving ethical clearance for the first interview study, 16 participants were recruited through contacting Dutch tertiary education institutions and a post in a Dutch magazine aimed at professionals in education. The number of participants satisfied the aim of 12 participants to reach data saturation for qualitative analysis (Clarke & Braun, 2013; Fugard & Potts, 2015; Guest et al., 2006). Their experience with iVRLEs in education ranged from 0 to 15 years ($m = 3.0$, $\sigma = 3.52$), with a median of 2 years. The sample was diverse regarding educational level, with two participants from VMBO (preparatory secondary vocational education), one participant from MBO (post-secondary vocational education), eight participants from HBO (higher vocational education), two participants from universities, one participant from a (non-)immersive VR company, and one consultant for educational iVR. Quotes from Dutch participants were translated from to English.

Study 2

After receiving ethical clearance for the second interview study, five participants were recruited through the network of the researcher and the teachers from the first interview study. The number of participants was based on feasibility, suggesting further (practical) follow-up research. The participants' teaching experience ranged from 3 to 11 years ($m = 6.00$, $\sigma = 3.08$), with a median of 6 years. The sample was diverse regarding educational level, with two participants from HAVO/VWO (higher general secondary education/pre-university education), one participant from gymnasium (pre-university education), one participant from MBO (post-secondary vocational education), and one participant from a university.

3.3. Procedure and Data Collection

Study 1

Before the interview, participants read and agreed with the informed consent form (see Appendix A.1.) that stated what data would be collected, how data would be anonymized and stored, and that their participation was voluntary. Participants were informed that data was collected through audio recordings and that they had the possibility to withdraw their data up to 24 hours after the interview was recorded.

Before the first interview study was conducted, the constructed questions were tested and reflected on by both supervisors and an independent researcher in the field of educational iVRLEs. Due to covid-19 restrictions, all but two interviews were conducted online. The researcher took a Covid-19 test before the face-to-face interview with participants. Additionally, to limit the risk of spreading Covid-19, the researcher wore an FFP2 mask and kept a 1.5-meter distance during the interview.

The first semi-structured interview study lasted 60 minutes and consisted of three segments (see Appendix B.1.): an opening segment which included broad, open questions, a middle segment with more specific questions, and a concluding segment that included reflexive questions. The benefit of using the form of a semi-structured interview is the attention to personal experience while also considering theoretically driven variables of interest (Galletta & Cross, 2013). Firstly, the open questions explored the educational background of the participant and the choice of using certain media in their lessons (SQ1). Secondly, the specific questions explored explicit learning goals for using media (SQ1) and how participants used iVRLEs in their lessons (SQ2). Thirdly, the reflexive questions explored the participant's satisfaction with their selection process (SQ1) and use (SQ2) of didactical media compared to theoretical models. Next, the participant was asked for their recommendations for educators who want to start using iVRLEs. Finally, they were asked how they preferred to be aided with the didactically-grounded selection and use of iVRLEs. The participant had the opportunity to touch on any points of interest that were not discussed.

After completing the interview, participants were thanked for their contribution to the study and given a €10 book voucher as a token of appreciation. Once the interview was completed, the audio recording was transcripted, and the data was anonymized to prepare for the analysis.

Study 2

Before the interview, participants read and agreed with the informed consent form (see Appendix A.2.) that stated what data would be collected, how data would be anonymized and stored, and that their participation was voluntary. Participants were informed that data was collected through summarizing notes by the researcher and that they had the possibility to withdraw their data up to 24 hours after the interview was recorded.

Before the second interview study was conducted, the constructed questions were tested and reflected on by both supervisors. Due to covid-19 restrictions, all but one interviews were conducted online. The researcher took a Covid-19 test before the face-to-face interview with participants. Additionally, to limit the risk of spreading Covid-19, the researcher wore an FFP2 mask and kept a 1.5-meter distance during the interview.

The second semi-structured interview study for verification lasted 30 minutes and consisted of three segments (see Appendix B.2.): an opening segments which included introductory questions about the teachers' background, a middle segment with questions about the DIL framework, and a concluding segment with reflections on future use of iVR and the DIL framework. First, the introductory questions explored the educational background of the participants, and whether they had experience with iVR in their lessons. Secondly, the questions about the DIL framework explored understanding, recognizability, and prioritization of the framework elements (SQ3). Here, the DIL framework included the changes made after the first interview study. Thirdly, the reflexive questions explored participants' views on didactical iVR use in the future, usage of the DIL framework as support for iVR use (SQ4), and possible framework improvements (SQ5). In the end, participants had the option to share any additional thoughts.

After completing the interview, participants were thanked for their contribution to the study and given a €5 book voucher as a token of appreciation. Once the interview was completed, the data was anonymized to prepare for the analysis.

3.4. Analysis

Study 1

Interview audio recordings were analyzed using a content analysis (Bernard, 2013) to generate codes for pieces of interview data which later were sorted into overarching themes. Content analysis is a qualitative data analysis method where verbal or behavioral data is classified, summarized, and tabulated. Commonly, a theory or set of hypotheses is tested.

The first interview study explored how educators choose and use iVRLEs and whether educators follow an instructional model for this process. At the start of the content-analysis (Bernard, 2013), variables were created based on the theoretical categories and systematically applied to the interview transcriptions. The data was then systematically searched for elements in the data that confirmed or rejected the hypotheses (Gronmo, 2020) that educators often use intuitional techniques in selecting and using media (SQ1 and SQ2; see Appendix C.1.). As patterns within the categories emerged, they were compared and linked together using a visual correlation model. Supplementary to the analysis of the hypotheses, exploratory themes were explored regarding details of the decision and usage process of iVRLEs. The reliability of the codes and themes was verified on the basis of a random selection by the second supervisor, during which no disagreements were found.

Next to coding reliability, a reliability factor of the data is interference by the researcher during the interviews, which can be caused by a misplaced probe, expression of emotion relating to a participant's story, or an exploration of a theme that is emerging but did not serve the interview well (Galletta & Cross, 2013). At times a participant would explore a theme that did not suit the interview well (e.g., frustration with current educational curriculum or program offerings by a company). In these situations, the topic was shortly explored before moving back to the interview questions. No other interferences were ascertained within the research activities or relationships between researcher and participants. All things considered, high code reliability and low researcher interference were found, in part due to the semi-structured form of the interviews, which had a solid theoretical basis.

Study 2

The verification interviews were analyzed using a content analysis (Bernard, 2013) to generate codes for (pieces of) interview question answers which later were sorted into overarching themes. On grounds of feasibility, the data consisted of the participants' answers summarized by the researcher during the interview under observation of the interviewee (see Appendix C.2.). The DIL framework and the related hypotheses were tested with the outcome of the content analysis.

In the second interview study, it was explored how educators view the DIL framework, how they would use it, and what they think could be improved. At the start of the content-analysis (Bernard, 2013), variables were created based on the theoretical categories and systematically applied to the interview answers. The data was then systematically searched for elements in the data that confirmed or rejected the hypotheses (Gronmo, 2020) that the framework was too complex (SQ3), that external factors and established intuitional teaching practice habits would influence the use of the DIL framework (SQ4), and that some educators prefer a simpler framework (SQ5). The reliability of the codes and themes was verified on the basis of a random selection by the second supervisor, during which no disagreements were found.

Next to coding reliability, a reliability factor of the data is interference by the researcher during the interviews, which can be caused by a misplaced probe, expression of emotion relating to a participant's story, or an exploration of a theme that is emerging but did not serve the interview well (Galletta & Cross, 2013). No interferences were ascertained within the research activities or relationships between researcher and participants. All things considered, high code reliability and low researcher interference were found, in part due to the structured form of the interviews, which had a solid theoretical basis.

4. Study 1 - The Role of Didactics in Introducing iVR in the Classroom

The DIL framework was updated with the results of the first interview study before conducting the second interview study, the two studies have therefore been divided into two sections with respective results and discussion.

4.1. Results

The interviews revealed two pathways of implementation (see Figure 9). A direct pathway existed for educators who did not explicitly consider didactics nor affordances and immediately moved to the implementation part. An indirect pathway existed for educators who (usually explicitly) considered didactics, as they tended to base the implementation of iVR on its affordances more frequently.

First, the background of the selection and usage of iVR is discussed. After this, the affordances mentioned by participants are discussed. Finally, how iVR was used in practice by educators is explored.

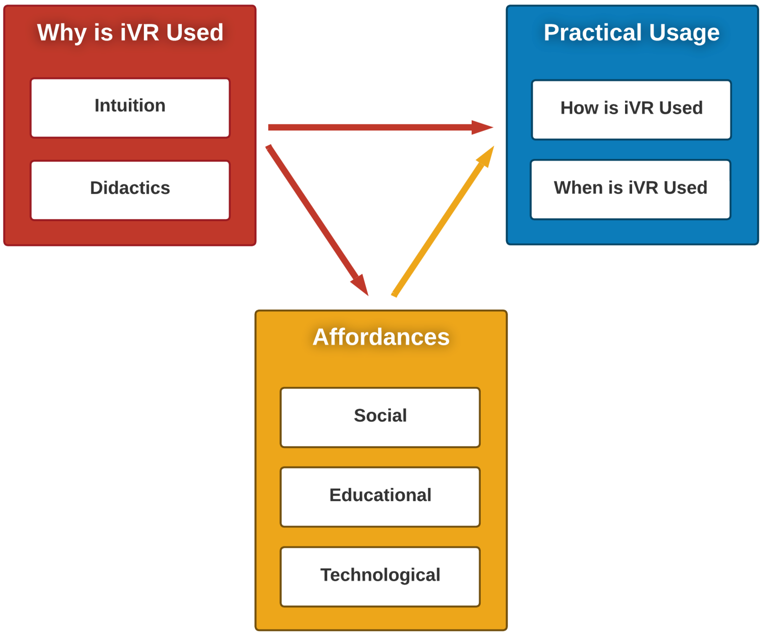

Figure 9. Overview of the results. Didactical iVR use was frequently mediated by iVR affordances. At times, intuitional iVR use was also mediated by these affordances. Some educators did not consider affordances of iVR in the decision process or use.

4.1.1. Selecting and Using iVR: Intuition Versus Didactics

Intuitional iVR use. From the interviews emerged that educators use iVR based on intuition. They tend to stick to familiar methods and need to be made enthusiastic about overcoming experienced barriers and using iVRLEs in their lessons. When educators overcome the challenges and use iVRLEs, they rarely explicitly consider didactics.

Theme: Educators Need to be Motivated and Supported to use iVR. Participants used various lines of reasoning for sticking to familiar methods and needing to be motivated and supported to use iVR. Firstly, educators reported their and colleagues' tendency to stay within their comfort zone, a common inclination for humans. A prime example of this was the desire of educators to stand above the learning content, which is naturally more difficult with iVR being a novel didactical medium with which they have to get familiar. One educator from preparatory secondary vocational education (technology) argued that educators should, nevertheless, let go of the security of their usual methods and open up to learning about iVR:

> [T]he teacher always wants to stand above the learning content, so they want to know exactly what the app is about. Yeah, while I think, if you want that, then you will never get there. ... You cannot know everything anymore, and if you admit as a teacher that you do not know everything, then a world opens up for you. (P1, preparatory secondary

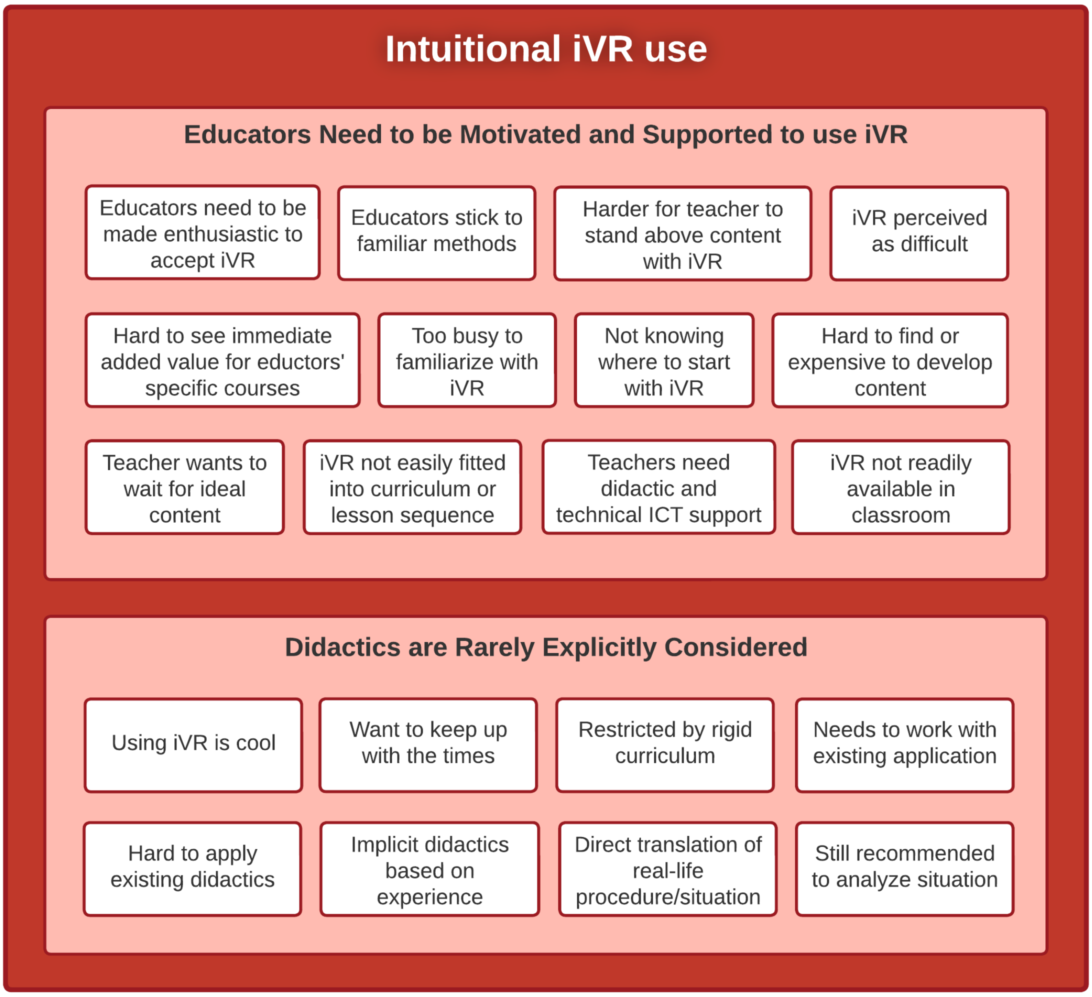

Figure 10. Results of thematic analysis of study one. Theme: iVR use based on intuition.

vocational education - technology, 3 years of iVR experience)

An essential factor that heightened the threshold of moving beyond familiar methods was the perceived difficulty of using iVR. The perceived difficulty in using iVR focused on the practical use of the technology (e.g., loading the correct scenario on the iVR HMD). As stated by P4 (primary and secondary education consultant, 5 years of iVR experience): "They [educators] all think that it [iVR] is very difficult, that a lot can go wrong..." The perceived difficulty was related to insufficient iVR information and training from the educators' educational environment and to the hesitation of educators to experiment with the technology and learn from mistakes.

From a didactical perspective, educators also struggled with perceiving the immediate added value of iVR for their specific course. Learning benefits for general use of iVRLEs or unrelated topics was not sufficient for educators to consider using the technology themselves. Educators struggled to learn from research on iVR benefits due to a lack of time, a low number of studies, and limitations in the studies. IVR was also more difficult to comprehend for educators since the technology was substantially different from the educational media they were familiar with. As a result, educators had to be convinced of the added values, as stated by P11 (higher vocational education - healthcare technology, 6 years of iVR experience): "... you have to convince people of the added value of that [iVR]." Participants mentioned that the best method to show and convince educators of iVR learning benefits was to give them hands-on experience with the technology through training/introduction sessions, as mentioned by an iVR consultant for primary and secondary education:

> [T]he teacher has to see the added immediate value [of iVR] for ... their own course. So not for VR in general... They accept this most effectively by experiencing it themselves, ...for example, through an introduction session. (P4, primary and secondary education consultant, 5 years of iVR experience).

One major contributor to educators' struggle with iVR was the lack of time to familiarize themselves with the technology. P10 (higher vocational education - applied psychology, 2 years of iVR experience) stated: "Teachers are often busy." This challenge is supported by P15 (higher vocational education - nursing, 1 year of iVR experience), who also mentions that preparation time is already too short for familiar methods: "[Y]ou get a number of hours to prepare the lessons, and that is already too short. Teachers are under enormous pressure already, and then something new [iVR] is added." While a large part of the time pressure was caused by governmental rules and the educational environment of the educators, it also appeared to be influenced by the educators' personalities. Educators who are adept at prioritizing and focusing on topics they enjoy find fewer issues with integrating iVR in their lessons, as stated by P9 (higher vocational education - nursing, 15 years of iVR experience): "[T]his is prioritizing. You can do everything you want. If you keep saying you are busy, then you will maybe also keep thinking you are busy."

Even when educators were motivated to explore the use of iVR, a barrier to using the technology was that they had a hard time knowing where to start with iVRLEs. The main challenge was the technological aspect of iVR, where educators struggled with the tough choice of which technology they should use. Not to mention the consideration of which applications are available on which platform and the expected future reliability of the different platforms. Next to the technological aspect, educators experienced difficulty with determining how to apply the technology in their lessons. The struggle by educators in exploring iVR as a didactical medium is stressed by an educator from higher vocational education (applied psychology):

> A lot of teachers would not know where to start with using VR in education, like which technology do you use, which tasks are available? ... How expensive is it? (P10, higher vocational education - applied psychology, 2 years of iVR experience).

Closely related to not knowing where to start with iVRLEs were the difficulties finding or developing content for iVR. Multiple participants stated it was difficult to find good didactical content for iVR that they could use in their lessons. Up to date, little content has been developed due to the relative novelty of iVR in education. This absence was mentioned by P9 (higher vocational education - nursing, 15 years of iVR experience):

"There is almost no good content yet." Any available content could seem unattractive for educators because of the language (e.g., only available in English) or limited customizability. P1 (preparatory secondary vocational education - technology, 3 years of iVR experience) explained: "A lot of content is in English and often not customizable." Since limited content is available, the other option would be to develop content for iVR, which remains very expensive, as said by P1: "The content for VR is very expensive to develop, so that is a problem." Interviewees also mentioned that some colleagues postponed using iVR because they waited for ideal content. In light of this, most interviewed educators stressed the need to start minimally workable applications, which could already have a didactic benefit for the learning process.

Educators motivated to try iVR also experienced difficulties integrating it into the existing lesson sequence and curriculum. A significant reason for this was the rigidity of the curriculum, which was often set for multiple years without much room for individual educators to make decisions or changes. The struggle is described by P11 (higher vocational education - healthcare technology, 6 years of iVR experience): "During curriculum development, these things [learning goals] were of course considered, ... but now with VR you build something, and it then has to be crammed into an existing lesson plan."

Both educators who were motivated and wanted to use iVR and educators who already used iVR expressed the need for improved ICT support. Support is required regarding the technical aspects of iVR technology, such as troubleshooting when something goes awry, helping the educators prepare the correct iVR application, and maintaining the iVR HMDs (e.g., updating, charging, repairing). Next to technical support, educators also called for media-didactical assistance with integrating iVRLEs into their lesson plans. Participants often described that they are responsible for these technical and didactical tasks, adding to their workload. One educator was even responsible for the maintenance and troubleshooting of all the iVR equipment due to his personal interest and knowledge (P9, higher vocational education - nursing, 15 years of iVR experience): "[A]ll of that [updating, troubleshooting of iVR headsets] I have to do myself now. But yeah, that could be better supported."

Even though some educators were motivated and had iVR technology available, they often still did not use it because they had to exert more effort to retrieve the headsets and use iVRLEs in their lessons. Since traditional methods were more readily available, they frequently resorted to these less labor-intensive methods. Educators often had extensive experience with traditional methods, which further decreased the effort of using them. Examples of traditional methods mentioned were books, PowerPoints, images, and videos. The effort of retrieving the headset, as well as restrictions due to limited amounts of available headsets, was stated by one educator from preparatory secondary vocational education (technology):

> The teacher doesn't use it because he has to retrieve the headset, ... and also only has one or five headsets. Yeah, ... then it is way easier to show an image or a YouTube video. (P1, preparatory secondary vocational education - technology, 3 years of iVR experience)

Theme: Didactics are Rarely Explicitly Considered When educators do use iVRLEs, they rarely explicitly consider didactics. Some educators report affective reasons for using iVR, such as believing that iVR is an appealing technology (P9): "I just think it is a very cool technology." Another affective argument was wanting to keep up with the times. P15 explained: "Given my age, I would like to keep up with the times as long as possible." Only some educators were aware of their tendency to use methods based on their feelings, like P1: "I base the materials I use more on my feelings than on a didactical model."

Other educators do not explicitly consider didactics because of restrictions caused by the rigid curriculum within which they have to design their lesson sequences. Additionally, it is more difficult for educators to use an established didactical framework when they make use of an existing educational iVR application (P4): "We have to search how we can combine that [existing didactics] with the complexity of an existing application." A minority of educators report not explicitly having considered didactics because they struggled with applying existing didactics to the new medium of iVR, as stated by P12 (tertiary teaching education, 2 years of iVR experience): "for iVR, I really missed the didactical embedding [in literature]."

Predominantly, educators mentioned that they implicitly considered didactics. They relied on their teaching experience or "simply" translated the real-life situation/procedure. As exemplified by P3 (VR company, 1 year of iVR experience): "My experience is that professors have done things a certain way for a very long time." Some educators did research available iVR didactics after deciding to use the technology but still initially based their decision on their teaching skills:

> I have been taught to design good education with my teaching skills, fitting for the situation of a student and with the materials, you have at hand. Then you do not start from the theory, ...[however] I do hope that the PABO [teachers' college for primary education] was built like that [based on theory]... (P12, tertiary teaching education, 2 years of iVR experience)

Surprisingly, teachers who did not explicitly consider didactics still frequently stressed the need for an extensive investigation (e.g., skill decomposition) to decide whether iVR was the answer to the learning situation. P2 (higher vocational education - therapy, 2 years of iVR experience) exemplified this need: "Use it [iVR] in a targeted way and also see if VR is the answer to the question you have." Both context and learning goals were mentioned as part of the analysis.

To summarize, for educators, a personal interest in iVR, openness to experimenting and learning through mistakes, and the ability and position to prioritize and make time for projects they are interested in were positively correlated with iVR use. Educational environments had a positive or negative effect on iVR-use depending on the facilitation of ICT support (technical and didactical), curriculum tightness, and available time/resources for didactical innovations.

iVR use Based on Didactics. Next to intuitional teaching practice, some educators based the use of iVRLEs on explicit didactics. Two sub-themes were found in the didactic use of iVRLEs. First, to apply appropriate didactics, educators suggested conducting a thorough analysis of the situation. Second, as previously mentioned, they experienced using (existing) didactics to iVRLEs as complex. Therefore, to guarantee the didactical and consistent use of iVRLEs, they suggested including the medium and relevant didactics in the curriculum.

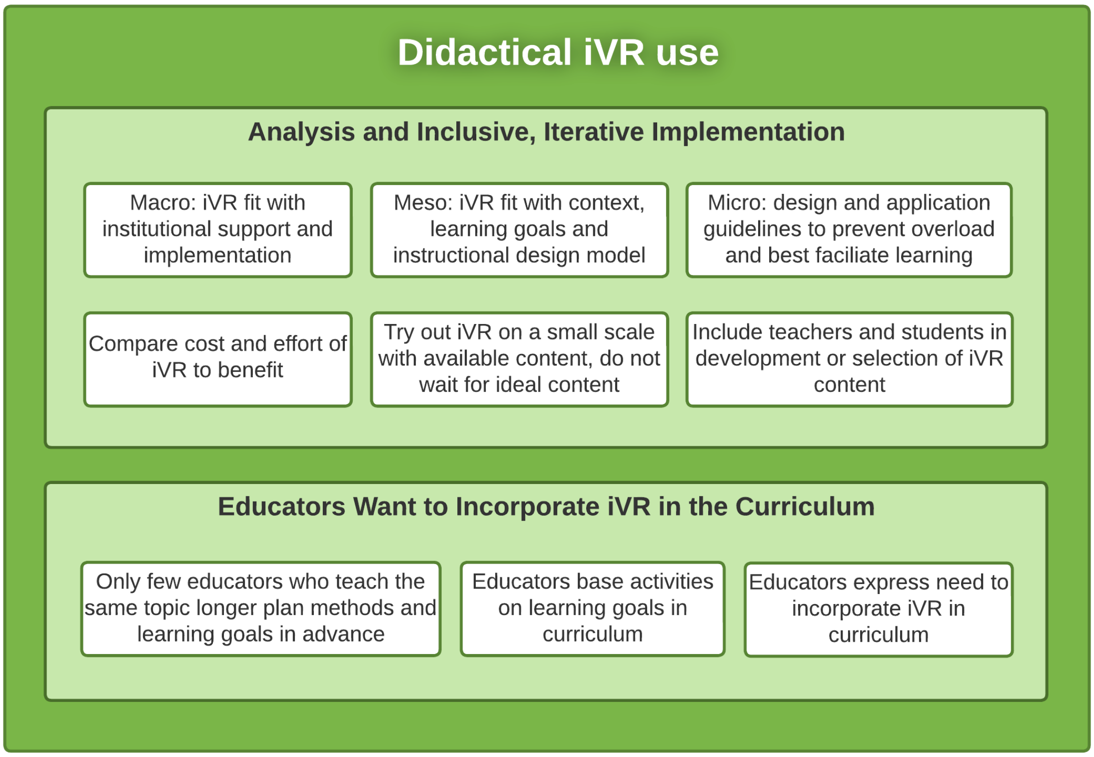

Figure 11. Results of thematic analysis of study one. Theme: iVR use based on didactics.

Theme: Analysis and Inclusive, Iterative Implementation. When educators based the use of iVR on didactics, they supported this through analysis and inclusive, iterative implementation. Different types of analysis were mentioned, which could be divided into macro, meso, and micro-levels (P5). The macro-level involved the educational institution and how iVR can be implemented and supported (e.g., by the ICT department). The meso-level regarded the design process of the course where iVR should fit with the learning goals and desired instructional methods. Most situated is the micro-level, which denoted the design and application of specific iVRLEs inside lessons (e.g., preventing cognitive overload when using the application. It is crucial to start with the educational needs on each level and only then determine which medium fits, as mentioned by an educator from higher vocational education (digital innovations):

> Macro is the entire organization, meso is the curriculum level, and micro is within a course. Within a course, you have the learning outcomes, and you translate these to content and activities. As soon as you consider the activities, then you are going to look at which medium [fits], and then you have to consider per course whether it fits the big picture. (P5, higher vocational education - digital innovations, 1 year of iVR experience)

A combination of multiple levels stated by multiple interviewees was the balance of costs and efforts involved with iVRLEs compared to the educational benefits. Especially if the educational institution needs to license or develop simulations for iVR, the funds required might be used more effectively by investing in other didactical methods or educational support systems. Even if iVRLEs provided a significant benefit to the learning process, they could still be considered too expensive, as stated by one educator from higher vocational education (social studies):

> Now I have simulations...they last five to six minutes, and a student learns to understand the concepts better. If you look at the whole module, that is four, five ECTs [The European Credit Transfer and Accumulation System, equal to 140 hours]. So if you calculate how many costs you make for the VR and how much it adds to the education in the entire module, then that is very small. So then it might be better to say, for those €4.000 per year which the simulations would cost, we are just going to look for better materials. (P7, higher vocational education - social studies, 2 years of iVR experience)

When iVR was determined as a suitable and cost-effective medium, the application needed to consider the context in which it would be used. To achieve this, educators included teachers and students in selecting and developing iVR learning content. One educator (P2, higher vocational education - therapy, 2 years of iVR experience) described their process: "I composed a group of people of nine different healthcare study programs, and they were allowed to bring a student ambassador or a curriculum designer. With them, I sat down, and together we made the design for the simulation." The development of educational applications was usually the role of curriculum commissions or other teams from the educational institution, so the teacher had a limited role in this. In selecting existing content, inclusivity was deemed easier, depicted by various educators who involved students in exploring existing applications that would be suitable and educational for their course (P2, P3, P9, and P11).

Additionally, in the iVRLE design process, participants suggested to trying out the technology on a small scale with available content before developing a large-scale application. Interviewees also recommended that educators experiment with available iVRLEs content on a small scale before buying more iVR HMDs or solidifying the position of the medium in the lesson sequence. This try-out gives educators and designers valuable information about the context in which the iVRLE will be used. The final iVRLE design could be adapted using this knowledge, and the macro, meso, and micro levels of implementation could be adapted to fit the needs of teachers and students best:

> Start small, start with something that has an obvious added value and which you trust in yourself... So that the success experience for yourself [the educator] and for your students is immediately significant, because if it disappoints the first time, there is a large chance it will never be used again. (P4, primary and secondary education consultant, 5 years of iVR experience)

This experimental try-out phase was also recommended to avoid educators waiting for the ideal iVR content while their learning goals can already be achieved with available materials. Ideal content for educators was exemplified by very realistic scenarios or a wide range of (interactive) functionalities from the onset of using the iVRLE. This tendency was experienced by individual educators looking to develop iVRLEs for their course and colleagues of iVR-experienced interviewees who were reluctant to try iVR and wanted to wait for ideal content. One educator from tertiary education (teaching education) also struggled with this tendency and came to the following realization:

> What is the basis, and what do you minimally need to achieve the same goal? Maybe also,

> what is the first easy module upon which you can build further... First, try out whether the smaller situation...also just works. What is minimally needed and what is nice to have? (P12, tertiary teaching education, 2 years of iVR experience)

Theme: Educators Want to Incorporate iVR in the Curriculum. Most educators reported not having time to plan learning goals and educational methods and media in advance, leading to the advice to include iVR in the curriculum for consistent and didactical application. The lack of time for educators to plan ahead was caused by the limited time designated for planning by educational institutions. Only a few educators manage to plan learning goals and methods in advance, as mentioned by an educator from higher vocational education (healthcare technology):

> There are also people who ... work with plans of learning goals and methods worked out in advance. But they are people who do the same thing for years, I think because otherwise it is too time-intensive. (P11, higher vocational education - healthcare technology, 6 years of iVR experience)

To limit the time investment needed to figure out how to use iVRLEs in a didactically-grounded way, educators explicitly stated their request to include iVR in the curriculum. The curriculum could then help with methods, learning goals, and activities suitable for the specific study program. Merely supplying educators with manuals and guidelines on how to use iVRLEs was insufficient, stressing the need to include it in the official curriculum. As mentioned, curricula are often set for multiple years, with few updates by the educational institution along the way. As a result, it is common that curricula are considered too inflexible to new didactic innovations such as iVR. The need for curriculum integration is exemplified by P2, who underestimated how difficult it would be to help educators consistently and didactically use iVR without incorporation in the official curriculum:

> [W]hat happens now is that it is a kind of gadget ... and then we go back [to the familiar methods]. If you want to integrate it [iVRLEs] sustainably, ... you need ground it with the curriculum commission. Now it is still too reliant on teachers who like it. I also thought too easily about it, because I wrote [voluntarily usable] manuals for the lessons plans. But yeah it does not work like that, and only the teachers who were involved from the beginning integrate it [iVRLEs] in their lessons consistently. (P2, higher vocational education - educational technology ambassador, 2 years of iVR experience).

Besides the concrete support of didactical iVR use, educators also mentioned the importance of feeling supported by their educational institution. One educational VR consultant (P4) mentions: “They [teachers] want to have support and feel supported within the policies, they want to see that VR is included in the pedagogical project of the school.”

Remarkably, the need to incorporate iVR in the curriculum contrasted with the expression of educators that they are unhappy with current curricula because these are too rigid and do not have any room for individual decisions (e.g., to include iVR in the course). A frustration that participants mentioned was the long period for which the curricula were set in stone, limiting the possibilities to update it even if a new method proved to be didactically beneficial (e.g., iVR in certain educational situations). A subset of educators also expressed their general discontent with the strict and overly-comprehensive curriculum since this also limited them in adjusting learning content to their teaching style, the context, and the specific students.

All in all, several educators considered didactics by conducting an extensive analysis of the benefits of applying iVRLEs and how this medium should be implemented. They included relevant teachers and students during the selection or development to ensure the iVRLE fit the contextual needs. However, both on the grounds of individual differences between educators and generally limited resources (e.g., time and funding), they recommended that iVR be integrated into the curriculum. Only this way would the didactical and consistent use of iVRLEs be guaranteed.

4.1.2. Educational, Social and Technological Affordances

Participants were asked for the learning goals afforded by the iVRLEs that they had used. The mentioned learning goals were structured under the same overarching themes as the social and educational affordances in the literature review (p.12) and can be seen in Figure 12.

Recreate Aspects of the Physical World. Skill practice was frequently mentioned by participants as a goal of using an iVRLE. Within these environments, both procedural skills and human-interaction-based soft skills were facilitated. Comparatively, the procedural skills were most common because these were easier to simulate than human interaction, as stated by P4: "Education is usually behind the industry, while the industry screams for well-educated people. ... The first [iVRLE] applications are focused on that. Comparatively there is a prevalence of procedural hard skills compared to soft skills." Metacognitive procedural skills were also facilitated by iVR, as in P13, who supplied environmental psychology students with virtual environments which they had to evaluate and improve. Different forms of iVR could be used depending on the learning goals and students' familiarity with the topic. As stated by P9:

> To show how to measure blood pressure with a patient, [allow students to] look around in a [hospital] room ... we use the 360-degree videos with decisions and later we use avatars [in iVR] for higher order practice. The VR element is there first so students will do well in real-life situations. (P9, higher vocational education - nursing, 15 years of iVR experience)

Contextual information was used during the immersive learning experience to facilitate learners' development of comprehensive and practically applicable knowledge (e.g., in practicing skills or applying acquired knowledge). By allowing learners to practice and experiment in a realistic environment, they could develop personal strategies and confidence for handling real-world situations. P12 exemplified this facilitation of experimentation:

> [iVR was used to] teach [primary education] classroom-management skills, to experiment with different methods of drawing attention and maintaining order. For me the most important was that students could find their own way and try different strategies... in a realistic setting. (P12, tertiary teaching education, 2 years of iVR experience)

Participants deemed reduced resource costs important since educational budgets were commonly perceived as being strict. When the iVRLE application did not provide a benefit in terms of monetary or effort-related costs, it had to provide an obvious and sig-

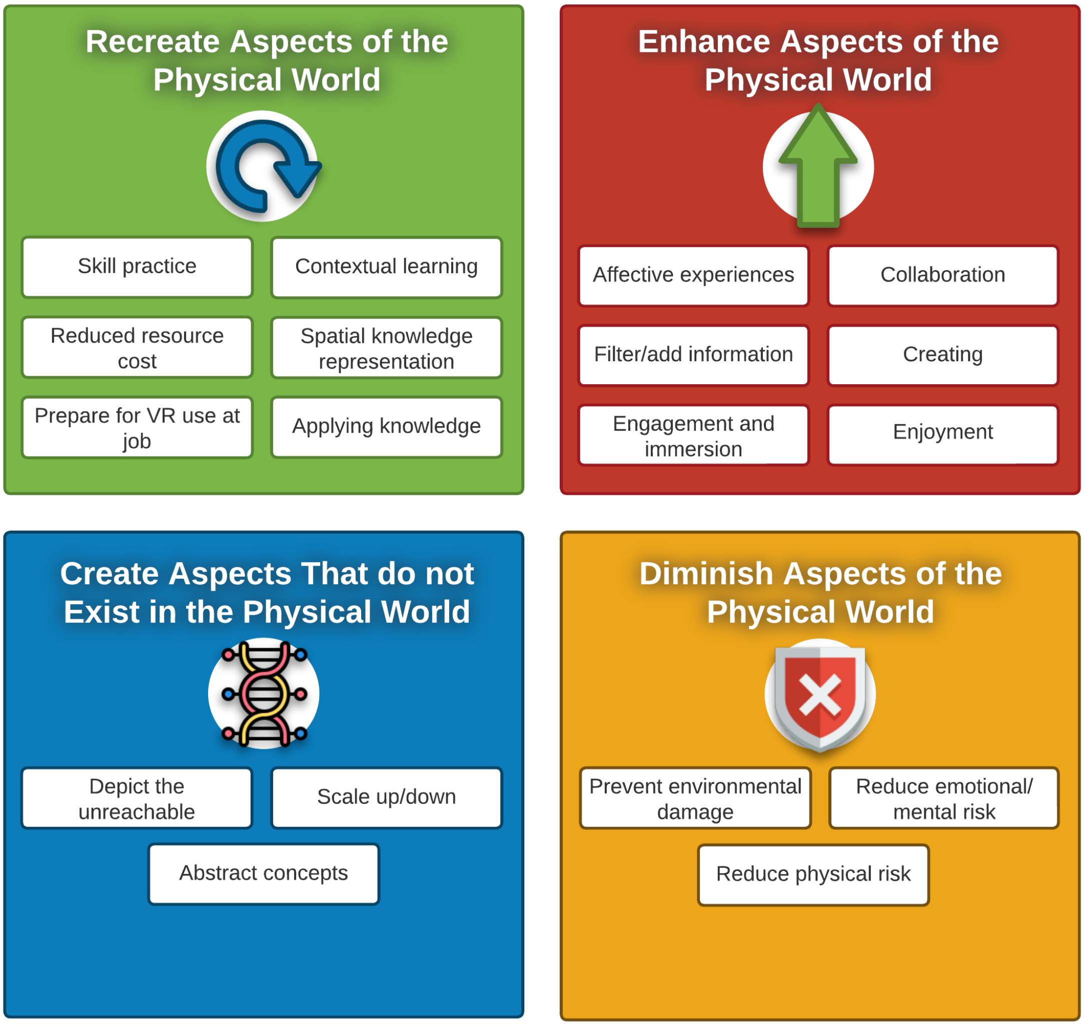

Figure 12. Results of thematic analysis of study one. Theme: learning goals and affordances of iVRLEs.

nificant educational benefit before being deemed worthwhile to use. In several situations, iVRLEs realized a reduction in resource costs. Resource costs decreases were exemplified by replacing or providing additional experiences related to physical laboratories (P3) or field trips (P13):

> [P]rofessors have actually used this [simulations] to cut costs, in the US, we have a university that has been able to cut the price of the study because they use [company name] so that they spilled and broke and used the lab so much more effectively. (P3, VR company, 1 year of iVR experience)

> I think education can become a lot more interesting if they use this [iVR] more. It should not be at the cost of real-life experience that students gain, but you can make the lessons of the study a lot more interesting with it. You can use situations where you cannot come

in real-life, because it is infeasible with large [student] numbers, not allowed, too far away, or too expensive. (P13, higher vocational education - work and organizational psychology, 2 years of iVR experience)

IVRLEs facilitated spatial knowledge representation. The material was more understandable for students, and teachers experienced teaching as more straightforward due to the easily navigable 3D nature of the subject matter. P3 mentioned that interactable simulations (2D and iVR) were used to teach students about molecules in chemistry (e.g., interaction of bases and acids). Another participant (P9) had positive experiences with using iVRLEs for a lecture on human anatomy:

I notice that the knowledge [when using iVR] sticks a lot better and that people see better what happens than if you were to get it from a book. I can explain it a lot easier and shorter ... using the visual thing where people look at and walk around. (P9, higher vocational education - nursing, 15 years of iVR experience)

Preparing for iVR use at a later job was a goal for several participants. Participants mentioned educating students on the possible use of technology for teaching in secondary education, healthcare education, and the healthcare workplace (e.g., assistance for addiction). P7 exemplified the need to educate students about the methodological and ethical implications of iVR:

We are going to see what really happens in the work field. What is interesting for professionals and what should we teach our students about using the technology [iVR] and its possibilities. So we make choices based on what they will encounter in their job and which skills and knowledge they need for that. ... And that they can make responsible methodological and ethical choices from the perspective of their occupation. (P7, higher vocational education - social studies, 2 years of iVR experience)

Applying knowledge was also used in educational situations unrelated to procedural or soft skills. Skill practice inherently incorporates the application of knowledge. However, the specific sub-theme of applying knowledge referred to using iVRLEs for fundamental knowledge, e.g., P3 mentioned applying knowledge of the different molecules to a (2D and iVR) simulation to help students solidify their knowledge. Applying knowledge could also be parallel to skill practice in the form of fellow students giving feedback to a student practicing a skill in iVR. P12 exemplified this by having peers give feedback on the teaching skills of the active learner in the iVRLE:

We had the intention to work with groups of 4 students, so when they came to the lab we also had a large screen so that the other students [when not in the iVRLE] could also watch along. We also had an observation form for that ... so they could give feedback and the student [who was in the iVRLE] could immediately apply it. (P12, tertiary teaching education, 2 years of iVR experience)

Enhance Aspects of the Physical World. Affective experiences were mentioned by participants in the form of motivating empathy in students, reducing anxiety, or simulating emotional impact. Empathy was stated a lot by educators of healthcare and social studies, see P7: "[E]mpathy, experiencing depression, ... a bad divorce, and then you ... can try how it would be to step in the shoes of your client."

The iVRLEs facilitated collaboration by allowing learners to interact with the study material in novel ways when they were in the same physical space. As stated by P13 (higher vocational education - work and organizational psychology, 2 years of iVR experience): “[I]t gives the opportunity to give specific tasks, .. where students ... take off the headset, discuss with each other. ... So it is also more possibilities to interact with the study material.” Learners could also collaborate on the learning material in novel ways (e.g., on realistic tasks) when they are not in the same physical space. They can meet in virtual spaces and feel like they are in the same space, as stated by P4: “[T]he social aspect is that you can bring together people in the same virtual space, that is a real added value.”

Filtering or adding information to a learning task is easily facilitated by iVRLEs. Filtering information was stated to aid the learning process by guiding the attention of learners to the relevant elements of the environment. An example of a field where this was applied was healthcare, as according to P11: “[P]icture in picture ... is also done at certain activities [in iVR] where you want to zoom in on a part of the action. ... For example in wound care, then you can zoom in on the wound.” Information can also be added to give assistance or create a more realistic practice environment. A realistic environment could aid in remaining calm in real-life situations, as mentioned by an educator from higher vocational education (applied psychology):

> [F]irst aid, then you can try the exercises on a dummy, but you are in a classroom so when you put on the headset you also see an environment around you. For example a crowd in panic or a highway, ... so it gets more realistic. (P10, higher vocational education - applied psychology, 2 years of iVR experience)

Creating was made possible in new dimensions through the means of iVR. In particular, P4 mentioned benefits for fields of study that focused on creating prototypes, various art forms, or other three-dimensional design-based practices.

IVRLEs facilitated engagement and immersion since learners wore an HMD which blocked out the real world and immersed them in a digital environment. This immersion helped the engagement in two ways. The first was limiting the distraction of the natural world around the learner. One common distraction was the learner’s mobile phone: “When I ... show a video ... I know exactly who will react ... and who leans back and try to look at the latest messages on their phone. That is not possible now [in an iVR headset]” (P8, post-secondary vocational education - sports instructor, 2 years of iVR experience). Another distraction was the social environment, which provided distracting conversations and social pressure, limiting engagement with the learning content: “[I]n a classroom you are always aware that ten other students are looking at you. ...[I]f you enter the VR environment, you forget this within a second. So you are more immersed in the task in that environment” (P11). Besides limiting distractions, iVRLEs also aid in the engagement of learners by giving them the feeling that they are at a different location instead of at their educational institution: “[S]o that they [students] had the feeling that they were actually in the classroom [of the case study] and not just [in the room] on teaching college” (P16).

The enjoyment of the learning process was a benefit of iVR that various participants mentioned. Both the teachers (P11) and learners (P2, P9, P11, and P13) enjoyed using the medium in the lessons. Compared to “regular” education, learners appeared to like iVR-based lessons more and lessons turned out to be more dynamic. One educator from higher vocational education (work and organizational psychology) stated:

> You have to come with something new every once in a while. That gathers the attention, stimulates, and improves learning. It was very positively experienced by students, ... they laughed a lot. Those were fun, dynamic lessons where everyone was really working. (P13, higher vocational education - work and organizational psychology, 2 years of iVR experience)

Create Aspects That do not Exist in the Physical World. Unreachable learning activities were especially beneficial aspects of iVRLEs. For specific skills, knowledge, or empathy-based educational activities, iVR was used to immerse students more than other available media and methods (e.g., books or videos). P13 used the technology to let students "experience things that would normally be impossible," e.g., isolation chambers at mental health facilities that would otherwise have been inaccessible.

Scaling up and down in iVRLEs was used by participants to help students in their understanding of concepts. P5 and P9 mentioned using iVR to scale down and let students experience human anatomy from the inside. A (2D/iVR) simulation was also used to zoom in and teach students about molecules and scientific machinery (e.g., analyzing DNA using a PCR test), as mentioned by P3.

Abstract concepts were clarified to students by participants with the help of iVRLEs. P2 used a virtual avatar to provide learners with more consistent and widely available practice opportunities for conversational techniques. The simulation analyzed the conversation and supplied the student with objective feedback on communication skills in listening (e.g., eye contact and not interrupting), asking follow-up questions (e.g., concerning feelings or factual content), and summarizing. Abstract theoretical models can also be clarified by immersing the students in the different steps or levels, as exemplified by P8:

> In the theory lesson I address a topic, for example the violence pyramid. ... I can show or draw this on the blackboard, and then you just have some letters and that's it. I can also show in the VR headset what the different steps of the violence pyramid are, what happens, and how the instructor acts. Then it basically supports the theory lesson. (P8, post-secondary vocational education - sports instructor, 2 years of iVR experience)

Diminish Aspects of the Physical World. Preventing environmental damage was made possible by iVR for several participants. One subcategory of this was the training of safety procedures without worrying about risking damaging the environment (P3). Two participants (P1 and P4) mentioned practicing skills (e.g., learning to drive a forklift or operate dangerous machinery) in a simulation that is safe from damaging the surroundings or expensive machines. Besides providing a simulation that resembled the real-world situation, a participant (P5) also mentioned the usage of iVRLEs to immerse students in environmental effects:

> [A]n experience regarding sustainability in VR. So for example they [students] can experience deforestation or smog in China. This way students will register better what the effects are of climate change compared to seeing a photo or a video, because they are inside of it. The added value is that sustainability will live more for the students. (P5, higher vocational education - digital innovations, 1 year of iVR experience)

The learners' emotional and mental risks were decreased by participants using iVRLEs, for procedural and soft skills. Procedural skills (e.g., laboratory work) were practiced so that students would feel more comfortable executing real-life tasks, decreasing students' tendency to overwhelm teachers with questions of affirmation (P3). Students also felt safer if they could practice in iVR compared to if they had to do it in front of peers. P2 used an iVRLE so that learners "would not have to cry or be anxious because they have to do something in front of a group. They can try it safely at home first .. without feeling like you will be laughed at." Similarly, people skills were trained in an iVR simulation instead of jumping directly into real-life situations to make it less emotionally intensive, as stated by P12:

> What I heard there was 'oh those horrible preschoolers, they always do random things, I don't like it.' ... You have to learn this and I understand that if you are very into the theory that the step to a kindergarten class is very big. ... So I thought, why do we not support this with VR. This can be so much safer for students, they can really experiment. (P12, tertiary teaching education, 2 years of iVR experience)

Reducing physical risk in iVR was closely related to preventing environmental damage since they both tended to be caused by generally dangerous activities. Therefore, safety procedures could be trained in iVRLEs without the risk of bodily harm (P3). Training skills that required handling dangerous equipment or machines in iVR also sharply decreased any bodily harm (P1 and P4). Additionally, the virtual environment provides a safe training ground to learn how to deal with dangerous behaviors of people, as exemplified by P11:

> We have a VR application to learn to deal with aggression. In the field students will sometimes encounter this during their internship [or job]. It is important to regulate your own emotions when encountering this misunderstood behavior. To teach students this we simulate this in the [iVR] environment, where the teacher plays and voices the [aggressive] avatar. (P11, higher vocational education - healthcare technology, 6 years of iVR experience)

4.1.3. Practical use of iVRLEs

Participants were asked when and how they used iVRLEs in their educational practices. How iVR was used was categorized under the organization, learner familiarity with iVR, social setting, and iVR type.

Regarding the organization of iVR, the time inside the iVRLE should be limited to prevent strain on the learners. It also ensured that the lesson did not merely exist of the virtual environment. For uninterrupted wear of the iVR HMD, participants suggested a maximum between 10 (P8) and 20 minutes (P4). Depending on the learners' freedom of movement in iVR, it was recommended to conduct the lesson in a larger classroom than usual. Some teachers had experienced challenges keeping the students engaged due to logistic problems. They suggested preparing and organizing well so that the transition to and from the iVRLE is smooth, keeping students' attention. Alternatives should be provided for students who cannot or wish not to use iVR.

Learning familiarity was deemed crucial since students were easily distracted by the novel technology and controls. To combat this, participants suggested taking time to introduce iVR and giving students the time to familiarize themselves with it. A test could be conducted beforehand to determine how long this introduction should take (P4).

Participants used iVRLEs in different social settings within their lessons. Students experienced iVR individually, in small groups, or in a class-based format where one student was in iVR, and other students watched along on a screen. Settings differed based on available iVR HMDs, available time, and the specific iVR application.

Different types of iVR were used by teachers based on available material, their budget, and the learning goals. The iVRLE could be a 360-degree video, with or without choices, or a simulation, controlled by a teacher or independently usable. While no clear distinction existed, a minor tendency existed for participants to use 360-degree videos for impressions and remembering. Meanwhile, simulations were slightly more often focused on practicing a skill.

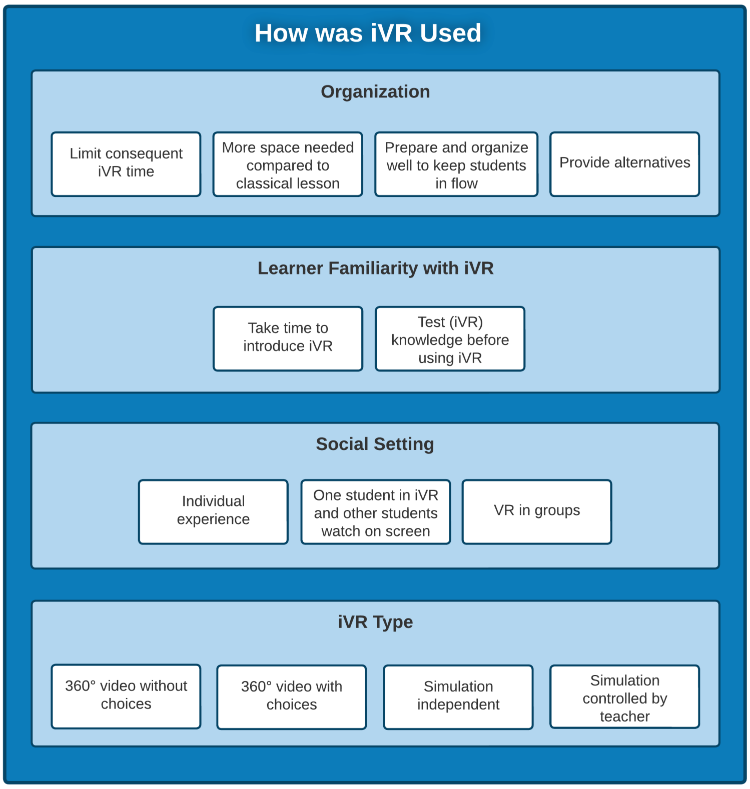

Figure 13. Results of thematic analysis of study one. Theme: how iVR was used in education.

When iVR was used in participants' educational practice was divided between singular lessons and lesson sequences. For individual lessons, most teachers saw the most value in iVR after the appropriate theory was discussed. The iVRLE was then used for a deeper investigation of the topic. For deeper investigation, iVR was used in the middle (e.g., as a practice tool) or at the end (e.g., as a test) of the didactical process. When it was used at the beginning of a lesson, it tended to serve the purpose of "convincing students about the emotional severity of an issue" (P1 and P14, e.g., child abuse or dementia) or "giving students a visual mental image" (P9, e.g., anatomy). Participants stressed the need to reflect on the experience afterward to ensure it was deeply processed. Reflection could be done individually (e.g., based on a text prompt in or outside the iVRLE), in groups, or with the entire class. In the words of one participant:

> Reflection is very important, if you are always busy without reflecting then it will stay at just playing around. It is just a principle of learning, ... getting asked where you are now and how you will do things differently after having learned. How reflection should be done depends on the setup of VR, ... in the class together or ... in a group. It also depends on how much time you have as a teacher. (P4, primary and secondary education consultant, 5 years of iVR experience)

Teachers recommended "building around" the iVR experience (P7) for individual lessons and lesson sequences. With this, the iVRLE could best fill its role in the didactic process (begin, middle, or end). Additionally, they ensured that any appropriate theory was processed before the iVRLE was used, and sufficient time would be available to reflect afterward.

When considering a lesson sequence, educators mentioned that students could use it as a practical tool, even outside of lesson time (e.g., at home). To further learning, the difficulty of simulations could be increased as the lesson sequence progressed. These iVRLEs were frequently used to prepare for internships (P11, e.g., dealing with aggressive patients) to make the transition from theory to practice smoother. After practicing with the theory or internship, some participants used the iVRLE to test the students' knowledge. Both formative (to learn from) and summative (graded) tests were conducted. Teachers often faced challenges in garnering acceptance from the curriculum and educational institution for graded iVR tests. On some occasions, a participant would also "use these [360-degree] sorts of videos as a reflection method of real-life practice (e.g., during an internship), so students record their own [teaching internships] lesson and then watch and discuss this in a group" (P16).

Finally, participants were asked about the form of the framework they thought would be most helpful. The most common preference was to have a visual framework, e.g., in the form of a decision tree. Some interviewees mentioned that partially worked-out lessons, short explanations, and further readings were a desired addition to a visual framework. However, some participants expressed their doubts were a general didactical model could already be made and what the model would contribute if the available content were still limited. The following participant exemplified this:

> I think you cannot make a framework yet because there is too little content..., so you have to be really creative... to think how you are going to use it [iVR] in the classroom. When there will be more content later, it will keep getting easier for the average teacher to use VR. (P9, higher vocational education - nursing, 15 years of iVR experience)

4.2. Discussion

Immersive virtual reality learning environments have great potential in supporting the educational practice of educators, and there is a growing evidence base in support of using the technology for a range of learning goals. However, at present, no didactical

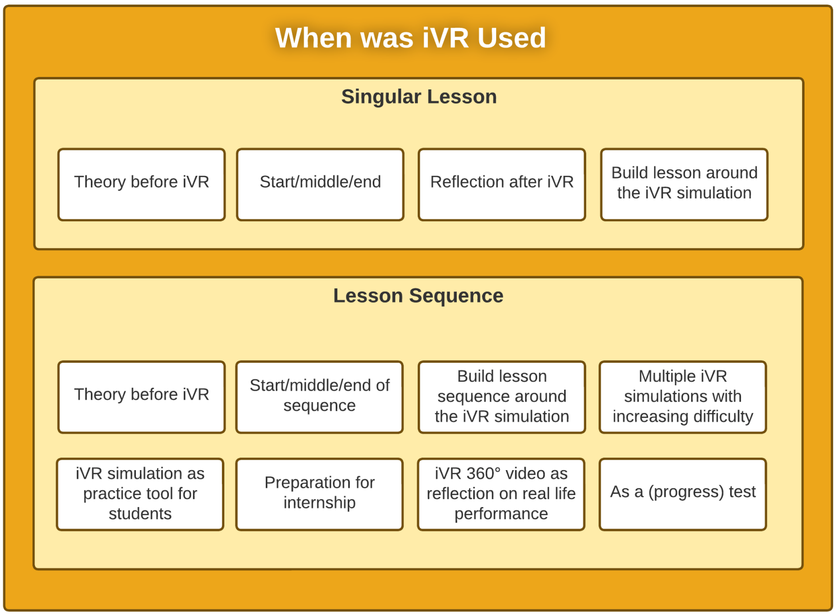

Figure 14. Results of thematic analysis of study one. Theme: when iVR was used in education.

framework is used to analyze or implement these learning tools. As a result, iVRLEs have frequently been used in less befitting situations, and didactically beneficial opportunities have been overlooked. When iVRLEs were used, educators were still exploring the implementation guidelines in their lessons and lesson sequences. While the literature review concluded with an elaborate framework, it missed the connection with how educators teach in practice. This first interview study was aimed to elucidate these questions. In this context, a qualitative interview study was conducted to investigate teacher experiences on the decision to use iVRLEs in education (SQ1) and how they implement iVRLEs in their educational practices (SQ2). The in-depth qualitative interviews were analyzed with a content analysis to distill insights. Based on these results, the DIL framework was updated to incorporate teacher experiences, improving its practical usefulness.

4.2.1. Educators' Decision Process to use iVR

For the first sub-question, "What guides the decision of educators to use iVRLEs in education?", it was hypothesized that "Most educators base the decision to use iVRLEs in education on intuition rather than on didactical theories." The results confirmed that, compared to didactics, intuition was more often the underlying reason for using iVR. Additionally, the distilled themes revealed different levels of adoption of the technology by educators, mapping onto the previously mentioned awareness, acceptance, adoption model by Leoste et al. (2021). Their model described six factors that influence the teacher's perception of Technology-Enhanced Learning (TEL) innovations:

- personal factors, e.g., knowledge, skills, experience, openness to change;
- technological factors, e.g., ease of use of the technology, compatibility, trialability;
- organizational factors, e.g., size and scope of organization;
- perceived-value factors, e.g., perceived usefulness of innovation, its efficacy, cost-effectiveness;
- contextual factors, e.g., public opinion, political pressure, competitors;
- social practices, e.g., teamwork, scaffolding, participation of end-users in designing innovations.

The model by Leoste et al. (2021) helped analyze the first interview study, even though this thesis predominantly focused on the didactical aspects of iVR selection and implementation.

Teachers often neither accepted nor adopted iVR and instead stuck to familiar methods, which is in line with the previously mentioned research by Bischof et al. (2016) which found that educators' understanding of learning, teaching, and accompanied didactic methods is known to only change slowly over the years. One reason for this was that teachers felt that they lacked knowledge (a personal factor) and that the technology was not easy to use (a technological factor), as exemplified by their perception of iVR as difficult, not having time to familiarize themselves with iVR, and finding it harder to stand above the learning content when using iVR. As a result, teachers felt a low sense of self-efficacy (their own beliefs about their ability to accomplish a specific task) which influenced their level of effort and persistence in learning a complex task such as iVR (Bandura, 2009; Lunenburg, 2011). Since organizational and contextual motivators were rarely present and teachers struggled to perceive the added value, only social practices remained to motivate iVR usage. It is therefore not surprising that many teachers report the need to persuade and excite fellow educators in order for them to experience higher self-efficacy and adopt iVR. Naturally, it would be more beneficial to educate teachers on the added value of the iVR and train them on how to use it. This way, they could base the decision to use the technology on the didactical benefits of the learning situation, instead of only relying on the persuasion by innovative colleagues. Considering that these reserved teachers are likely not the first to adapt iVR in an educational institution, a recommendation has been included in the implementation phase of the DIL framework to clarify the added value for teachers' individual courses and to train educators before rolling out iVR throughout the institution.

When teachers accepted iVR, their adoption depended on the accessibility of the headsets and ICT assistance for equipment and didactical challenges. Accessibility of educational technology is one of the strongest determinants of usage (Burke et al., 2018) and should be a careful consideration with iVR implementation. Naturally, placing iVR headsets in every classroom brings about cost-related challenges, stressing the need for smart sharing options (e.g., designated iVR classrooms that teachers can reserve). Teachers' need for material (a technological factor) and immaterial support (e.g., didactical support, an organizational factor) is a critical determinant of the acceptance and adoption of iVR as a technological learning innovation (Leoste et al., 2021). Here, the material, technological support also included aiding teachers in finding or developing iVR content. The difficulty of fitting iVR into an existing curriculum or lesson sequence was also an organizational challenge in adopting the technology.

When educators adopted iVR, it was rarely based on explicit didactics. Some teachers used the technology because they thought it was “cool” (a personal factor) or was seen as such by public opinion (a context factor). This emotional cue is a possible source of self-efficacy (Bandura, 2009; Lunenburg, 2011) and likely increased the teacher’s level of effort and persistence in adopting iVRLEs in their lessons. In some cases, teachers had outstanding didactical knowledge or skills (a personal factor). However, they struggled to apply existing didactics to the new medium of iVR (a technological factor) or an existing iVRLE application (technological factor), especially within the current rigid curriculum (an organizational factor). As a result, most teachers used “implicit didactics” based on their teaching experience or a direct translation of a real-life learning situation. To aid teachers in applying didactics to the analysis and implementation of iVR, the educational institution can aid by creating space in the curriculum. Even when teachers did not explicitly consider didactics when using iVR, various teachers still recommended analyzing the situation to determine if the medium was a fit for the learning situation. The created DIL framework in this thesis aims to help teachers apply didactics to the medium of iVR, even if they use an existing application.

A minority of educators based the decision to use iVR on didactics. They analyzed the educational situation on a micro-, meso-, and macro-level. Here, the micro-level refers to design guidelines for individual learning situations, meso-level to learning goals and instructional design model of the course, and macro-level to the organizational support. As previously mentioned, this thesis focused on the usefulness of iVR based on its usability and educational utility. Nevertheless, it benefited from taking a macro-level perspective, e.g., regarding organizational factors, context factors, and social practices (Leoste et al., 2021). Teachers frequently mentioned the macro deliberation of cost-benefit effectiveness (a perceived-value factor). The purchase or rental of iVR equipment and software remains expensive for the available education budgets. It was deemed wise to consider if other investments could contribute more to learning outcomes (e.g., updating online material, hiring more staff), particularly in situations where iVR would only be a marginal part of the course. Therefore, educators are recommended to take the proper time to analyze and value the iVR technology and its uses, costs, and restrictions as part of the “Analyze - Discover Existing iVR Materials” theme in the DIL framework (see Appendix D.3.4.). To reduce costs and learn about using iVR in lessons, teachers recommended trying out iVR on a small scale, especially before developing an application themselves. When educators concluded that the development of an iVRLE would fit best with the didactical and macro (organizational and perceived value factors) situation, they recommended including teachers and students in the design process. This inclusion was in line with previous studies (Southgate, 2020; Tacgin & Dalgarno, 2021).

A majority of the teachers who used iVR based on didactics recommended incorporating the medium in the curriculum to ensure it was used didactically and consistently. They often based learning activities on learning goals in the curriculum and stressed the lack of time to plan methods and learning goals in advance outside of a curriculum. It is striking that teachers saw the curriculum as an obstacle or solution, depending on their level of iVR adoption. Educators in the awareness or acceptance phase tended to see the curriculum as an obstacle to trying out iVR, while some of the educators who had adopted the technology saw it as a solution to safeguard didactical usage. All things considered, it is recommended to provide space within the curriculum for teachers to experiment but also incorporate iVR into the curriculum for courses in which the didactical analysis and subsequent try-out showed positive effects on learning outcomes.

Finally, the educational and social sub-affordances of iVRLEs reported by interviewees were in line with previous research (see Figure 5 on p. 12). Skills are a common learning goal for using iVR in literature and in the first interview study results. Care has to be taken not to focus too much on skills and hereby forget to lay the knowledge foundation, as too much focus on skills has been shown to decrease achievement scores in education around the world (Hirsch, 2016). IVRLEs are reported to facilitate engagement, immersion, and enjoyment. While these affective experiences can stimulate learning, it is crucial to mention that engagement and motivation themselves are poor proxy indicators for learning (Nuthall, 2007). As Nuthall describes: "... students can be busiest and most involved with material they already know. In most of the classrooms we have studied, each student already knows about 40-50% of what the teacher is teaching" (Nuthall, 2007, p.24). Motivation and engagement are essential for learning, but it is thus crucial to use them in conjunction with a substantiated educative activity. Following the frequently mentioned sub-affordance of applying knowledge, it is included in the affordances of the DIL framework.

4.2.2. Educators' Implementation of iVR in Lessons

For the second sub-question, "How do educators implement iVRLEs in their educational practices?", it was hypothesized that "Most educators apply iVRLEs in education based on intuition rather than on didactical theories." The implementation of iVR in lessons often was guided by intuition, similar to the decision process. However, some teachers still analyzed the educational situation to determine how iVR could provide the most substantial learning contribution.

Teachers tended to consider feasibility (an organizational and perceived-value factor) before didactics in their iVR usage. Understandably, didactics were considered more frequently when the educators had more freedom in iVR social settings and iVR types. More freedom in budget and curriculum allowed them to use more iVR HMDs, allowing smaller groups or individual experiences. It also allowed teachers to use 360-degree videos or more expensive simulations, depending on the didactical situation. Some recommendations by interviewees were in line with previous research, e.g., regarding taking time to introduce iVR (Southgate, 2020), providing alternatives (Southgate, 2020), and needing more space than conventional lessons (Johnson-Glenberg, 2018). One participant expanded on the concept of familiarizing students with the suggestion to conduct a short test beforehand to determine how much assistance they would need regarding using the iVRLE or regarding the educational subject matter. Another new insight that participants recommended was limiting consequent iVR time (blocks of max 20 minutes) to prevent health and safety concerns and ensure learners had time to reflect on their experiences. Additionally, teachers should prepare and organize iVR lessons well such that students will be kept in the flow, away from distractions.

Participants made recommendations for when to use iVR, providing value additions to previous research which rarely explicitly considered this temporal placement. Regarding singular lessons and lesson sequences, teachers used iVRLEs at the start, middle, and end. Naturally, the goal of the usage differed depending on the placement. At the start of a lesson, iVR revealed the emotional severity of issues (P1 and P14, e.g., child abuse or dementia) or gave students an overview or image of the to-be-learned content (P9). Using iVR as an opener of a lesson (sequence) has presently been given limited attention in research. In previous research, the usage of iVRLEs has predominantly been in the middle (e.g., as a practice tool) or at the end (e.g., as a test) of the didactical process. Therefore, this insight provides educators with an additional usage case for which iVR can provide educational benefits. However, it is not surprising that research has been focused on the middle and end-use of iVR, as participants often recommended discussing theory and giving learners background information before diving into the virtual experience. With this, the time in iVR could be effectively used since learners could focus on interacting with the content (Kerres, 2018; Mulders et al., 2020). In line with previous research (Di Stefano et al., 2014; Johnson-Glenberg & Megowan-Romanowicz, 2017), participants recommended motivating learners to reflect on their iVR experience afterward (preferably in the same lesson) to solidify learning. Teachers advised building around the iVR experience (P7) for individual lessons and lesson sequences. The essential theory could then be discussed before the iVR experience, and sufficient time would be available for reflection afterward.

Participants had various novel suggestions for iVR use in lesson sequences. Amongst others, they recommended using iVRLEs to prepare students for internships and using 360-degree videos as a reflection on real-life performance. In line with previous research, they also mentioned the usage of iVRLEs as a practice tool for students (Jensen & Konradsen, 2018; Steffen et al., 2019), as a summative or formative test (Johnson-Glenberg, 2018; Karpicke & Roediger, 2008), or to increase the difficulty of subsequent iVR sessions (Hattie & Yates, 2014; Kalyuga, 2009; Vygotsky, 1978).

5. Study 2 - Validation of the DIL Framework

Based on the findings from the interviews in stage one, the DIL framework is updated. The insights regarding the selection and usage of iVR are added to the ADDIE-based visualisation (see Appendix D.3.4.). Note that these decision-related findings are added to the framework directly (e.g., accessibility as part of "Implementation - Teachers"), while the design specific findings are added to the social, educational and technological design principles that should be considered in designing the iVR learning experience (see Appendix C.3. for final design principles).

Participants indicated a preference for a simple decision tree style visualization, so an checklist-based overview was added to the DIL framework (see Figure 15), in addition to the updated ADDIE-based visualisation.

5.1. Results

5.1.1. Complexity

The understandability of the framework differed between the two visualization elements. Some participants thought the detailed ADDIE-based framework visualization was too complex because it was made up of too many elements. They were unsure which

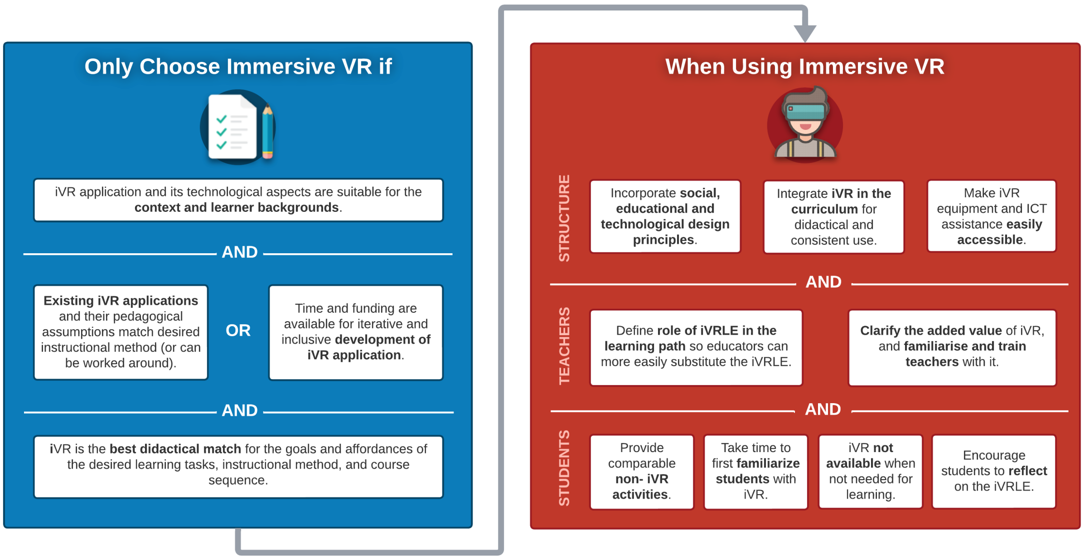

Figure 15. Simplified decision tree as addition to the updated Didactics for Immersive Learning (DIL) framework (see Appendix D.3.4.).

order they had to read, especially since the design and teaching process is circular in practice instead of linear. One participant was uncertain whether all considerations in the white blocks were required or selective since it lacked the overview's clear "AND" and "OR" indications. All participants considered the general overview clear, and only the abbreviation "iVR" was unclear to a few participants.

All participants recognized their educational practice in the framework and its different phases. They did note that, in reality, phases blend into each other and can be done in different orders. Running a pilot session was a less appropriate framework guideline for non-iVR lessons since educators would be working with familiar methods. Phases were also frequently not explicitly considered as teachers used "Fingerspitzengefühl" (intuition) based on their experience in day-to-day teaching. Teachers were reported not to think extensively about their delivery methods due to practical considerations, e.g., available time or theoretical versus applied lessons. Unless a lesson went remarkably poor, analysis was also faster and more concise after the first design cycle had been completed. One participant stressed the need for adaptivity depending on "mundane" factors that influenced a lesson, e.g., how close students were to the vacation or if students just had an exam in a different course. This information was only available close to the start of the lesson, stressing the importance of analysis of short-term contexts and adapting accordingly. Therefore, teachers were recommended to be prepared for their plans not going as anticipated. Fully preparing for any unexpected events was deemed near impossible, so teachers should stay spontaneous.

A majority of the participants prioritized the implementation phase of the framework. The other phases (analysis, design, development, and evaluation) were essential for the educational foundation. However, the main goal of these phases was to facilitate the implementation of qualitative teaching. Participants mentioned challenges in implementing educational measures due to discussions about education but a lack of execution by educational institutions (P1, e.g., setting deadlines, guarding the process, or try-outs). For new technologies such as iVR, teachers and students should be familiar with how it works before they use it in lessons (P2 and P4).

5.1.2. Practicality

Teachers saw a substantial benefit to using iVR in their lessons in the future but pinpointed several bottlenecks in its practical usage, learning materials, teacher ICT knowledge, and logistics.

Practical usage of iVR by teachers could be motivated by including it in the curriculum or didactical method (P1, P3, and P4). Even teachers who are inclined to teach based on intuition would benefit from this. Therefore, communication on immersive learning benefits should focus on departments (e.g., physics), instead of individual teachers, as these typically created lesson plans and structures for high schools. Teachers themselves would have challenges seeing where iVR can be used, the added benefit, and how it should be used (P1 and P2). One participant (P4) also suggested first testing iVR on specific schools to gather hands-on advice (e.g., how do you get students out if they like it too much) and other specifics that conduce successful use. One such example was control over students in iVR, as laptops were presently already challenging to control and distracted more than they added to the learning process (P1 and P4). An atmosphere of trust was also required in the classroom to take the real-world vision away of students and teachers in using iVR. Teachers or departments would need to rethink and develop (parts of) lesson sequences since iVR would not be used in large lecture rooms but instead individually or in small groups. Since iVR would be dangerous to use in a practicum classroom, it would have to be used in designated classrooms for safety. Presently, future teachers are taught about subject-specific resources (e.g., online practicums) during subject-didactical courses at teacher college, making it an opportune moment to cover iVR as a medium (P5).

Participants experienced general insecurities about iVR content, e.g., where to retrieve the didactical simulations. Participants did not trust that that any purchased software would still exist one year later. Even if the software would "just" get an update, this leads to a lot of work for teachers to relearn and update their learning material. Additionally, teachers wanted pre-made material which they could easily modify and use, similarly to how Casio and Texas instruments provide material for mathematics which uses the graphical calculator. However, participants simultaneously saw issues with adapting premade iVR materials. Any material also had to be compatible with the existing curriculum and not use different approaches to theories (P3, e.g., the right-hand versus the left-hand rule in physics).

The general ICT knowledge of teachers was seen as a challenge, with glitches and bugs being especially complicated to handle. Especially older teachers already struggled with new technology and would similarly face challenges with iVR. Teachers in the beta subjects tended to be more technically skilled and would be more likely to use iVR. The technology would see less usage if many steps were required to start an application (e.g., starting the HMD, logging in, and loading the application).

Funding and logistics would be hard, as it was already difficult to currently arrange a personal device (e.g., iPad or laptop) for students. There sometimes were not even enough chairs for all students to sit in German high schools. Participants expressed worries about diverse logistic issues regarding the infrastructure (e.g., too few sockets in old buildings, wireless internet issues, complicating regular check-ups of technical appliances) and legal affairs (e.g., copyright of material or insurance complications for health risks involved with iVR). One participant (P3) offered the solution to using mobile-phone-based iVR but stressed the accompanying challenges for students with fewer resources.

The expressed benefits of using iVRLEs were explaining abstract concepts (e.g., atom models, anatomy), making theory tangible and interactive, having fewer constraints, and practicums being faster than in real life. By aiding students' imagination with iVR, participants expected more of their mental capacity to be left to focus on the explanation instead of trying to understand the visualization. Seeing as iVR is a novel technology, a participant also expected an initial boost of motivation when students would use it. How a teacher would use the technology was considered especially important here since this novelty effect would not last.

Educators saw the DIL framework as a helpful checklist for applying iVR in education. While the framework would help teachers determine if iVR would be of added value, a minor inclination existed towards using it for guidance on the design and implementation of iVR when it had already been decided to use the medium. One participant stated that it could be a good starting point but that acquiring and using iVR would mostly be a decision by the school or educational ministry. Given that teachers do not have time to learn how to do small portions of their lessons better, the framework would best be most suitable for teacher education (P1, P4, and P5) or training days to which a teacher could apply and get time off for from teaching. Here, participants stressed that voluntary workshops would likely only be attended by interested teachers.

5.1.3. Improvements

The detailed ADDIE-based part of the framework was overwhelming and could be improved by explanations of what the phases and sections within the phases are. To make it more inviting and easily digestible, teachers suggested visualizing the circularity of the process and using infographics and icons. Next to helping in the design process, the framework could also aid teachers who merely use iVR in their lessons. These teachers would benefit from a more concise guide tailored to their practical needs (P2 and P5).

5.2. Discussion

Immersive virtual reality learning environments have great potential in supporting the educational practice of educators, and there is a growing evidence base in support of using the technology for a range of learning goals. In the first interview study, the DIL framework was expanded with teachers' experiences on the decision to use iVRLEs in education (SQ1) and how they implement iVRLEs in their educational practices (SQ2). A second interview study was conducted to verify and improve the created DIL framework. This verification aimed to ensure that it is comprehensible and usable by educators.

Compared with prior work in the area of educational iVR, this study puts a greater emphasis on the day-to-day influences and practices of teachers. Teachers' identify key personal and external factors that influence its adoption. Such an adoption approach is not uncommon in the acceptance and use of innovative education technologies and resonates with earlier studies pointing to the importance of facilitating both personal and external factors (Leoste et al., 2021). The teacher-experience-based approach is novel for studies on educational technology adoption and didactical iVR use, but matches earlier studies on concerns of didactical theories (Biesta, 2007; Gerstenmaier, 2002; Kerres, 2018; Nuthall, 2007; Reinartz, 2003).

5.2.1. The DIL Framework is Comprehensible and Recognizable to Teachers

For the third sub-question, "How do educators perceive the complexity of the DIL framework?" it was hypothesized that "Most educators appreciate the visual overview of the DIL framework, but some are overwhelmed by the number of elements of the model." The results confirm that visualization of the general overview in the framework is comprehensible and recognizable but that some teachers struggle to grasp the ADDIE-based visualization fully. This detailed element of the framework is seen as unclear, as it is made up of too many elements, and it is unclear how the phases interconnect. The DIL framework thus displays the established phenomenon that increasing completeness makes didactical theories more complex, in line with previously mentioned research by (Kerres, 2018), since it attempts to create a holistic foundation for the use of iVR. This complexity makes it more challenging to implement and evaluate whether the effort for many analysis steps is worthwhile. To make the DIL framework easier to understand, an intermediate visualization could be added which explains the phases and their interconnection. It is expected that the added clarity of the supplementary visualization outweighs increases in mental effort related to the expansion of the framework.

Another solution to simplify implementation and evaluation in the didactical development of iVRLEs could be the rapid application development (RAD) strategy, as described by Whitten and Bentley (2007, p.98). This agile approach focuses on user involvement in a "rapid, iterative, and incremental construction of a series of functioning prototypes of a system" (Whitten & Bentley, 2007, p.98). By focusing on early prototypes, difficult to form didactic concepts can be illustrated to clients (e.g., teachers and institutions), communication between actors is more reliable, prototypes can be tested with the target group (e.g., teachers and learners), technical feasibility and conceptual approach can be tested at an early stage (Kerres, 2018). Work can be terminated at any time while still having a usable version of the iVRLE. Using the RAD strategy can lighten the load associated with the DIL framework. However, it only applies to the development of iVRLEs and not for the selection of existing material. Additionally, it also comes with developmental disadvantages such as the encouragement of a "code, implement, and repair" mentality that increases lifetime costs, the possibility of solving the wrong problems, the RAD prototype discouraging the consideration of more suitable methods, and sticking to prototypes while starting anew would be best (Whitten & Bentley, 2007). All things considered, the RAD approach can be circumstantially beneficial, but an adequate analysis is still recommended. Particularly since using iVR while better alternatives would be available would be costly in time and money.

All participants recognize their educational practice in the framework and its different phases, even though teachers mostly rely intuition in teaching. Intuitional teaching practice is used due to practical considerations like time constraints and because generalist didactical theories have limited applicability in day-to-day challenges in educational situations, which is in line with the previously mentioned research by Biesta (2007) and Reinartz (2003). Minor differences between the DIL framework and participants' educational practice are that the phases "melt into each other" in real life and that the process is more cyclical than the linear visualization depicts. The challenges of visualizing the cyclical instructional design process were expected (see Introduction at p.29) and are in line with previously mentioned research (Gagne et al., 2004, p.21). Therefore, the DIL framework would benefit from an intermediate visualization that explains the phases, their interconnection, and the process's cyclicality.

The implementation phase of the framework is seen as the most important since this is the actual act of providing qualitative teaching. Participants mention factors that presently hinder the adoption of educational measures. These factors are in line with the previously mentioned TEL innovations model by Leoste et al. (2021). One participant (P1) mentions a lack of following through (e.g., setting deadlines, guarding the process, or try-outs) on discussed educational measures by their educational institution (an organizational factor). Other teachers (P2 and P4) state the need for knowledge and skill acquisition regarding iVR before it can be used in lessons (a personal factor).

To conclude, the DIL framework is comprehensible and recognizable, even though participants struggle with elements of the ADDIE-based visualization. While participants recognize the phases, teaching is still primarily reliant on intuition, meaning phases will frequently not be deliberately considered. Intuitional teaching can be helped with the DIL framework, training, and assistance but is primarily a logical product of the time-constrained, continuously changing environment. Here, the implementation phase is seen as the most important since this is where teaching happens.

5.2.2. IVRLE use is Influenced by Personal and External Factors

For the fourth sub-question, "How would educators put the DIL framework into practice?", it was hypothesized that "Educators would use the DIL framework in varying ways, affected by external factors (e.g., school environment) and established habits of using intuitional teaching methods." The results confirm that teachers' use of the DIL framework and iVR is predominantly influenced by external factors. However, participants also mention teachers' knowledge and skills (personal factors) besides their habits. The model by Leoste et al. (2021) is used to categorize the external and personal factors that are expected to influence future iVR use in education.

Personal Factors. Participants see teachers' ICT knowledge as a challenge, especially for older teachers who already struggle with current educational technologies. As part of ICT knowledge, teachers experience general insecurities about iVR content, e.g., where to retrieve the didactical simulations. Teachers' ICT competence and confidence have been proven to be significant predictors of integrating ICT in teaching (Buabeng-Andoh, 2012).

Participants report that teachers prefer to have more hands-on knowledge about iVR before they start using it (e.g., how do you get students out if they like it too much), which is in line with the first interview study results. Here, participants also mentioned the desire to have partially worked out lesson plans. Training teachers on subject-didactical (hands-on) iVRLE knowledge is ideally done at teacher college since taking time out of teaching afterward is difficult.

Technological Factors. Participants are hesitant to rely on iVR since software updates and discontinuations could lead to additional work for teachers. Relearning the software and updating their learning material would be an added workload on top of their busy teaching and preparation schedule. Therefore, it is suggested to ensure software availability and forward compatibility of learning material as part of the technological design principles of efficiency and memorability (see Appendix C.3. for final design principles). Alternatively, if a software update would bring radical changes but with it substantiated learning outcome improvements, iVRLE developers should provide teachers with updated learning materials.

Participants report the teachers' need for pre-made materials that are compatible with the existing curriculum yet can still be adapted. This contradiction is in line with previous research (Timmermans, 2021). Additionally, the interview result is in agreement with research by Leoste et al. (2021) which describes the need for teachers to be provided with resources and support to adapt lesson plans to their classroom specifics.

Participants state that iVR will see more educational use if as few as possible steps are required to start an application. A streamlined usage will benefit its efficiency and the satisfaction of students and teachers, in line with previous research (Kirschner, 2002). The recommendation to streamline the process of starting and using the iVRLE is a valuable addition to the technological design principle of efficiency (see Appendix C.3. for final design principles).

Organizational Factors. IVR should be included in the curriculum or didactical method, and communication should focus on departments and schools since these create lesson plans and structures for high schools. The first interview study supports this inclusion and the focus on schools and departments (p.46, Theme: "Educators do not have time to plan learning goals and methods in advance, so incorporate iVR in the curriculum for didactical and consistent use").

Teachers' concern with infrastructure and legal affairs is supported by previously mentioned research by Southgate (2020), which stresses to "Determine spatial, network, and bandwidth requirements of the hardware and software" and to "Consider health and safety information of hardware and appropriateness of software." Compared to Southgate, the participants added considerations regarding electricity and socket availability, iVR devices complicating regular check-ups of technical appliances, and copyright issues for iVR material. Next to having the required space available, (parts of) lesson sequences will need to be remade since iVR will not be used in large lecture rooms or practicum rooms but instead individually or in small groups. This different teaching method is expected to require a partial alteration in the course design.

Perceived-Value Factors. Perceiving the added benefit of iVR is seen as a challenge for teachers, in line with previous research (Leoste et al., 2021; Timmermans, 2021). To clarify the value of iVR to teachers, the literature suggests (a) alignment with the target group, pedagogical needs and requirements, teaching contents and objectives, as well as learning situation and organization (Commissie Parlementair Onderzoek Onderwijsvernieuwingen, 2008; Kerres, 2018; Timmermans, 2021) and (b) including developers of learning material in the creation of iVRLEs (Timmermans, 2021). Participants expanded the list with the suggestion to educate teachers on iVR and its added value in teacher college or a workshop under work time.

While iVR has the potential for facilitating learning, it could prove to be more distracting than helpful to learners, similarly to current challenges with laptops and iPads. The importance of how learners actually use the provided support and that technology should not be available when not necessary for the learning process is in line which previous research by Kirschner (2002), Kirschner et al. (2020), and Rothkopf (1970).

Additionally, participants mention that it will be hard to arrange funding and logistics because of the ratio of costs and benefits, even if iVR is best suited to facilitate learning in a given educational situation. This challenge presently exists for simple personal devices (e.g., iPad or laptop) for students and is in line with the first study and previous research (E. A. Johnston et al., 2018; Kerres, 2018; J. Nielsen, 1994; Timmermans, 2021). Particularly smaller institutions are expected to require monetary support for iVR projects (Cook et al., 2019).

Two factors from the model byLeoste et al. (2021) are not mentioned in the second interview study, the contextual factors, and social practices. The smaller sample size might cause this absence since these factors are mentioned in the first study (p.44, Theme: "Educators ensure iVR fits the educational situation through analysis and inclusive and iterative implementation"). Here, participants mention the need to include teachers and students in selecting and developing iVR learning content (a social practice). Additionally, a participant (Study 1 - P4) in the first study mentioned that teachers want to have support from policies that include iVR in the pedagogical planning of the school. In turn, schools look toward the government and politics (a contextual factor):

> The school boards on their turn look toward the policies of the government, do they think VR is important? Management often looks to the focal points of the government. You might have seen that it [iVR] has gotten into an acceleration in Flanders [a region in Belgium]. (Study 1 - P4, primary and secondary education consultant, 5 years of iVR experience)

Benefits of iVRLEs and the DIL Framework. Participants mention several benefits of using iVRLEs, including an expected initial boost of motivation when students use the novel technology. Here, they stress it is especially crucial how the teacher uses iVR since this novelty effect would not last. This effect is in line with previously mentioned research (Bagiati et al., 2020; R. E. Clark, 1983; W. Huang, 2020; Kirschner et al., 2020). W. Huang (2020) found that increased engagement and motivation linked to the novelty of iVR technology only attenuated slowly. Nevertheless, the fit between the learning content and the learning method is deemed considerably more important than the motivation and engagement generated by the novel technology of iVR.

Educators see the DIL framework as a helpful checklist for applying iVR in education more than a framework to guide the selection process. Naturally, a difference exists between the information required for designing and using iVRLEs. Participants think it would be beneficial to have two versions of the framework, one for designers and decision-makers of learning materials and one for teachers who use the iVR in their lessons.

To conclude, the use of the DIL framework will be based on the personal factors of teachers, but mostly on practical non-personal factors like technological, organizational, and perceived-value factors. To promote didactical iVR use, the technology must (a) fit teachers' needs concerning learning materials, (b) be easy to use, (c) be supported by the curriculum, school, and government, (d) not pose infrastructure, or legal challenges, (e) have a clear added-value to teachers and schools, and (f) limit distraction.

5.2.3. The DIL Framework Needs Additional Clarity and a Concise Version

For the fifth sub-question, "What could be improved about the DIL framework according to educators?", it was hypothesized that "Few educators prefer a more simplified DIL framework including examples." Part of this question has already been discussed in the discussion of the second interview study. Mentioned improvements are (a) explanations of what the phases and sections within the phases are, (b) visualizing the circularity of the process and using infographics and icons, and (c) making a concise version for teachers who only need information on the application of iVRLEs in their lesson.

6. General Discussion

This thesis started with the aim to aid educators by guiding the didactically-grounded application of iVRLEs. The DIL framework was created based on a literature review on iVR affordances, design principles, and educational theories. Considerations of educators' experience, expertise, and professional judgment were absent in previous research, requiring further investigation to improve the DIL framework to be a usable and comprehensible guide to evidence-based teaching practice. Following the gap in research, the main research question of this thesis was, "How can teacher iVR-experience be integrated with didactics for immersive learning?" Towards this goal, an interview study was conducted on educators' selection and implementation of iVR. After updating the DIL framework with these findings, a second interview study was carried out to explore teachers' views on its complexity and practicality.

The results provided (a) insights on the personal and external factors behind teachers' use of intuition and didactics for decision-making and implementation of iVR, (b) confirmation of and addition to the educational affordances of iVRLEs, (c) additions to the design and implementation principles, and (d) improvements on the complexity and practicality of the DIL framework. One primary contribution of teachers' experience to the didactics for immersive learning was the influence of external factors (e.g., organizational, perceived-value, contextual, and social practices) on iVRLE use by teachers. While didactics are essential for educationally beneficial use, it is easy to underestimate the facilitation or hindrance caused by these external factors. Therefore, a successful framework must consider the dynamics between didactics, teachers' personal factors, and external influences. Another significant contribution of teacher experience is the somewhat counter-intuitive importance of intuition. Although some teachers benefit from a nudge towards didactics-focused decision-making and implementation of mediums like iVRLEs, the valuable role of intuition must be acknowledged in teaching a diverse range of learners in a dynamic environment under time constraints.

The teachers' evaluations of the DIL framework gathered from the verification interviews in the second study were used to update the framework and improve its practicality and comprehensibility. The additional explanations of the phases and sections within the phases and the circularity of the design process are added to the framework as an intermediate visualization (see Figure 16) between the general overview and the ADDIE-based visualization. Educators indicated the added value of a concise version of the framework focused on teachers who use the iVR in their lessons but do not design the materials. This tailored version is visualized in Appendix D.4.

By integrating the literature on (iVR) media didactic design principles with the qualitative empirical research, a pedagogical foundation was constructed to guide iVRLEs. With this, the thesis sets the first step to answer the pressing need from Lähtevänoja et al. (2020) for third-level design knowledge in order to guide the use of VRLEs by teachers and establish it as a didactically-grounded medium (see Figure 3). Next to pedagogical theories, the context of the learning situation in this media selection process was considered, satisfying the call by K. Nielsen and Miraglia (2017) and Wong et al. (2010). Similarly, the DIL framework attempted to satisfy the need by Cook et al. (2019) to "[d]evelop replicable workflows that can be implemented by a variety of stakeholders." The framework did this by incorporating learner, teacher, and organizational context in the framework, ensuring no essential factors of specific stakeholders are overlooked.

IVR topics and research often appeared to be based on researchers' common-sense (Dalgarno & Lee, 2010) or tenure and promotion portfolios (Cook et al., 2019). To promote and facilitate didactics-based research, the DIL framework first expanded on studies by integrating iVR studies with media didactics and general didactical principles. With this, the initial DIL framework could aid in "*how* iVRLEs should be used as part of the learning path and with other technologies" (see Figure 6). While providing scientifically well-grounded guidance on how iVRLEs should be used as part of the learning path and in relation to other technologies, the aspect of teacher experience was still missing. It was necessary to include educators' experience, expertise, and professional judgment to improve the DIL framework to be a valuable and accessible guide to evidence-informed teaching practice. As mentioned, a learning theory could have outstanding theoretical performance features but have minimal didactic benefit if learners and teachers do not accept it or do not use it according to its design (Gerstenmaier, 2002; Kerres, 2018; Nuthall, 2007). By including teachers' experiences in the DIL framework, this thesis attempted to build on the various established instruction design theories (see "Selection Process of a Didactical Medium," p.26) and guide the evidence-based iVR use.

Similarly, it is hoped that the DIL can facilitate the practical use of iVRLEs based on evidence (including didactics and teacher experience) so that it supports learning. Since no single method or medium works well under all conditions, it was essential to consider why and when iVRLEs support learning (Atkinson, 2000; Berliner, 2002; Commissie Parlementair Onderzoek Onderwijsvernieuwingen, 2008; Cook et al., 2019; "Immersive technology," 2020; Kirschner & van Merriënboer, 2013; Van Merriënboer & Kirschner, 2018). As Kirschner et al. (2020) noted, "[t]he content and learning goals should determine the choice of media, not the other way around. Technology for the sake of technology is bad practice” (p. 292). With the DIL framework, the thesis made progress in establishing why and when iVRLEs support learning. With this, the framework hopes to promote “using (iVR) technology for the sake of learning.”

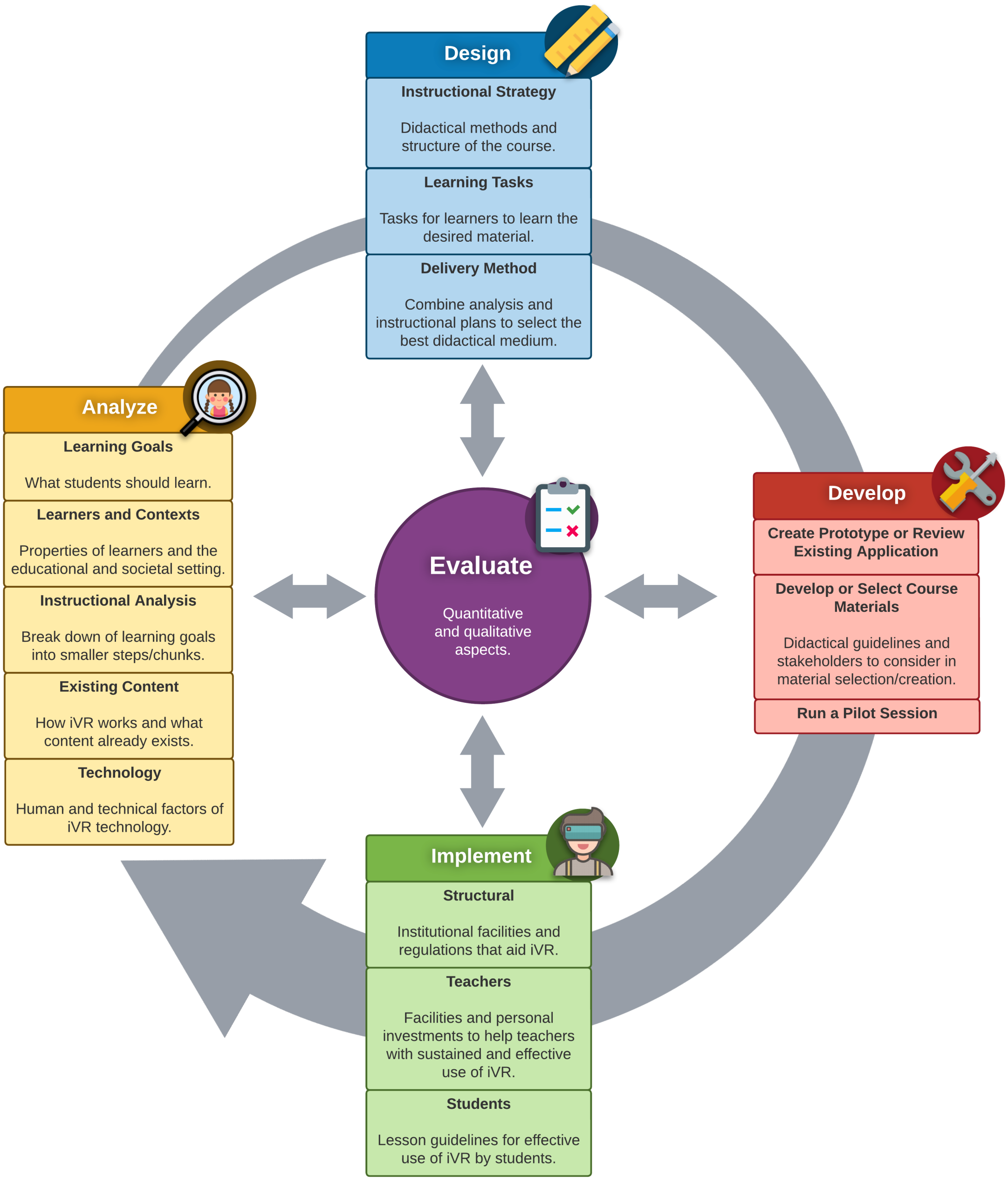

Figure 16. Circular visualization and explanation as addition to the Didactics for Immersive Learning (DIL) framework (see Appendix D.3.4.). Not shown are additional relationships between phases. In daily teaching, phases blend into each other and are used more fluidly.

6.1. Implications

At the start of the educational medium selection process, educators can use the DIL framework to assess learner, teacher, or organizational readiness to adopt iVR in their teaching and curriculum. Learner assessment could, among others, analyze the study conventions learners are used to, their iVR familiarity, and their cognitive and developmental differences. Teacher assessment could, among others, look into teachers' iVR knowledge and their openness to change/learn. Assessors can also take a more specific look at the teachers' course structure, learning tasks, and assessments. Organizational assessment could, among others, evaluate available spatial, network, and bandwidth facilities. Facilities also include accessibility of iVR equipment, ICT and didactical assistance, and available time and budget for teachers to train. Additionally, educators could analyze the curriculum to determine if iVR can be included or if it would give sufficient space for teachers to experiment with iVR.

At any point in time, the DIL framework can be applied (e.g., by educators, educational boards, or learning material designers) to aid in the development of iVRLEs. Here, it could assist in the process as a detailed guideline from analysis to implementation, even when the decision is already made to use iVR. Alternatively, the framework could be used more liberally as a checklist, which can occasionally be consulted to ensure that most essential points have been considered.

Next to assisting in developing iVRLEs, the DIL framework can be a tool to educate teachers or teacher trainees by guiding the educational discourse on the iVR decision process and implementation. It is recommended to educate future teachers about iVR in teacher college since it can be considered next to other didactical mediums relevant to their subjects. When experienced teachers are trained on iVR in a workshop, they must be given sufficient time off from other obligations.

When the iVRLE has been developed or selected beforehand, the DIL framework can still guide its implementation (e.g., in a lesson or course sequence). The framework could be overwhelming and less comprehensible since a focus on the usage of iVRLEs does not require the entire framework that includes design guidelines. Therefore, a concise version of the DIL framework is included (see Appendix D.4.). This concise version can aid teachers in the practical implementation of iVR in their lessons and course sequences.

A significant implication of the study's findings is that intuitional teaching practice will continue to play a role and have to be incorporated into the expectations from the beginning. Even with facilitation by external factors and didactical guidance by the DIL framework, many teachers will stick with familiar methods due to personal factors (e.g., openness to change or ICT knowledge). Above all, a degree of intuitional teaching practice will remain vital for teachers to adapt their learning contents to the dynamic setting of daily lessons.

An additional goal of this thesis was to further the scientific establishment of iVR as a didactical tool. The research community has seen limited recognition of iVR projects as scholarly or pedagogical pursuits (Cook et al., 2019; Dalgarno & Lee, 2010; De Freitas, 2006; Fowler, 2015; "Immersive technology," 2020; Steffen et al., 2019). Particularly because directly comparing different didactical methods is complex and possibly misleading (R. E. Clark, 1983; Kirschner et al., 2020; Neelen & Kirschner, 2020; Rosenthal & Jacobson, 1968; Szumski & Karwowski, 2019; Thorndike et al., 1968). To fully understand the educational potential of iVRLEs, there was a need for research on the necessary characteristics of instructional methods and the situational and personal contextual variables (R. E. Clark, 1983; Kirschner et al., 2020; Kozma, 1994). It is hoped that the DIL framework adds to the pedagogical acknowledgment of iVR. Towards this goal, the contextual and didactical considerations of the DIL framework should be practically implemented and built upon in future research.

6.2. Limitations

Study

A study of this kind has several limitations. Even though the participants in this study were selected as carefully as possible to comprise a representative sample of educators in secondary and tertiary education, a limitation of this study is the bias of consisting of available and interested educators. Due to the self-selection bias, this thesis may have missed inputs from teachers who are unconvinced that iVRLEs can play a positive role in education. Additionally, there are limitations to the extent to which teachers' feedback on the framework predicts the success/failure of iVRLEs in practice.

Nevertheless, this study is the first to merge didactics, context, and teacher experience into a single framework for educational iVR guidance. The impact of bias is expected to be decreased by the large sample size and qualitative nature of the thesis, adding more nuance to the findings. Conducting wide-scale and institutional-wide studies will allow for an additional investigation of didactical iVR with minimized bias. Conducting longitudinal or quantitative studies with larger sample sizes will further validate the DIL framework. Moreover, although many of the insights are likely valid for the larger population of teachers, there may be differences in personal and external factors across different educational institutions, levels, and topics. Since this study predominantly consisted of Dutch educators, differences are also expected to exist with other cultures.

DIL Framework

Educators' understanding of learning, teaching, and accompanied didactic methods is known to only change slowly over the years (Bischof et al., 2016), as previously mentioned in the literature review. The slow change is likely to hold true for didactics regarding iVR. However, since the framework accommodates many instructional methods, it can still be of added value through teachers' didactical transition.

The DIL framework is based on a literature review and two exploratory studies. Practical research is required to substantiate the validity of the framework further. Ideally, practical studies would investigate the use of the DIL framework for teacher/organizational iVR readiness assessment, education of teachers on iVR, iVR development, and iVR usage. Some aspects suggested by this thesis to assess iVRLE performance in development and use are: (a) subjective satisfaction of learners and teachers (Kirschner, 2002), (b) use and acceptance of the iVRLE (Kirschner, 2002), and (c) qualitative and quantitative learning outcomes (preferably of a natural evaluation) (Goodwin et al., 2015; Johnson-Glenberg & Megowan-Romanowicz, 2017; Kirschner, 2002). It is suggested to perform a longitudinal study to limit possible influence of the novelty effect.

Educational iVR

A potential limitation is the creation of extra work for teachers. Even though starting with iVR takes short-term effort (for which teachers should be accommodated), it is expected that the technology can unburden teachers in the long term. It is, therefore, critical to strive for the DIL framework to make work easier for educators.

The technology of iVR also knows limitations on potential physical (e.g., dizziness, nausea) and mental (e.g., merging of realities) side effects. However, since students have increasing experience with online and virtual environments, effects from educational iVR are expected to be no different from students' extra-educational devices (e.g., mobile and iVR devices). Nevertheless, it is crucial to consider the general impact of these technologies. Educators should also not overuse iVR and use it for all lessons since this poses a high risk of decreased learning outcomes and adverse effects.

6.3. Future Research

For future research on the didactical use of iVR, the DIL framework provides an extensive basis with its literature review and interview verification. A scientific implication of this study is the necessity of considering teacher intuition and experience for successful acceptance and adoption. A degree of experience-based intuitional teaching will always be required due to the dynamic nature of education, which can not all be captured in didactic theories. Therefore, future research is suggested not to investigate iVRLE-related didactics in isolation but to include teachers' intuition regarding iVR selection and use.

To ensure the sustainability of the iVR-enhanced learning, it is critical to further broaden the typical scope of analysis (focusing on technological and personal factors) to include organizational, perceived-value, and social practice factors. Future investigations could clarify how the different factors should be adapted to facilitate didactical iVR use best. An example is the perceived-value factor, where it should be considered what the learning benefits or usage time (e.g., relative to the total course) would have to be to make the investment worthwhile. These cost related limitations are a widely shared concern in the literature (Cook et al., 2019; Kerres, 2018; Onyesolu & Udoka, 2011; Xu et al., 2021). The need for institutional and organizational change is also in line with previous research (Bagiati et al., 2020). A non-conclusive tendency that could be worthwhile to investigate further is the difference in relative impact which the personal and external factors have, depending on the adoption stage of the teacher (awareness, acceptance, adoption). Following the research by Leoste et al. (2021), it is expected that teachers in different stages could be best approached by focusing on a subset of factors. However, educational institutions will be comprised of teachers divided over different stages, complicating the establishment of a singular institutional focus. Naturally, the educational context may further influence the prioritization of the external factors.

Future research is also recommended on how educators would put the DIL framework into practice. Previous research suggests that didactical theories are hard to implement and guide teachers' actions. However, research has not often considered the interaction between a theory and intuitional teaching practice. As stated by Biesta (2007), didactical theories tend to neglect the value of pedagogical professionals' judgment about what is educationally desirable in situations. As a result, didactics do not provide easy-to-use solutions for dealing with specific problems and should thus not be expected to influence the practical action of teachers directly (Reinartz, 2003). When teachers use instructional methods, they adapt these for usage in the classroom. However, this translation often leads to teachers who believe they are using a method to be doing different things (Nuthall, 2007, p. 32-33). This study developed tools to support teachers in the didactical decision-making and implementation of iVR. However, since real-life teaching first meets a translation step through the teacher, additional practical research on the interaction between the DIL framework and iVR implementation is recommended.

Participants requested the inclusion of templates or ready-made iVR material into the DIL framework, which they could still adapt and use in their lessons, similar to how Casio and Texas instruments provide material for mathematics that uses the graphical calculator. Participants simultaneously saw issues with adapting pre-made iVR materials because of their technical complexity and the need for the material to be in line with the curriculum's approaches. Therefore, it would be beneficial for future research to investigate what kind of supplied learning material (e.g., by schools, governments, or companies) would most help teachers of different subjects and educational levels.

7. Conclusion

This thesis aimed to construct a framework with interdisciplinary didactical guidelines to guide the didactically-grounded use of iVRLEs. Towards this goal, the DIL framework was developed based on a literature study and two qualitative studies on the selection and integration of iVR in education. The framework expanded on previous literature by combining media didactical theories relevant to iVRLEs. Additionally, the framework expanded on existing studies by linking didactical theory to real-world teaching by incorporating teacher experience. An overview is included of the didactical affordances of iVR and the design principles of iVRLEs, and the DIL framework (see Figures 17-19; see Appendix D. for all visualizations).

The study illustrates the potential of the DIL framework not only for the evidence-informed design of iVRLEs, but also for assessing iVR readiness of teachers/organizations, applying iVR in classrooms, training teachers, and gathering support from educational boards. Practical research is required to substantiate the validity of the framework further.

This thesis also raises the question of how external factors (perceived-value, organizational, contextual, and social practice) can best facilitate teachers in iVRLE use. Further research is recommended to determine how these factors should be addressed to promote didactical iVR use by teachers. Even with didactical guidance by the DIL framework and facilitation by external factors, intuitional teaching practice will continue to play a role since some teachers will stick with familiar methods due to personal factors. Additionally, a degree of intuitional teaching will remain vital for teachers to adapt their learning contents to the dynamic setting of daily lessons. All in all, the newly developed

DIL framework is directly applicable to motivate and improve iVR use in education.

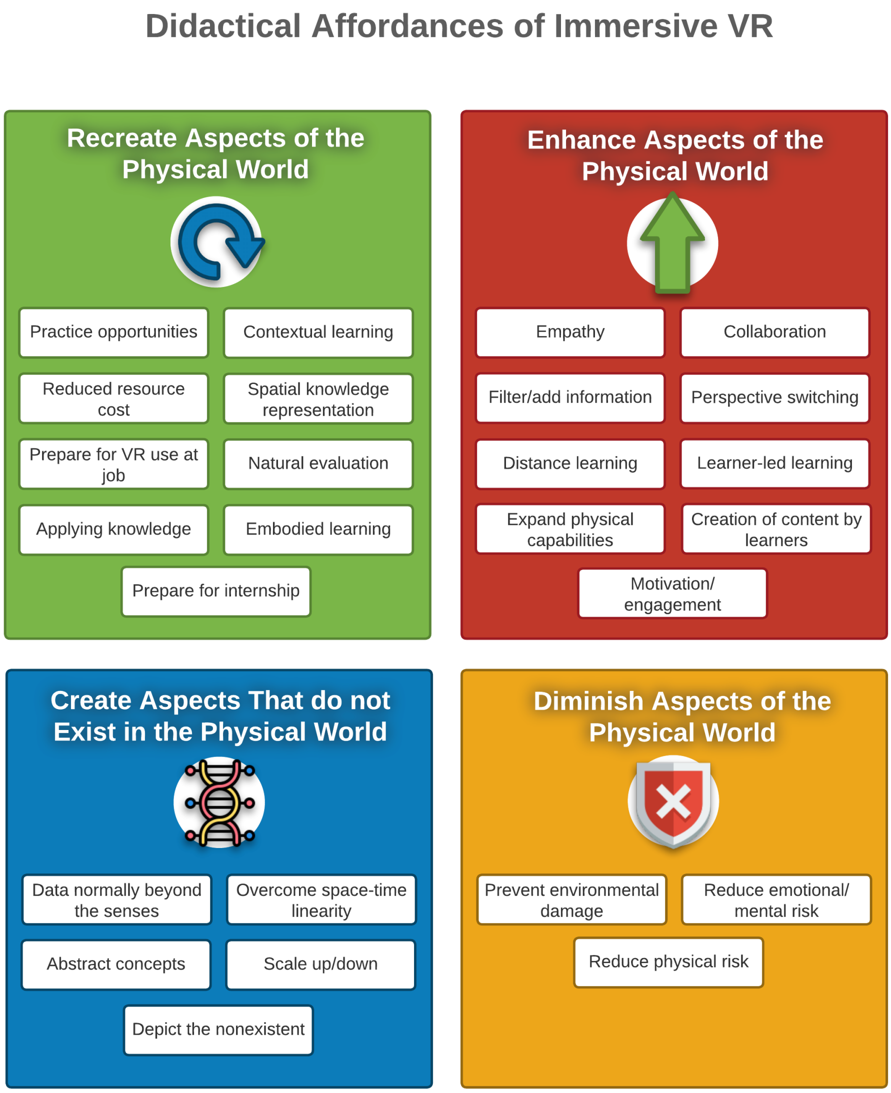

Figure 17. Didactical affordances (social and educational) for immersive Virtual Reality.

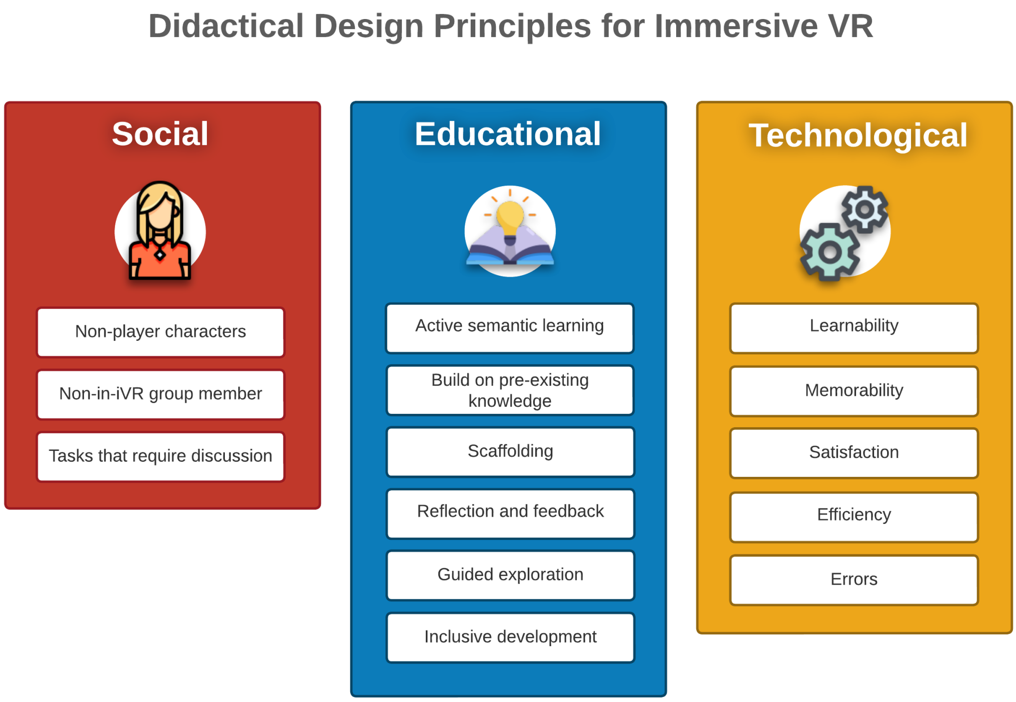

Figure 18. Design principles for immersive Virtual Reality Learning Environments.

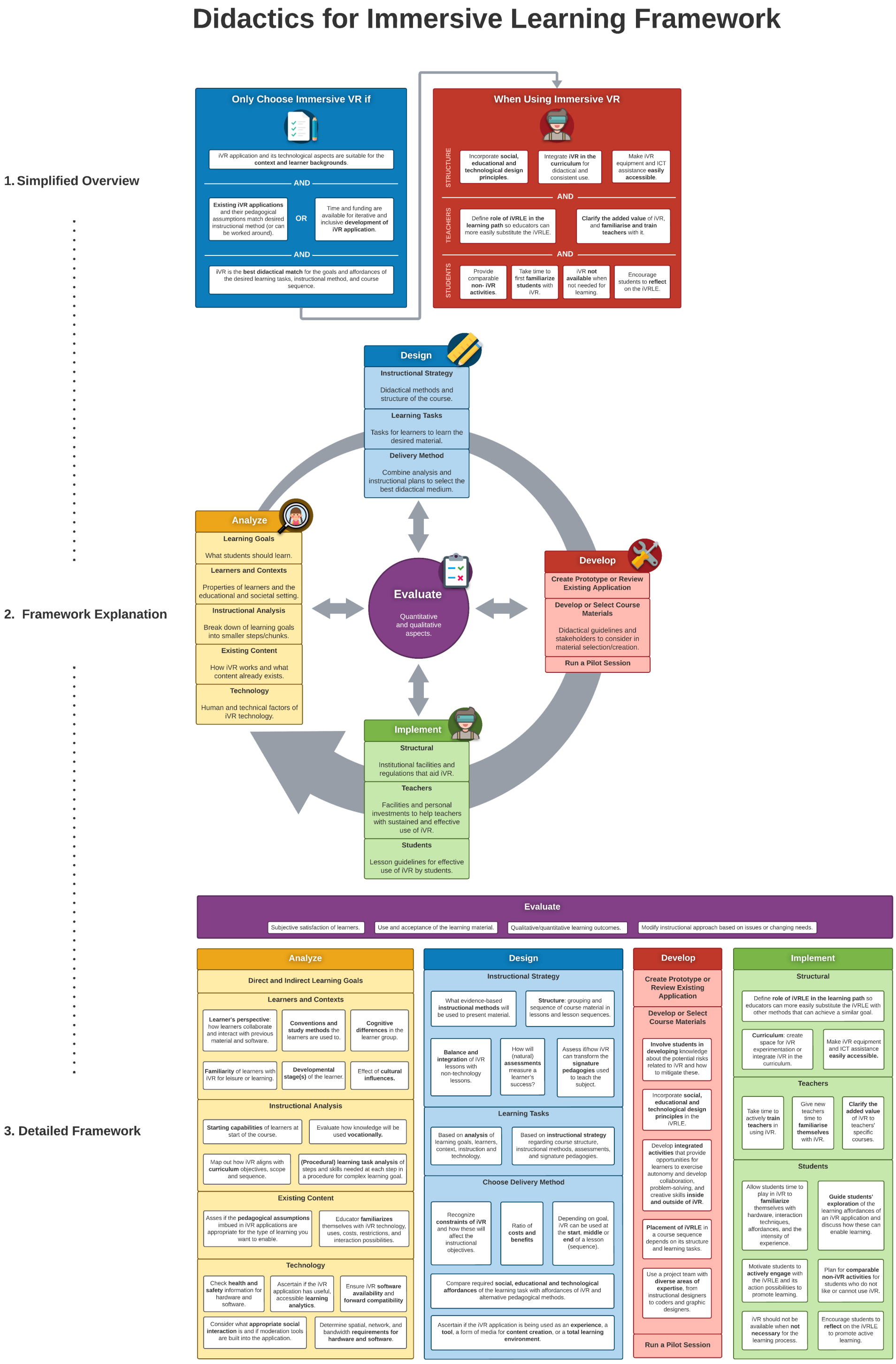

Figure 19. Overview of the complete Didactics for Immersive Learning framework. For enlarged final images see Appendix D.3.

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Appendices

Appendix A.1. Informed Consent Study 1: The Role of Didactics in Introducing iVR in the Classroom

TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

Information form for participants

This document gives you information about the study "*Virtual reality in education: When and how to use it as a didactic medium.*" Before the study begins, it is important that you learn about the procedure followed in this study and that you give your informed consent for voluntary participation. Please read this document carefully.

Aim and benefit of the study

The aim of this study is to investigate practical experiences on lesson planning and didactic (VR) media selection in lesson planning. This information is used to update theoretical models on didactic VR usage based on real-world practice. With this, the goal is to make VR as a medium in education more accessible and based on didactics.

This study is performed by Floris van Himbergen, a student under the supervision of Wijnand Ijsselsteijn of the Human-Technology Interaction group.

Procedure

During the interview questions will be asked about your experiences with VR, didactics and (the selection of media as part of) lesson plan construction. Some questions can ask for your elaboration in the form of simple sketches.

Risks

The study does not involve any risks, detrimental side effects, or cause discomfort. For the face-to-face interview with participants, the researcher will take a COVID test beforehand. During the interview, an FFP2 mask will be worn, and 1.5 meters of distance will be attended to at all times to make the risk of spreading COVID-19 as low as possible.

Duration

The instructions, measurements and debriefing will take approximately 60 minutes.

Participants

You were selected because you are an expert in the field of didactics or VR, and/or you have experience with VR in teaching.

Voluntary

Your participation is completely voluntary. You can refuse to participate without giving any reasons and you can stop your participation at any time during the study. You can also withdraw your permission to use your data up to 24 hours after they were recorded. None of this will have any negative consequences for you whatsoever.

Compensation

You will receive a book voucher for participating in the interview.

Confidentiality and use, storage, and sharing of data.

All research conducted at the Human-Technology Interaction Group adheres to the Code of Ethics of the NIP (Nederlands Instituut voor Psychologen – Dutch Institute for Psychologists), and this study has been approved by the Ethical Review Board of the department.

In this study personal data (name, email address, age, gender, occupation) and experimental data (responses to the interview and sketches made during the interview) will be recorded, analyzed, and stored. The goal of collecting, analyzing, and storing this data is to answer the research question and publish the results in the scientific literature. To protect your privacy, any data that can be used to personally identify you will be stored on an encrypted server of the Human Technology Interaction group for at least 10 years that is only accessible by selected HTI staff members. No information that can be used to personally identify you will be shared with others.

Your email address will only be collected for communication and sending the reward in the case the interview takes place online. Your email address will be kept separate from the experimental data and will be deleted after the reward has been sent.

The coded data collected in this study and that will be released to the public will (to the best of our knowledge and ability) not contain information that can identify you. It will include all answers you provide during the study, including demographic variables (e.g., age and gender) if you choose to provide these during the study.

We will not share personal information about you or your responses in this study with anyone outside of the research team. Only the researchers will know your identity and responses and we will store that information in an encrypted and password protected database.

Audio recordings are made that could identify you. The recordings will not be distributed and will not be played back in the presence of persons other than the researchers. The material will be used only for scientific analysis and deleted after transcribing the data.

Further information
If you want more information about this study, the study design, or the results, you can contact Floris van Himbergen (contact email: f.f.v.himbergen@student.tue.nl).

If you have any complaints about this study, please contact the supervisor, Wijnand IJsselsteijn (W.A.IJsselsteijn@tue.nl). You can report irregularities related to scientific integrity to confidential advisors of the TU/e.

TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

Informed consent form

Virtual reality in education: When and how to use it as a didactic medium.

- I have read and understood the information of the corresponding information form for participants.

- I have been given the opportunity to ask questions. My questions are sufficiently answered, and I had sufficient time to decide whether I participate.

- I know that my participation is completely voluntary. I know that I can refuse to participate and that I can stop my participation at any time during the study, without giving any reasons. I know that I can withdraw permission to use my data up to 24 hours after the data have been recorded.

- I agree to voluntarily participate in this study carried out by the research group Human Technology Interaction of the Eindhoven University of Technology.

- I know that no information that can be used to personally identify me or my responses in this study will be shared with anyone outside of the research team.

- I
  □ **do**
  □ **do not**
  give permission to store an audio recording that can be used to personally identify me only for scientific analysis and which is deleted after transcribing the data.

Certificate of consent

I, (NAME) ………
want and provide consent to participate in this study.

Participant's Signature

Date

Appendix A.2. Informed Consent Study 2: Validation of the DIL Framework

EINDHOVEN UNIVERSITY OF TECHNOLOGY

Information form for participants

This document gives you information about the study "*Immersive Virtual reality in education: When and how to use it as a didactic medium.*" Before the study begins, it is important that you learn about the procedure followed in this study and that you give your informed consent for voluntary participation. Please read this document carefully.

Aim and benefit of the study

The aim of this study is to explore how educators experience the constructed iVR-ISD model in terms of complexity, how they would use it, and what could be improved. By verifying the model, which was constructed based on literature review and a first round of interviews, the aim is to help educators with evidence-informed selection and application of immersive Virtual Reality.

This study is performed by Floris van Himbergen, a student under the supervision of Wijnand Ijsselsteijn of the Human-Technology Interaction group.

Procedure

During the interview questions will be asked about your experiences on lesson construction in comparison to the iVR-ISD model, how complex the constructed model appears to be, how you would use the model in practice and what could be improved about the model. Some questions can ask for your elaboration in the form of simple sketches.

Risks

The study does not involve any risks, detrimental side effects, or cause discomfort. For any face-to-face interview with participants, the researcher will take a COVID test beforehand. During the interview, an FFP2 mask will be worn, and 1.5 meters of distance will be attended to at all times to make the risk of spreading COVID-19 as low as possible.

Duration

The instructions, measurements and debriefing will take approximately 60 minutes.

Participants

You were selected because you are an expert in the field of didactics or immersive virtual reality (iVR), and/or you are an educator with or without experience with iVR in teaching.

Voluntary

Your participation is completely voluntary. You can refuse to participate without giving any reasons and you can stop your participation at any time during the study. You can also withdraw your permission to use your data up to 24 hours after they were recorded. None of this will have any negative consequences for you whatsoever.

Compensation

You will receive a book voucher for participating in the interview.

Confidentiality and use, storage, and sharing of data.
All research conducted at the Human-Technology Interaction Group adheres to the Code of Ethics of the NIP (Nederlands Instituut voor Psychologen – Dutch Institute for Psychologists), and this study has been approved by the Ethical Review Board of the department.

In this study personal data (name, email address, age, gender, occupation) and experimental data (responses to the interview and sketches made during the interview) will be recorded, analyzed, and stored. The goal of collecting, analyzing, and storing this data is to answer the research question and publish the results in the scientific literature. To protect your privacy, any data that can be used to personally identify you will be stored on an encrypted server of the Human Technology Interaction group for at least 10 years that is only accessible by selected HTI staff members. No information that can be used to personally identify you will be shared with others.

Your email address will only be collected for communication and sending the reward in the case the interview takes place online. Your email address will be kept separate from the experimental data and will be deleted after the reward has been sent.

The coded data collected in this study and that will be released to the public will (to the best of our knowledge and ability) not contain information that can identify you. It will include all answers you provide during the study, including demographic variables (e.g., age and gender) if you choose to provide these during the study.

We will not share personal information about you or your responses in this study with anyone outside of the research team. Only the researchers will know your identity and responses and we will store that information in an encrypted and password protected database.

Audio recordings are made that could identify you. The recordings will not be distributed and will not be played back in the presence of persons other than the researchers. The material will be used only for scientific analysis and deleted after transcribing the data.

Further information
If you want more information about this study, the study design, or the results, you can contact Floris van Himbergen (contact email: f.f.v.himbergen@student.tue.nl).

If you have any complaints about this study, please contact the supervisor, Wijnand IJsselsteijn (W.A.IJsselsteijn@tue.nl). You can report irregularities related to scientific integrity to confidential advisors of the TU/e.

EINDHOVEN UNIVERSITY OF TECHNOLOGY

Informed consent form

Virtual reality in education: When and how to use it as a didactic medium.

- I have read and understood the information of the corresponding information form for participants.
- I have been given the opportunity to ask questions. My questions are sufficiently answered, and I had sufficient time to decide whether I participate.
- I know that my participation is completely voluntary. I know that I can refuse to participate and that I can stop my participation at any time during the study, without giving any reasons. I know that I can withdraw permission to use my data up to 24 hours after the data have been recorded.
- I agree to voluntarily participate in this study carried out by the research group Human Technology Interaction of the Eindhoven University of Technology.
- I know that no information that can be used to personally identify me or my responses in this study will be shared with anyone outside of the research team.
- I
  □ **do**
  □ **do not**
  give permission to store an audio recording that can be used to personally identify me only for scientific analysis and which is deleted after transcribing the data.

Certificate of consent

I, (NAME) ………
want and provide consent to participate in this study.

Participant's Signature

Date

Appendix B.1. Interview Questions Study 1: The Role of Didactics in Introducing iVR in the Classroom

Interviews – Round 1: Exploratory Questions

Thesis Research

Topic: Immersive virtual reality as a didactic medium in education

Researcher: Floris van Himbergen

Supervisors: prof. dr. IJsselsteijn & dr. ir. Ruijten-Dodoiu

Affiliation: Eindhoven University of Technology

1 Opening

Introduce myself and my thesis.

Give the participant the informed consent to sign, if on Teams, proceeding with the study will be seen as a signature.

Notify them of my audio recording.

Write down:

- Gender
- Preferred pronouns,
- Age,
- Occupation,
- How long they have had this occupation,
- Email address (if I do not have this already) for reward.

2 Opening Segment (broad questions)

Let the participant speak from their experience.

When necessary, probe for clarification.

Note down important parts of their story to come back to later.

1. Can you tell a little bit about yourself? *What subject do you teach?*

2. Can you tell something about how you select didactic media for individual lessons or lesson sequences? *Can you explain your steps? Do you use any theoretical models?*

3. If an example lesson plan, or tips about such a plan, for VR usage were to be made, how would you prefer this to be presented? *How detailed?*

3 Middle Segment

Come back to notes from earlier.

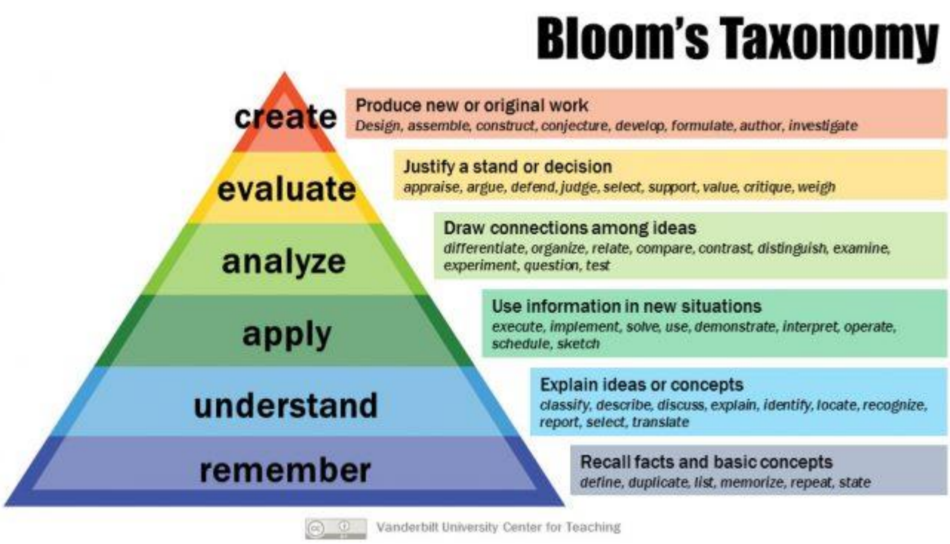
Extend my probes beyond clarification to "meaning making" regarding my research topic.

4. What are the most common goals for using media in your lessons?
    a. *Is it based on learning outcomes such as knowledge, understanding, application and action?*
    b. *Or is it based on attitudes such as self-regulation, strategic knowledge or planning competence and coping with other demands of the life world?*
    c. *Is it based on a different goal?*

5. In which way do you use VR in your lessons? *Which instructional method do you use? What are the benefits of VR in this situation? How does this look technologically, is it a video or an immersive environment? How much gestures and actions do students do in VR?*

Bloom, 1956

6. How do you adapt the media to the (competency) level of the students? *How about VR?*



4 Concluding segment

Reflect on theoretical considerations.

Return to stories in need for further exploration.

Explore contradictions.

7. What do you think of the instructional methods you have used in and around educational media up until now? *How well do they work for you, what can be improved? How about for VR specifically?*

Reigeluth, 1983

8. How do you feel about the following structure to making lesson plans? *Is this something you have experience with?*

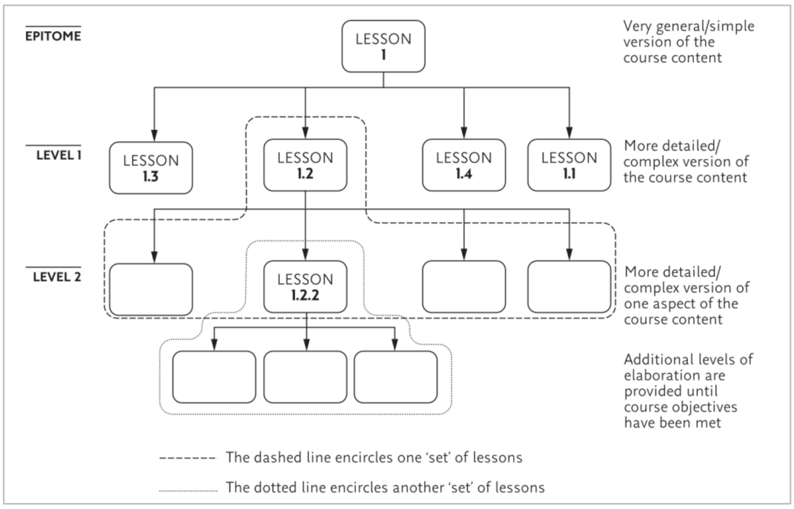
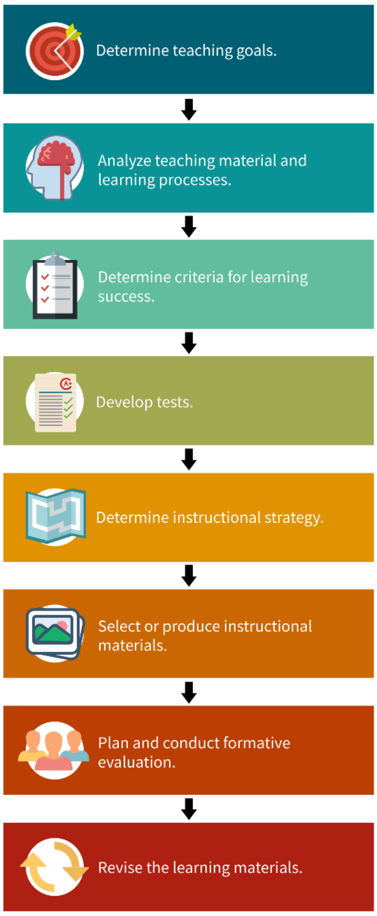


Image Source: Kirschner, P. A., Hendrick, C., & Caviglioli, O. (2020). How learning happens : seminal works in educational psychology and what they mean in practice.

9. Do you take into account a similar kind of lesson structure when deciding on which media to use, and when?

Dick et al., 2015

10. What do you think of the following process of selecting an educational medium? *Do you follow a similar process? What differs most with the process below?*



Kerres, 2018

11. To which degree do you take the following criteria into account when selecting a medium?

- Should **abstract concepts**, relationships, processes be made clear (diagrams, sketches, flow charts)? To what extent is a spatial representation helpful?
- Should **specific examples**, situations or contexts be made visible (photos, video recordings, cartoons, simulations)? To what extent are these phenomena that benefit from a spatial representation?
- Should **skills** be presented and trained? To what extent do these skills relate to settings in which a spatial representation supports the learning process?
- Can learning be embedded in everyday action routines that provide information or feedback through innovative interfaces? **Can the display of information and feedback disrupt the natural flow of action?**
- Is it about conveying **emotional experiences** and attitudes? To what extent is there a risk that these sensations will be assessed as emotionally "overwhelming"?

12. What is your experience with constructivist learning with didactic media? *For instance, with inquiry or exploration-based learning, or problem-based learning? How about with VR?*

Mayer, 2014 | Mulders et al., 2020

13. Do you take into account the two information processing channels, pictorial and verbal, of the students? *How?*

14. Do you, for example, guide learning by highlighting essential material in a didactic medium? *How about in VR?*

15. How do you promote active learning by students? *How do you motivate them to organize and integrate the information with the existing knowledge?*

16. How do you make sure to adjust the didactic medium content to the learners' current level of knowledge? *Do you take into account that students with higher prior knowledge benefit from different amounts of preparation and support in and outside of the medium? How about in VR?*

17. What would you recommend to any teachers who would want to use VR in their lessons? *Do you have any recommendation on the timing of it, in a lesson itself or in a lesson sequence?*

18. After considering the last couple of questions, would you like to update your answer on how you would like an example lesson plan to be presented?

19. Do you have additional thoughts or final points you would like to express?

Finishing up

Thank the participant and emphasize their contribution to the research.

Ask for contact details of possible contacts who I could also interview.

Point them to my email address (on the informed consent) for any questions.

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Appendix B.2. Interview Questions Study 2: Validation of the DIL Framework

Achtergrond

(1) Op welk onderwijsniveau geef je les? In welke vakken?
(2) In welke mate heb je VR reeds geadopteerd in je lessen?
    (a) Geen gebruik. Ik wil/kan het niet beginnen te gebruiken.
    (b) Minimaal gebruik. Niet onderdeel van mijn dagelijkse routine.
    (c) Passief gebruik. Ik beperk me tot de standaard mogelijkheden van VR.
    (d) Actief gebruik. Ik gebruik VR in de klas met enige regelmaat; ik probeer nieuwe VR mogelijkheden uit in de klas.
    (e) Innovatief gebruik. Ik ben een aanjager van VR gebruik binnen mijn school. Ik ben op zoek naar innovatieve toepassingen van VR in de klas.
(3) Hoeveel jaar onderwijs je reeds? (Hoe lang daarvan gebruik je VR?)

Herkenbaarheid van het Didactiek voor Immersief Leren framework

(4) Begrijp je dit framework? Zijn er dingen onduidelijk?
(5) Herken je jouw eigen lesgeven in de praktijk in dit framework? Wat zijn de verschillen?
(6) Zou je bepaalde fases prioriteren? Zo ja, welke en waarom?

Bruikbaarheid van het DIL framework

(7) Hoe kijk je naar het gebruik van VR in de toekomst? Wat zijn de knelpunten?
(8) Hoe kan dit framework jouw VR gebruik ondersteunen?
(9) Wat kan er aan dit framework verbeterd worden?
(10) Zou je nog iets anders willen zeggen?

Appendix C.1. Variable Matrix for Interview Study 1: The Role of Didactics in Introducing iVR in the Classroom

General					Core thesis					Usability			
#	VR Exp.	Educational level	Topic	iVR type	Instructional models used	Selection process	Learning goals iVR	When iVR in lesson plan structure	How iVR applied in lesson	Promoting active learning	Highlighting in iVR	Dual processing	Student level adaption
1	3 years	VMBO	Technology	Individual simulation	No model, experimentation	unfamiliar with iVR, needs practice before being able to use	Distance learning	iVR before real-life application, cannot break things	Take time to familiarize students with iVR	Reflection	Expensive		
			History	360 video without choices	Gamification	Teachers stick to methods they know	Contextual learning	the middle after theory or at the end of a lesson.	does fast, too expensive to buy HMD for entire		Questions outside of iVR		
					Needs to work with existing	accessibility --> iVR not readily	Spatial representation	iVR as preparation for internship	iVR in small groups				
						Too busy to learn about and practice with iVR	outcomes would help convince teachers	Reflection aftrer iVR experience					
						develop knowledge about what could be improved about							
						Based on feeling							
						Search available							

General					Core thesis					Usability			
#	VR Exp.	Educational level	Topic	iVR type	Instructional models used	Selection process	Learning goals iVR	When iVR in lesson plan structure	How iVR applied in lesson	Promoting active learning	Highlighting in iVR	Dual processing	Student level adaption
2	2 years	HBO	Therapy	Individual simulation	No model	Approached by iVR company	Enjoyment	One time gimmick					Hints (e.g., exagerate behavior)
					Direct translation of real-life procedure	Include students and teachers in development	Practice conversation.	Incorporate iVR in curriculum for consistent use					students with metrics from iVR simulation to analyze
						360 video cheaper	Affective	Practice tool for					
						Gather enthusiasm for teachers to	Creation as mastery						
						Analyze learning situation to see if	Depends on teacher						
						Incorporate iVR in curriculum for	Social safety						
						Teachers need IT support for when issues arise	More consistent and fair than actors						
3	1 year	tertiary education	sciences	non iVR simulation	Direct translation of real-life	Include students and teachers in	Practice lab work	iVR before real-life application		Questions during	Arrows	Visual and voice over	Hints are present
					Gamification	Based on feeling	Safety of practice	the middle after theory or at the end of a lesson.		Reflexive questions	Voice over	Voice over can be turned off	
					Existing curriculums	Teachers stick to methods they	Reduce anxiety for real-life						
							Abstract concepts						
							Embodied learning						
							Engagement						
							Spatial representation						
							Reduced costs						

General					Core thesis					Usability			
#	VR Exp.	Educational level	Topic	iVR type	Instructional models used	Selection process	Learning goals iVR	When iVR in lesson plan structure	How iVR applied in lesson	Promoting active learning	Highlighting in iVR	Dual processing	Student level adaption
4	5 years	primary and secundary education		simulation independent	Uses specific model	Teachers need IT support for when issues arise	Skills	Incorporate iVR in curriculum for consistent use	Limit consequent iVR time. Max 20-25 minutes	Reflection	Voice over	Visual and voice over	Removing hints
					Within existing curriculums	Teachers need to see benefit of iVR	Empathy	Theory before iVR	Test how well a student can use	Feedback during or after		Voice over can be turned off	Expensive
					Needs to work with existing application	Consider context during developing	Communication skills	iVR before real-life application	iVR someone needs to master the learning	Roleplay			
						Incorporate iVR in curriculum for	Physical safety	Only part of lesson in iVR	Only part of lesson in iVR				
							Practice (more feedback)						
							Prevent environmental damage (e.g. machines)						
							Abstract concepts						
							Creating						
							Collaboration						
							Cutting costs						
							Impossible						
							Easier to organize						
							Practice, applying knowledge						

General					Core thesis					Usability			
#	VR Exp.	Educational level	Topic	iVR type	Instructional models used	Selection process	Learning goals iVR	When iVR in lesson plan structure	How iVR applied in lesson	Promoting active learning	Highlighting in iVR	Dual processing	Student level adaption
5	1 year	HBO	digital innovations	simulation independent	Uses specific model	Based on feeling	Skills	Theory before iVR	Experimental	Discussion			
				360 video without choices	Within existing curriculums	Based on didactics	Impossible activities		does fast, too expensive to buy HMD for entire				
						Support from ICT coach or	Affective experiences		iVR in small groups				
						Gather enthusiasm for teachers to							
						Developing iVR simulation too							
						Analyze learning situation to see if							
6	none	VMBO	behavioral specialist										

General					Core thesis					Usability			
#	VR Exp.	Educational level	Topic	iVR type	Instructional models used	Selection process	Learning goals iVR	When iVR in lesson plan structure	How iVR applied in lesson	Promoting active learning	Highlighting in iVR	Dual processing	Student level adaption
7	2 years	HBO	social studies	360 video without choices	No model	expensive considering limited content and consquent	Practice, applying knowledge and more practice oppportunities	iVR as progress test	iVR in small groups	Roleplay	Text questions before iVR	existing context so no influence of teacher	students create part of iVR environment
				simulation independent	Direct translation of real-life procedure	relatively short compared to total study time and	Creating	iVR as practice tool for students at home	does fast, too expensive to buy HMD for entire	Reflection		Present extra text before or after iVR	More general as part of curriculum
						AI should be improved for soft skills.	Affective experiences	Theory before iVR	have students watch a screen of other student in	Discussion			
						Incorporate iVR in curriculum for	Safety of practice	Incorporate iVR in curriculum for					
						learning goals and activies set for multiple years,	Cutting costs	around iVR (e.g., so switching goes smooth, students					
						When does it work better than video?	Prepare students to vocationally use						
						Based on didactics	Contextual						
8	2 years	MBO	sportinstruc tor	360 video without	No model	Based on feeling (like iVR)	Engagement	iVR as preparation for internship	Limit consequent iVR time	Questions during iVR			
				with multiple choice		develop knowledge about what could be	Contextual learning	Theory before iVR	iVR in small groups	Internship			
						Analyze learning situation to see if iVR is the answer	Affective experiences	iVR as practice tool for students in class	does fast, too expensive to buy HMD for entire				
						Teachers need IT support	Skills	No specific placement in					
							Abstract concepts						

General					Core thesis					Usability			
#	VR Exp.	Educational level	Topic	iVR type	Instructional models used	Selection process	Learning goals iVR	When iVR in lesson plan structure	How iVR applied in lesson	Promoting active learning	Highlighting in iVR	Dual processing	Student level adaption
9	15 years	HBO	nursing	with multiple choice	Needs to work with existing application	Based on feeling	Contextual learning	iVR as preparation for internship	One student in iVR, the others watch on screen		if student loops back if students		
				360 video without		Search available content	Engagement	Reflection after iVR experience	Provide alternatives				
				simulation independent		Teachers stick to methods they	Depends on teacher	iVR as lessons starter					
				simulation controlled by teacher		unfamiliar with iVR, needs practice before being able	Spatial representation	iVR as progress test					
						Include students and teachers in	Abstract concepts						
						Hard to find customizable or	Skills, applying knowledge						
						Teacher wants to stand above	Practice opportunities						
						Teachers need IT	Enjoyment						
						Too busy to learn about and practice							
10	2 years	HBO	Applied psychology	simulation independent	Uses specific model	Too busy to learn about and practice	Practice opportunities	Practice tool for students at home	One student in iVR, the others	Discussion	Sound cues		
						see benefit of iVR for their specific course	Skills, applying knowledge		does fast, too expensive to buy HMD for entire		guide in iVR than in normal film		
						Gather enthusiasm for teachers to	Contextual learning						
						iVR hard to use	Prepare students to vocationally use						
						Analyze learning situation to see if	Enjoyment						
						Teachers do not know where to	Skills						
						expensive considering limited content and	Affective experiences						

General					Core thesis					Usability			
#	VR Exp.	Educational level	Topic	iVR type	Instructional models used	Selection process	Learning goals iVR	When iVR in lesson plan structure	How iVR applied in lesson	Promoting active learning	Highlighting in iVR	Dual processing	Student level adaption
11	6 years	HBO	Healthcare technology	simulation controlled by teacher	No model	Include students and teachers in development	Affective experiences	iVR as preparation for internship	Provide alternatives	Zoom in	Exegerating behavior of artificial agent		teacher who controls the simulation
				with multiple choice		Based on feeling (like iVR)	Skills, applying knowledge	No specific placement in lesson sequence.	Dependent on teaching style	Picture in picture			environment to increase difficulty, e.g.
						Need a well trained teacher for	Safety (of practice)	Theory before iVR					
						For consistent use need to	Enjoyment	iVR crammed into existing lesson					
						learning goals and activities is set for multiple years,	Engagement						
						Teacher has to work within							
						Teachers need to see benefit of iVR							
						not plan out learning goals and methods. Too time							
						Analyze learning situation to see if							
						Consider context during developing							
						to have knowledge about VR, needs to have used it for a substantial							
						Too busy to learn about and practice							
						Teachers need IT							

General					Core thesis					Usability			
#	VR Exp.	Educational level	Topic	iVR type	Instructional models used	Selection process	Learning goals iVR	When iVR in lesson plan structure	How iVR applied in lesson	Promoting active learning	Highlighting in iVR	Dual processing	Student level adaption
12	2 years	tertiary education	teaching education	simulation controlled by teacher	No model for iVR	Learning goals	Skills	iVR as preparation for internship	iVR in small groups	Reflection	highlight gaze during reflection of performance	Visual and audio information	Controlled by teacher who controls the simulation
					Direct translation of real-life	Based on feeling (implicit didactics)	Safety (social)	Reflection after iVR experience	Experimental	Discussion			Hints
					interaction with environment or teacher/peers	Difficult to apply existing didactics	Engagament	No specific placement in lesson sequence.	Provide alternatives	during or after acitivity, depends on			
						learning goals and activities is set for multiple years,	Applying knowledge	Theory before iVR	iVR, the others watch on screen. Take turns				
						AI should be improved for soft	Practice opportunities	Start with easy simulation, later in					
						develop knowledge about what could be		iVR crammed into existing lesson structure					
						Analyze learning situation to see if		iVR as progress test (conflicts with					
						When developing, allow for easy							
						Teachers do not know where to							
						Teachers need IT							

General					Core thesis					Usability			
#	VR Exp.	Educational level	Topic	iVR type	Instructional models used	Selection process	Learning goals iVR	When iVR in lesson plan structure	How iVR applied in lesson	Promoting active learning	Highlighting in iVR	Dual processing	Student level adaption
13	2 years	HBO	organizational psychology	360 video without choices	No model	develop knowledge about what could be	Contextual learning	Theory before iVR (with entire class)	More space needed for iVR	Discussion	Highlighting is expensive	Visual and audio information	
						Teachers need IT support	Affective experiences	iVR as progress test (conflicts with	Take time to familiarize	Reflection	Text questions before iVR to	No specific consideration	
						Variation of	Easier to organize	Only part of lesson	No reflection, too				
						Learning goals	Cutting costs		Hygiene of HMDs				
						Based on feeling	Impossible		Prepare and				
						unfamiliar with iVR, needs practice before being able	Collaboration		Only part of lesson in iVR				
						Teachers stick to methods they	Enjoyment						
						Teacher wants to stand above	Skills						
						iVR hard to use							
						Gather enthusiasm for teachers to							
14	2 years	HBO	Healthcare technology	simulation independent		Teachers need IT support	Skills	iVR as preparation for internship	Take time to familiarize	Feedback after activity			Not individual to student
						develop knowledge about what could be	Affective experiences	Theory before iVR	Only part of lesson in iVR				
						Do not wait for ideal content	Practice opportunities	iVR as practice tool for students					
						Analyze learning situation to see if	Applying knowledge	Lesson starter or at end of lesson					
						Gather enthusiasm for teachers to	Engagement	iVR as test					
						Learning goals	Easier to organize	Only part of lesson					
							Impossible	Do not use iVR for					
							More consistent and fair than						

General					Core thesis					Usability			
#	VR Exp.	Educational level	Topic	iVR type	Instructional models used	Selection process	Learning goals iVR	When iVR in lesson plan structure	How iVR applied in lesson	Promoting active learning	Highlighting in iVR	Dual processing	Student level adaption
15	1 year	HBO	nursing	simulation independent	Direct translation of real-life	Based on feeling (implicit didactics)	Enjoyment	iVR as practice tool outside of	Provide alternatives	Discussion	Teacher does voice over		
					Uses specific model for class	Variation of didactic methods	Contextual learning	No specific placement in	One student in iVR, the others	Students make powerpoint or			
						Accessibility, use iVR because it is	Engagement	iVR crammed into existing lesson	Prepare and organize well to				
						unfamiliar with iVR, needs practice before being able	Prepare students to vocationally use iVR						
						Learning goals							
						accessibility --> iVR not readily							
						learning goals and activities is set for multiple years,							
						Too busy to learn about and practice							
16	2 years	HBO	teaching education	without choices (*mobile vr)	Direct translation of real-life procedure	Teachers do not know where to start with iVR	instead of video	iVR as preparation for internship	Take time to familiarize students with iVR	Internship		Visual and audio information	
						privacy is a barrier for making 360	engagement	Theory before iVR	Limit consequent iVR time.	Discussion	Text questions before iVR to		
						AI should be improved for soft	Prepare students to vocationally use	iVR as starter, same 360 video	Prepare and organize well to	Reflection	teacher prompts		
						Teachers stick to methods they	Skills	Reflection after iVR experience		Roleplay			
						Learning goals	Affective experiences	360 video as reflection on real					
						lesson within curriculum but with different		Planned learning goals and methods/media					
						Analyze learning situation to see if		Divide content to not overload					
						unfamiliar with iVR, needs practice before being able							

Appendix C.1.1. Change of Learning Goal Phrasing after Conducting Study 1 Interviews.

The learning goal questions from the first interview study were reported on differently after new academic insights regarding the taxonomy by Bloom et al. (1956).

Following the insights, the learning goals will be phrased, where possible, in terms of holistic authentic learning tasks (Neelen & Kirschner, 2020). Often, learning goals are viewed in the light of atomistic design (Neelen & Kirschner, 2020), where learning is reduced to simpler or smaller components. A commonly used example is Bloom's taxonomy (Bloom et al., 1956), at times also used with an extra dimension of the knowledge domain (factual, conceptual, procedural, and meta-cognitive) added to the traditional cognitive domain (remember, understand, apply, analyze, evaluate, and create) of the framework (Anderson et al., 2001). While fragmented, linear frameworks of learning appear to aid in education by clarifying and visualizing the difference between learning goals, this clarification is but a semblance that might actually do more harm than good. Critiques for fragmenting the learning process in such a manner involve the inseparability and content-dependence of categories, incompleteness, and the codependency of affective and cognitive aspects of learning (Pring, 1971; Sockett, 1971).

Inseparability refers to the impossibility of separating remembering from understanding or even application. Learning is not sequential or linear, to remember which gases expand when heated, it is important to understand under what sort of conditions these statements are considered to be true or false. Remembering knowledge entails both comprehension and application, and additionally, learners might skip over or revisit categories in the learning process. The content-dependence involves the fact that within the cognitive categories large differences in behavior can be identified, e.g., "remembering that William the Conqueror landed in 1066 is a quite different sort of behavior from that of remembering how to ride a bicycle" (Pring, 1971, p.83). At the same time, the taxonomy is incomplete due to its specificity for which Bloom omitted more general objectives such as 'understanding society' and motivation. Lastly, the codependency of affective and cognitive objectives entails Bloom's attempt to isolate cognitive objectives from affective aspects to form distinct teaching goals. However, what it means to truly know and understand, or to feel a concern for the standards of scientific truths clearly indicates the degree of codependency between cognitive and affective aspects in learning.

Appendix C.2. Interview Results Study 2: Validation of the DIL Framework

Op welk onderwijs niveau geef je les? In welke vakken?	voortgezet onderwijs, HAVO/VWO, natuurkunde (en geschiedenis)	MBO, niveau 2, 3 en 4. Motorvoertuigentechniek.	NASK, techniek, natuurkunde HAVO/VWO	Highschool - gymnasium - Biology, pedagogoy	universitair, onderwijskunde
In welke mate heb je VR reeds geadopteerd in je lessen?	Geen gebruik. Ik wil/kan het niet beginnen te gebruiken.	Geen gebruik. Ik wil/kan het niet beginnen te gebruiken.	Geen gebruik. Ik wil/kan het niet beginnen te gebruiken.	Geen gebruik. Ik wil/kan het niet beginnen te gebruiken.	Geen gebruik. Ik wil/kan het niet beginnen te gebruiken.
Hoeveel jaar onderwijs je reeds? (Hoe lang daarvan gebruik je VR?)	6 jaar	4 jaar	6 jaar	3 years	11 jaar
Begrijp je dit framework? Zijn er dingen onduidelijk?	Plaatje 1 is overzichtelijk en duidelijk. 2e plaatje onduidelijk of ik van links naar rechts moet kijken, wat is de volgorde? Duidelijker maken dat het een cyclisch process is.	Is duidelijk. Is makkelijker dan vantevoren gedacht door duidelijke stappen.	Op zich duidelijk, bij gedetaillerde niet duidelijk OF/AND Is een cirkel proces, mag duidelijker.	iVR abbreviation is new, makes sense but not clear. Besides that clear.	Is begrijpelijk, overzicht is op een abstracter niveau. Tweede is handiger bij een cursus, over welke stappen je echt zet.
Herken je jouw eigen lesgeven in de praktijk in dit framework? Wat zijn de verschillen?	Herkent de aanpak wel, begint met vraag die je gaat analyseren. Verschil is dat lesgeven in praktijk meer cyclisch verband is. Docenten gebruiken vingerspitsen gevoel, gebaseerd op eigen ervaring en gevoel wat een goede aanpassing/methode zou zijn.	Herken: wat is de beste manier om de informatie over te brengen. "Is deze tool van toegevoegde waarde?" Verschillen: nog geen VR gebruikt.	Cirkel van implement naar analyze voor cirkel. Herken lesgeven wel maar niet elke les volg ik alle blokjes. Is situationeel, ligt aan theorie vs praktikum les. Niet heel veel nadenken over delivery methode, vanuit praktisch oogpunt makkelijk om terug te vallen op de methodes die je kent. Ook tijd technisch is dit belangrijk.	Yes it is very recognizable. Biggest difference is that phases (develop and design) melt into each other, and phases can be done in different orders, also depending on mundane things such as how close students are to the vacation, or if they have an exam (if you want to do something very cognitive after an exam this will not work). This is information you usually only get very close to the lesson. So analyze is both long and short term stuff.	Herken het sowieso, blij dat het begint met de leerdoelen. Verschillen zitten in de nadruk op de pilot, is relevanter bij VR dan bij traditioneel lesgeven.

Zou je bepaalde fases prioriteren? Zo ja, welke en waarom?	Toepassingsgerichtheid (implementatie), docenten staan te vaak stil bij ideale situatie maar zetten weinig op papier. Vaak praten over onderwijs maar weinig uitvoering, navoering. Deadlines stellen, iemand die het process bewaakt. Prototypes maken, uittesten, proces bewaken.	Implementeren, docenten moeten goed weten wat ze aan het doen zijn. Ook belangrijk: dat studenten weten hoe VR werkt voordat ze aan de slag gaan.	Implementeren is de blangrijkste, maar kom je pas als je de andere doorlopen hebt. Analyseren tweede ronde gaat sneller, tenzij het erg fout is gegaan.	Implementation, all the other stuff is just leading up to so you can teach well. Implementation is teaching, and is where students get the material. Teachers should know you can't plan everything, be prepared for your plan/anticipation not going as planned. HArd to plan for the unpredicted so stay spontaneous (like a ball game). Other phases are more time consuming but only make implementation teaching possible.	Zijn allemaal belangrijk. Fases bouwen op elkaar verder.
Hoe kijk je naar het gebruik van VR in de toekomst? Wat zijn de knelpunten?	is knelpunt. Glitches en bugs zijn moeilijk voor leraar. Device kan ook gebruikt worden voor andere dingen, in de gaten houden wat leerlingen doen is lastig. Laptops leiden meer af dan ze toevoegen aan het leerproces. Hebt een vertrouwelijke leeromgeving nodig om zicht te ontnemen van leerling en leraar. Eerst inloggen, veel stappen die leerlingen moeten doen voordat ze in VR aan de slag kunnen. Docenten hebben behoefte aan gemaakt lesmateriaal wat ze kunnen aanpassen en gebruiken, net zoals bij grafische rekenmachines van Casio/Texas	Ziet het zichzelf gebruiken, heeft grote toegevoegde waarde. Knelpunt: - Waarvoor kan je het inzetten? Eventueel om stage te simuleren voor algemene dealer versus merkdealer, of repetitieve oefeningen. - Gevaarlijk om je af te sluiten in werklokaal dus apart klaslokaal gebruiken.	- middelen, is al moeilijk om een eigen device voor studenten te regelen. - Voor docenten een flinke stap om VR te gebruiken omdat het onbekend is. Mensen zijn gewoonte beestjes. Vooral oude leraren zullen moeite hebben. Kennen het niet, hoe houden ze orde. - Ik zie de klas niet meer als ik wil zien wat de klas ziet. - Waar haal je simulaties vandaan. Meer kans bij exacte hoek dan bij talen, zijn technischer onderlegd. Moet niet docenten meekrijgen maar hele secties (bv natuurkunde). Sectie samen maakt lesplan/structuur.	underfunded (sometimes not even enough chairs) so technology is behind. Most classrooms do not have enough power for cable VR, even battery powered headsets would need charging and would be problematic. All technical appliances need to be checked regularly, will need to have a separate job position to do this. Need a way to limit students so they use the educational program and not a game, this is seen by ipads as well. They can be quite helpful but students find ways to be distracted. Technical difficulties can be a problem. Schools often have wifi issues. Very regulated with	- anders denken over het bereiken van groepen, ziet niet zo snel een hele collegezaal tegelijkertijd met een bril op. Zal individueler zijn of in kleinere groepen. Aanpassing van lesgeven. - VR materiaal moet er wel zijn. - ontwikkeling kost waarschijnlijk veel tijd. Weet niet of ernaar kijken voldoende is als demonstratie. In vakdidactiek vakken zitten studenten voor een bepaald vak (bv scheikunde), krijgen hier vakdidactische applicaties/hulpmiddelen. Online practica onder andere. Soms doen fanatieke

Hoe kan dit framework jouw VR gebruik ondersteunen?	Fijne checklist waar het aan moet voldoen.	Makkelijker implementeren. Gaat VR een toegevoegde waarde zijn ja of nee? Wanneer je het wil gaan gebruiken, maar wat nu -> dan is het framework handig.	Geeft handvaten waar mee rekening te houden. Checklist.	General overview, no hands-on advice. Hard to imagine cause accessibility is not there. Would be mostly a decision by the school or school ministry, top-down. Framework could be a good starting point. More something you would get at a further education for teachers, or at a teacher training school. During teaching you do not have a lot of time to learn how to do a little part of your lessons better. Would be something a teacher would apply for or a headmaster would sent you to, then the one teacher could help other teachers.	Goed model om te volgen, als checklist. Uitdelen of zelf gebruiken afhankelijk van doel.
Wat kan er aan dit framework verbeterd worden?	Het algemeen overzichtje is fijn. Gedetailleerd overzicht eerst zonder witte blokjes, uitleggen wat de kopjes inhouden. Is nogal een muur met tekst die op je af komt.	Meer met infographics werken, is nu een heel groot overzicht. Icoontjes bij kopjes of witte blokjes plaatsen. Komt het uitnodigender over, nu veel tekst.	Circulair proces.	Looking at the framework and thinking about it is a lot of effort, teachers tend to go to best practice. Showing a video which they have used before is easier and quicker. The framework would be more for training for teachers who do not teach as much so they have time. Big hurdle because it's a lot.	Dacht dat ik de evaluatie miste, maar staat bovenaan.

Zou je nog iets anders willen zeggen?	VR als onderdeel van curriculum (verplichten) of methode (aanraden, enthousiasmeren) zou helpen om vaker te gebruiken. Zou ook helpen voor leraren die op gevoel lesgeven. Bij vrijwillige training doen alleen geinteresseerde mee. Leraaropleiding kan al wel worden gebruikt. Maar ook lastig omdat de technologie zo snel veranderd.	Niet elke leraar gaat hiermee aan de slag. Vaak een persoon in een team die dat oppakt, die de dingen gaat maken. Kort framework nodig voor degene die het alleen gaan gebruiken: meer handleiding voor in de les.	Past altijd bestaand materiaal aan naar wat je zelf fijn/goed vind, dus je wil bestaande simulaties ook kunnen finetunen. Moet passen binnen bestaand curriculum, ook op detail niveau (bv rechter hand regel bij natuurkunde). Mobiele telefoon headsets zouden handiger kunnen zijn. Geen internet gebruiken voor de headset (of mobiele telefoon) ivm leerlingen die mindere middelen hebben.	Could have a VR day to get students used to the technology. To introduce it, also so you can test it in a certain school. What do you need to change? E.g., how do you get students out if they like it too much.	Past bij alle instructionele methodes, is generiek genoeg. Framework zal ook helpen voor leraren bij best-practice, omdat het helpt waar ze op moeten letten bij analyseren. Wanneer leraren het framework gebruiken zullen de leerdoelen minder relevant zijn. Losstaand vooraf toevoegen.

Appendix C.3. Overview of final social, educational, and technological design principles.

Social design principles	Educational design principles						Technical design principles				
	Active semantic learning	Build on pre-existing knowledge	Scaffolding	Reflection and feedback	Guided exploration	Inclusive development	Learnability	Efficiency	Memorability	Errors	Satisfaction
Non-player characters	Learning-relevant information and interaction	actively link the new information to pre-existing knowledge	Demonstrate what learners need to do, include though processes during demonstration	incorporate reflection moments	Highlighting	frequently playtest with age-appropriate novice and expert end-users	Let students acclimate to iVR	by including educators and learners in the development process, they can detect points of improvement	simple UI	be able to backtrack to the former step in a learning task effortlessly	include the target learner group in the development
Non-in-VR group member	Provide iVR pre-training	for experts: increasing the difficulty, remove support, let them aid novice learners	limit options and break up complex tasks	unobtrusive, immediate, and actionable feedback	Virtual pedagogical agents		declutter the user interface	material should focus and retain students' attention on the learning material without distractions	include the target learner group in the development	include a positional reset option in case learners get stuck in the environment	aim for a steady difficulty level without sharp peaks
Tasks that require discussion	stimulate students to think about how the new learning content is related to and distinct from other, already known concepts	knowledge-based preparation before going into the iVRLE		Formative feedback should also be specific, supportive, and non-evaluative	Less necessary when learners gain experience		Essential elements in the iVRLE should be placed close to each other	iVR should not be available when not necessary for the learning process	Ensure forward compatibility of iVR software and learning material		end with an easier task
	Application of material in different situations	novice learners benefit from a structured approach			Phase out as form of scaffolding		learning tasks should go easy on the learners' proprioceptive system	Use informative graphics or mini-animations instead of long texts in iVR			include pleasurable events near the end
	students rework the new material in their own words						experienced learners or iVR users should have the ability to skip the introduction	Include voice-over with the animations			ensure that users feel that they have control over the virtual environment
	relate the learning content to the student's personal experience	Structure content from simple to complex or general to detailed					as few as possible steps are required to start an application	To limit cognitive load:			
	transfer appropriate processing	Use iVR to create concrete examples and make abstract concepts more tangible						separate the engaging experiences from the presentation of learning materials			
	educate learning strategies	Test learners' knowledge before using the iVRLE						create experiences that do not require the presentation of facts			
	Repeated testing (formative and summative)							provide proper guidance			
	gestures as a more natural method of testing							Limit iVR time to blocks of max 20 minutes			
	prompting techniques										
	provided in addition to traditional lessons							Ensure iVR software availability and forward compatibility of software and learning material			
								as few as possible steps are required to start an application			

Appendix D.1. Didactical Affordances for Immersive Virtual Reality.

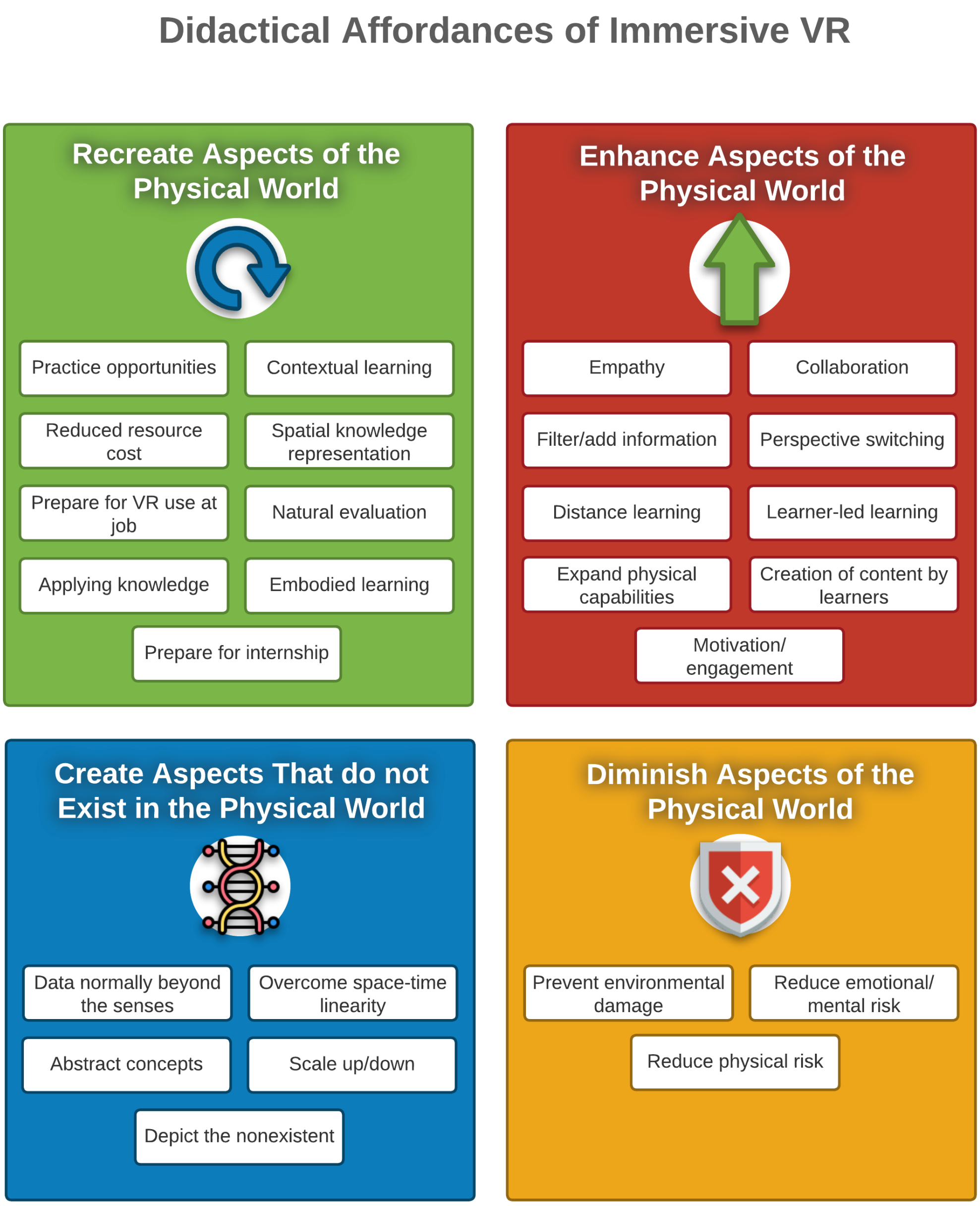

Figure 1. Didactical affordances (social and educational) for immersive Virtual Reality.

Appendix D.2. Design principles for Immersive Virtual Reality Learning Environments

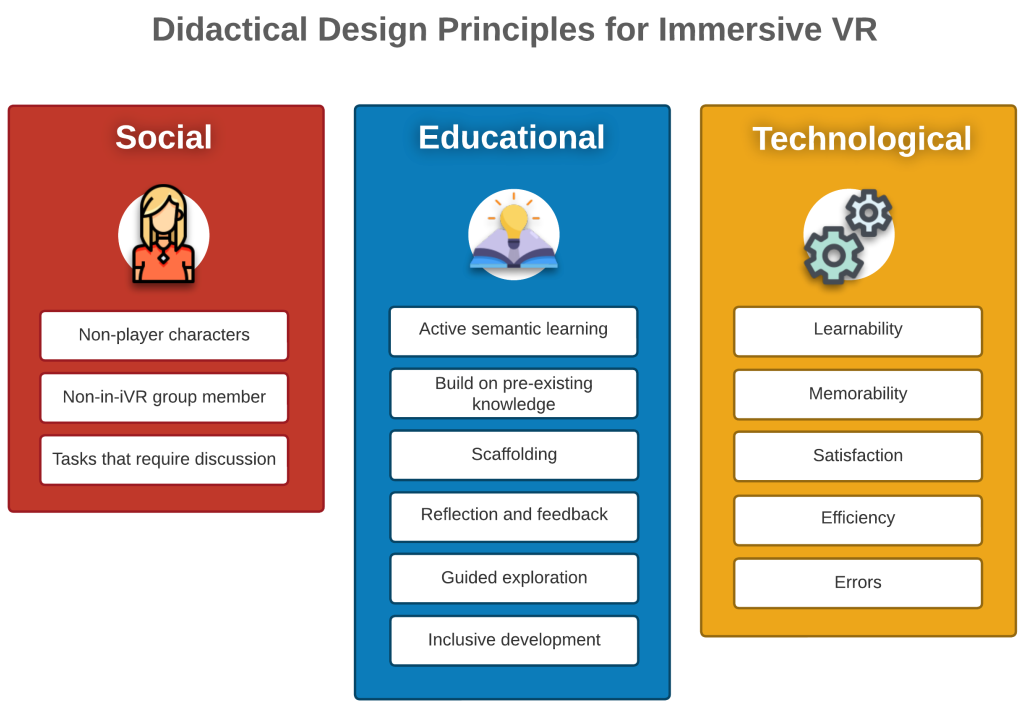

Figure 2. Design principles for immersive Virtual Reality Learning Environments.

Appendix D.3. DIL Framework

Appendix D.3.1. DIL Framework - Overview

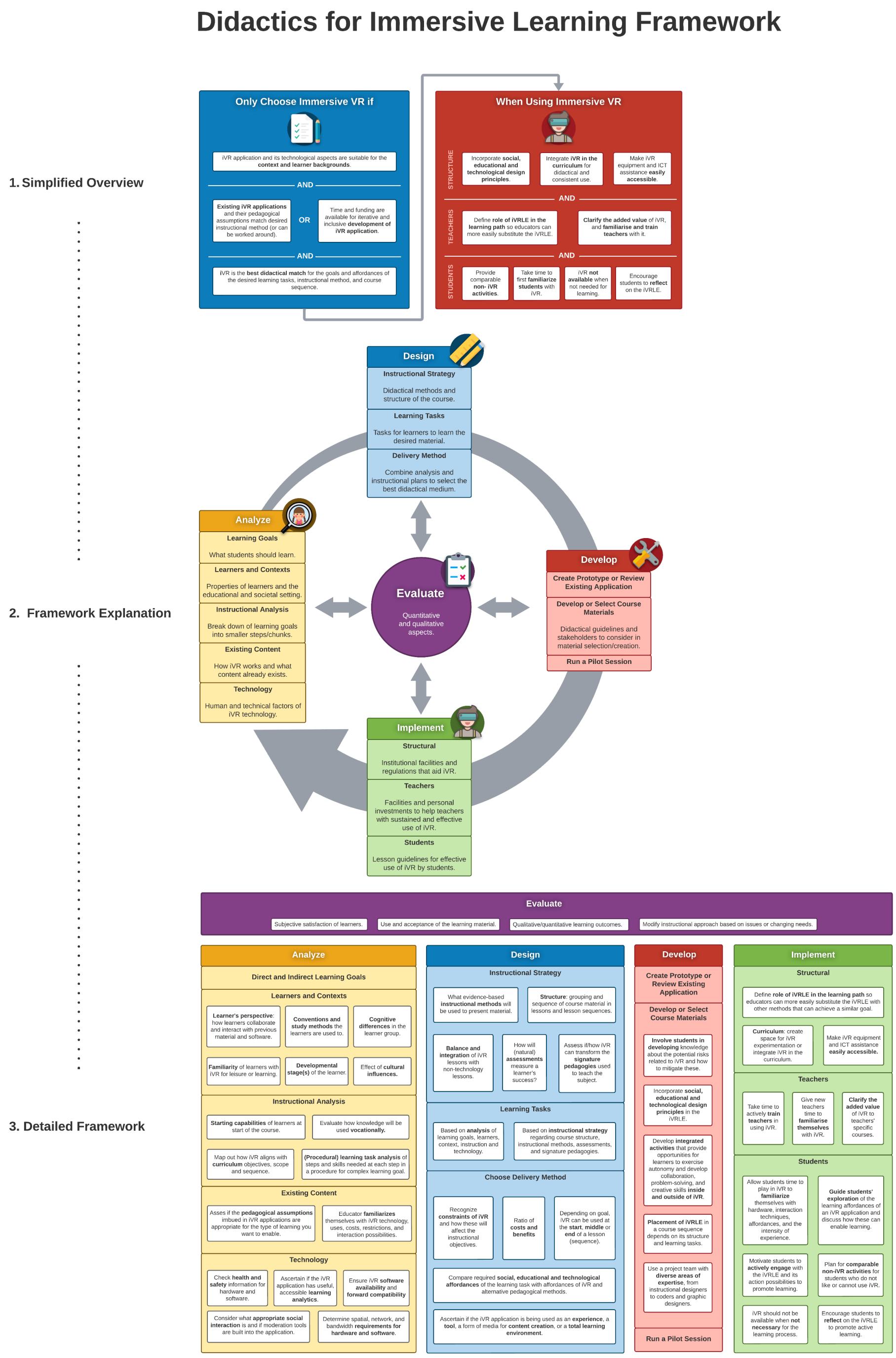

Figure 3. Overview of the complete Didactics for Immersive Learning framework.

Appendix D.3.2. DIL Framework - Simplified

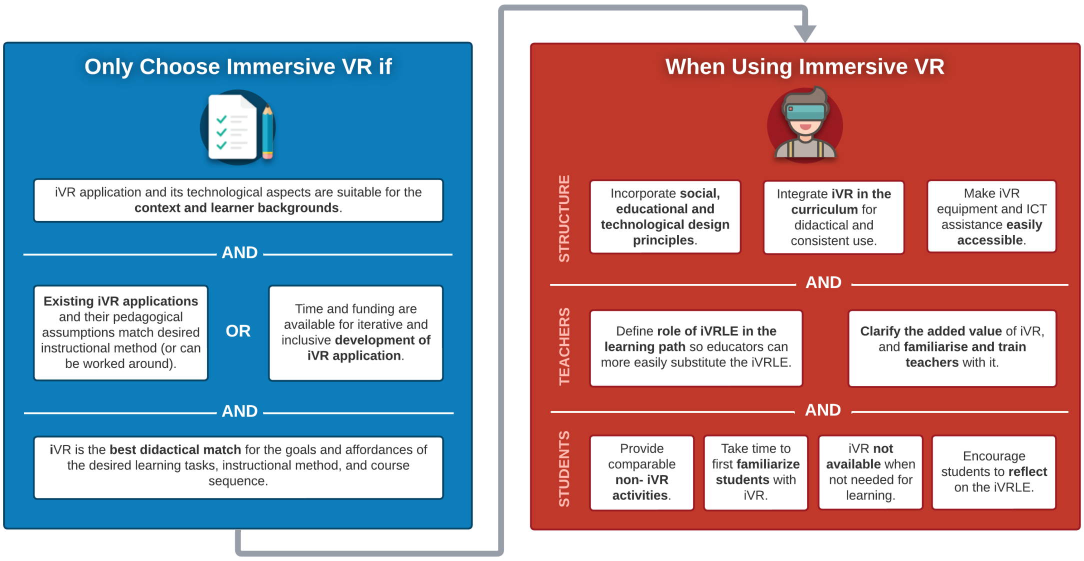

Figure 4. Simplified decision tree as addition to the detailed Didactics for Immersive Learning (DIL) framework (see Appendix D.3.4.).

Appendix D.3.3. DIL Framework - Circular Explanation

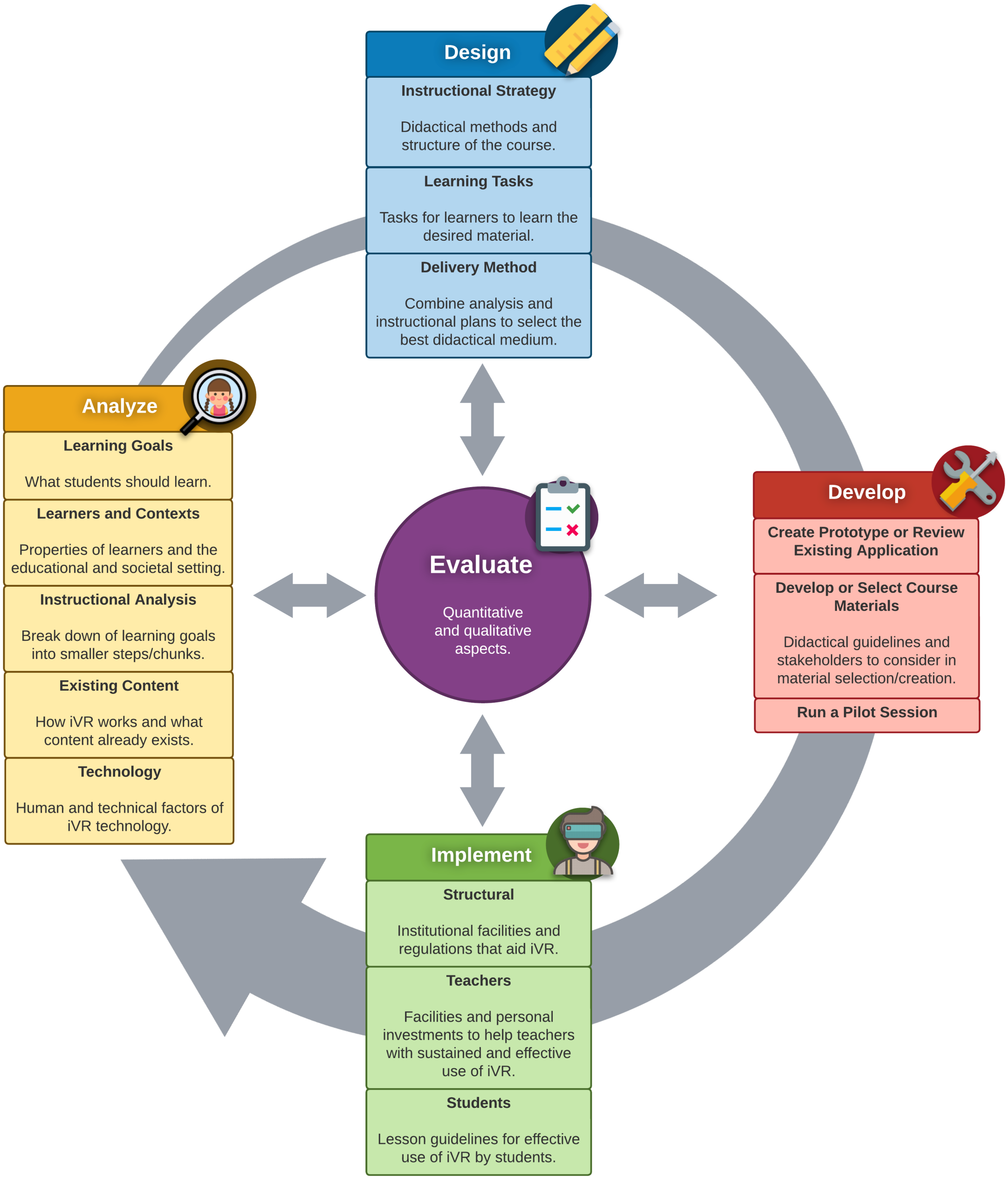

Figure 5. Circular visualization and explanation as addition to the Didactics for Immersive Learning (DIL) framework (see Appendix D.3.4.). Not shown are additional relationships between phases. In daily teaching, phases blend into each other and are used more fluidly.

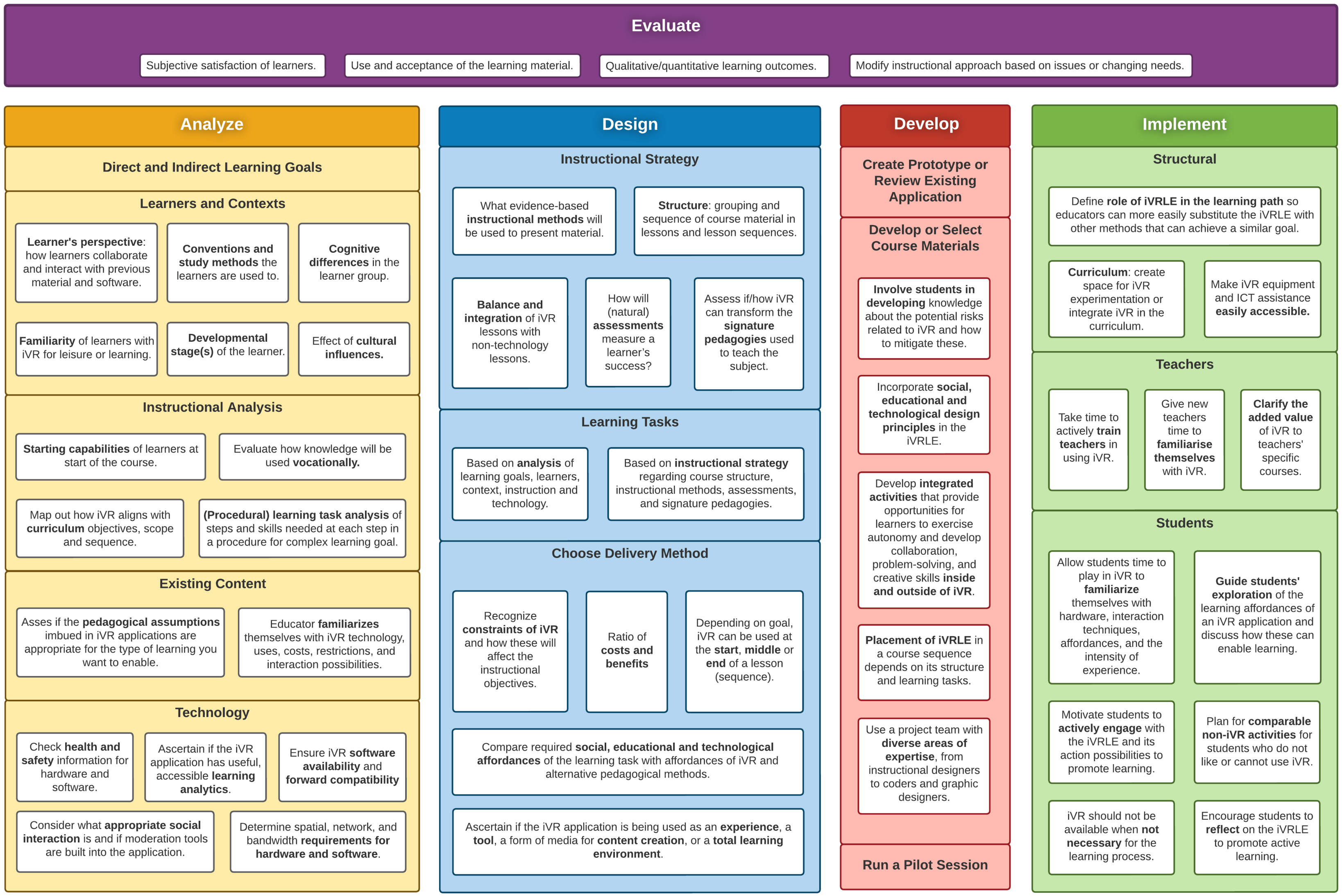

Figure 6. The Didactics for Immersive Learning (DIL) framework. For complete overview see Appendix D.3.1.).

Appendix D.4. DIL Framework - Concise Visualization for Application of iVR Only

Appendix D.4.1. DIL Framework - Application Only Overview

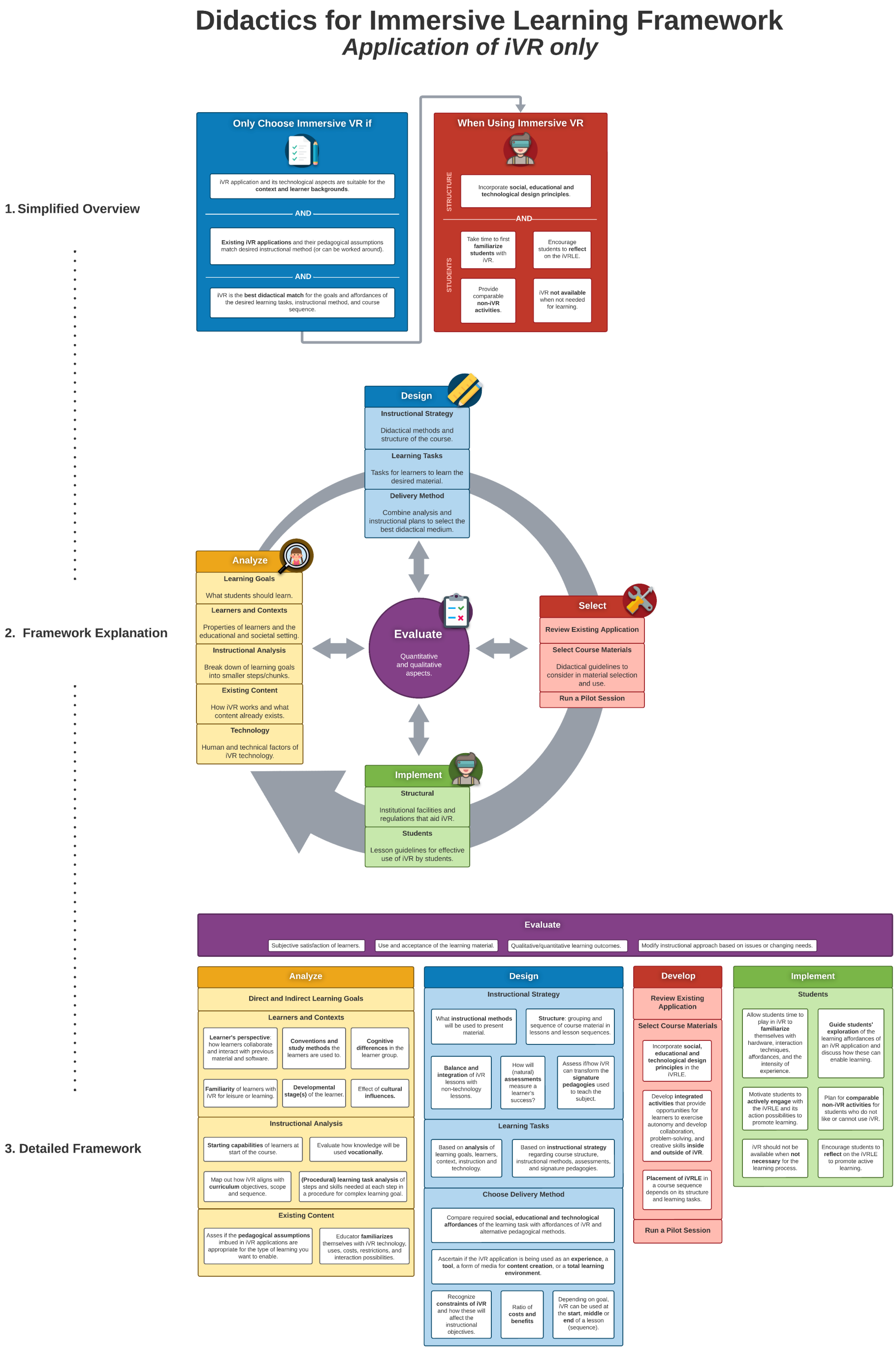

Figure 7. Overview of the complete Didactics for Immersive Learning framework, shortened for educators who use but do not design iVRLEs. For complete framework see Appendix D.3.1.

Appendix D.4.2. DIL Framework - Application Only Simplified

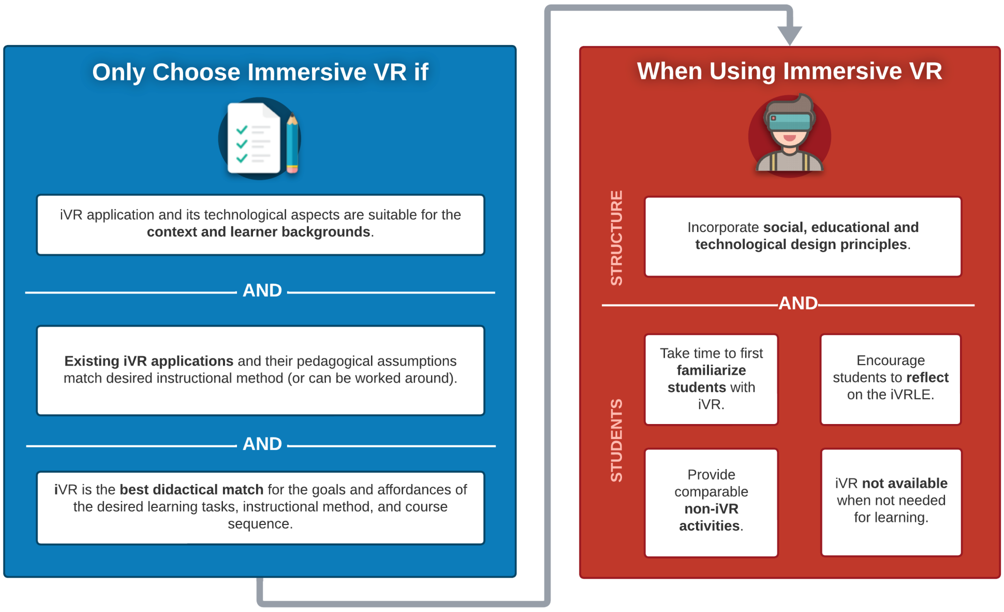

Figure 8. Simplified decision tree as addition to the detailed Didactics for Immersive Learning (DIL) framework, shortened for educators who use but do not design iVRLEs. For complete framework see Appendix D.3.1.

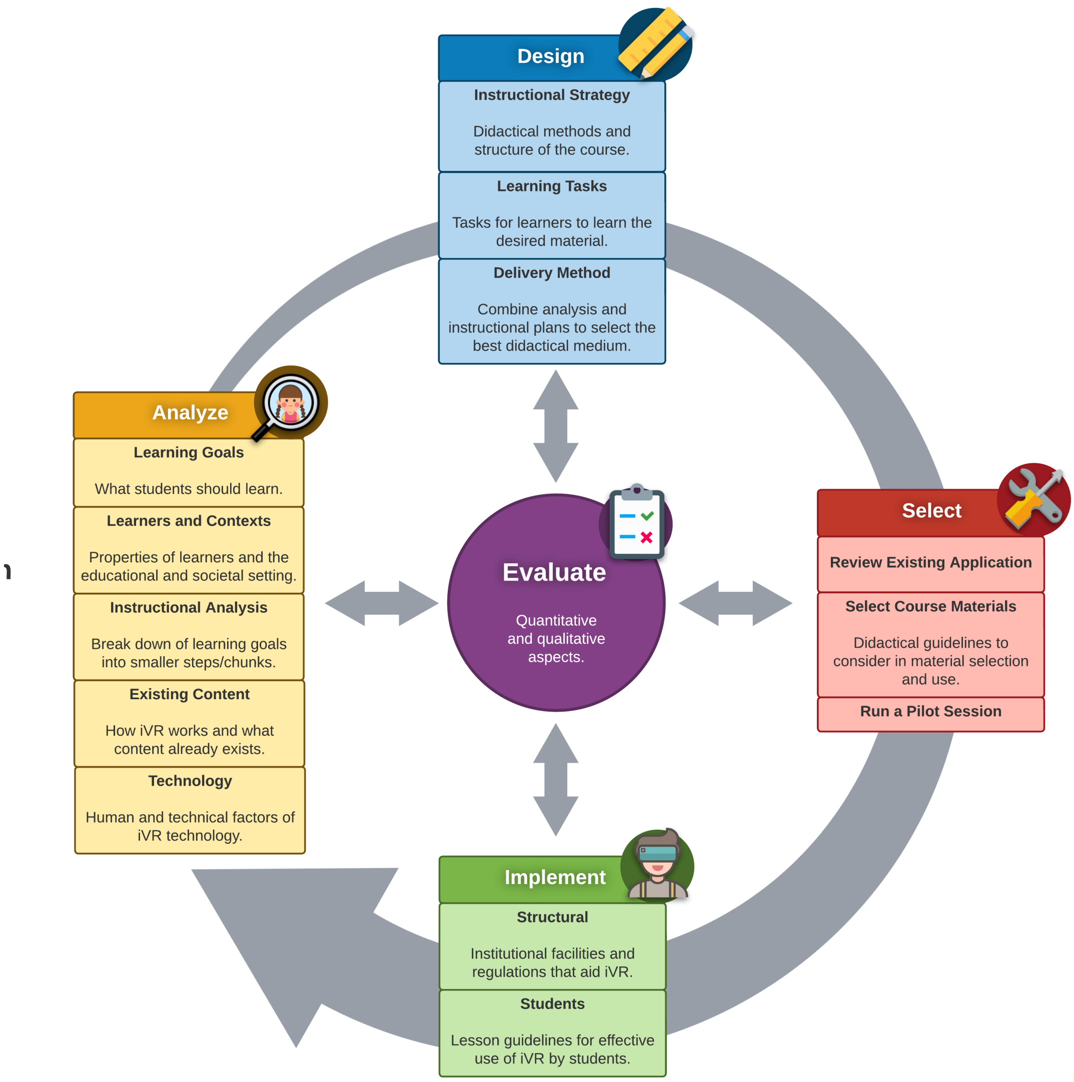

Figure 9. Circular visualization and explanation as addition to the Didactics for Immersive Learning (DIL) framework, shortened for educators who use but do not design iVRLEs. For complete framework see Appendix D.3.1. Not shown are additional relationships between phases. In daily teaching, phases blend into each other and are used more fluidly.

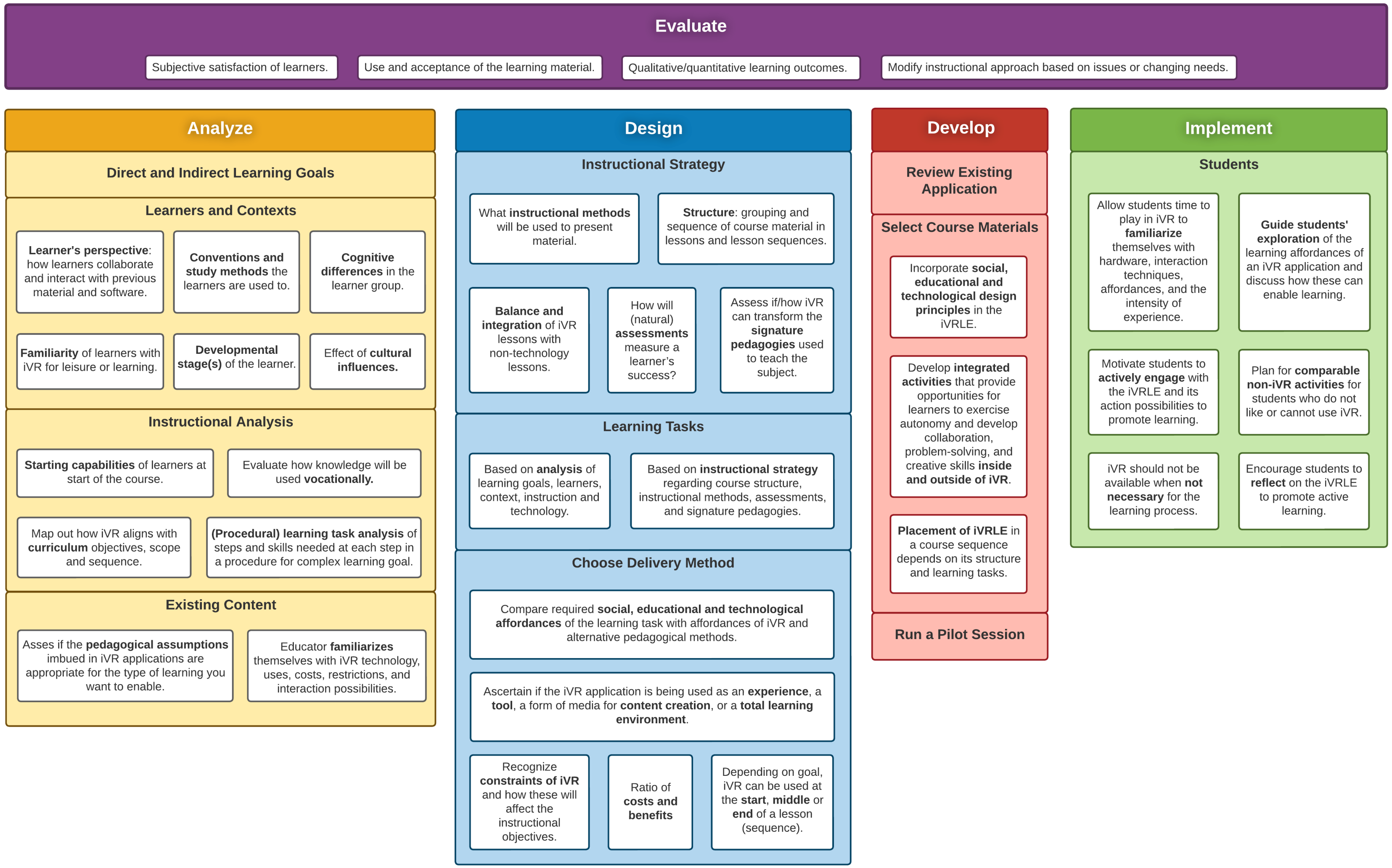

Figure 10. The Didactics for Immersive Learning (DIL) framework, shortened for educators who use but do not design iVRLEs. For complete framework see Appendix D.3.4.