# Virtual Reality in Higher Education: Preliminary Results from a Design-Science-Research Project

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**Abstract**

While researchers' interest in the educational use of virtual reality (VR) has generally increased, only a few studies have evaluated the effectiveness of VR in higher education. This research-in-progress paper presents an overview of an ongoing design-science-research (DSR) project that will (1) develop a conceptual framework for the design and use of VR in higher education, and (2) evaluate the framework by means of a series of field experiments. In addition, the paper presents preliminary results from a literature review, so it provides a foundation for framework development. Specifically, we identify several VR design elements (e.g., interaction, feedback, and instruction) and discuss what they can contribute to the acquisition of procedural and declarative knowledge and to the development of skills such as problem-solving, communication, and collaboration. We conclude the paper with an outlook on our research agenda.

**Keywords:** Virtual Reality, Immersive Systems, Higher Education, Design Science, Constructivist Learning.

## 1. Introduction

Virtual reality (VR) has enjoyed increasing popularity since 2016 when the gaming industry released affordable head-mounted displays (HMDs) like the HTC Vive, Oculus Rift, and Sony's PlayStation VR [6]. Accordingly, VR's market revenue in the United States alone is now about nineteen times higher than it was four years ago, having grown from $ 62.1 million in 2014 to $ 1,160 million in 2018, and experts predict the market revenue will increase another six times in the following four years [43]. VR has gained popularity not only because it enhances the gaming experience but also because it is versatile. In recent years, VR labs have emerged for target groups like astronauts [54], software engineers [10], real estate agents [29], and students in primary education [19], secondary education [36], and higher education [42].

Especially in the area of training and education, VR offers a variety of promising applications. While companies like the United Parcel Service and Walmart have started to train staff using VR [48,55], schools and universities are increasingly using VR as well. For example, the platform *Virtual Reality for Education*, which informs educators about how to organize VR field trips and VR tours, refers to numerous application scenarios in areas like astronomy, physics, engineering, biology, and aeronautics and aerospace [51]. In addition, VR offers educators such opportunities as interactive introductions to philosophical theories [39], architecture design education [7], and distance education that feels closer to reality [34].

In terms of higher education, researchers have pointed at the importance of constructivist learning approaches, experiential learning in particular [25], for which VR may constitute a valuable teaching tool [21]. Since the development of complex skills requires more than just passive learning, as addressed by experiential learning [25], educators are increasingly looking for ways to redesign their curricula. Because of its high fidelity, VR would allow learners to feel part of the learning environment and to actively participate rather than passively observe [30], but educators barely implement VR into their curricula stating time constraints or a shortage of support staff [20]. In the context of these challenges, the development of guidelines on how to design and use VR in classrooms is critical, which requires researchers to study the usefulness of VR design elements and to develop an understanding of which elements can help to develop which competences.

While education researchers have started to conduct design-oriented studies on VR-enhanced learning, artifact evaluations primarily consist of usability assessments [e.g., 23,37]. One of the primary goals of the Information Systems (IS) discipline is to research the design and use of information technology, so IS researchers are challenged to determine how to properly implement and use VR in higher education. While Walsh and Pawlowski described VR as "a technology in need of IS research" [57, p. 297] more than a decade ago, a search for "virtual reality" and "education" in the AIS electronic library returned only eight results for peer-reviewed conference papers and journal articles.[1] From these publications, only Walsh formulated design propositions for VR-based learning [56], but in doing so, he focused on technical aspects like bandwidth, noise, and their influence on learning, so social or organizational research on VR is still scarce [57].

Against this backdrop, this research-in-progress paper reports from an ongoing design-science project that aims to develop a conceptual framework for the design and use of VR in higher education and to evaluate the framework by means of a series of field experiments. We present preliminary results from the project and identify and categorize the most commonly used design elements for educational VR applications based on a literature review. In addition, we discuss the extent to which these elements contribute to acquiring competences such as procedural and declarative knowledge, problem-solving, and communication.

Section 2 reviews related work and constructivist learning theories, particularly experiential learning theory, which provides the kernel theory for the design-science project. Section 3 uses Peffers et al.'s guidelines for design-science research to present a project outline [31]. Section 4 summarizes preliminary results and discusses these results from a constructivist learning perspective. Section 5 concludes the paper and provides an outlook on future research.

## 2. Background

### 2.1. Related Work

Researchers have been using the term "virtual reality" to refer to multiple technologies, such as virtual worlds where multi-user games are played in online environments [47], desktop VR where screens display 3D environments [35], cave automatic virtual environments where projections surround the user [17], and so-called immersive VR where users wear head-mounted displays (HMDs) [44]. The first to conceptualize HMDs was Sutherland [46] and, today, researchers primarily mean immersive VR and HMDs when they

[1] We conducted the search in August 2018 and searched within titles and abstracts.

refer to virtual reality, and so does the present research project. For half a century, immersive VR was mainly available in labs [38] because consumers of HMDs faced high prices and technology-induced issues like motion sickness [49], but the technology has matured and the gaming industry has released affordable HMDs, so VR is increasing in popularity and receiving increasing attention from researchers.

Domains other than the gaming industry have also discovered VR. For example, research in medicine, one of the pioneering domains in the use of VR, has demonstrated that staff training, including trainings for surgeons [40] and nursing staff [41], can be implemented in VR without risking harm to patients. Similarly, staff training in high-maintenance industries (e.g., aircraft) and high-risk industries (e.g., mining) is less costly and less risky in VR than are traditional forms of training [50,53]. Companies have also started to use VR to train employees in interpersonal skills. For example, Walmart's employees receive VR training that prepares them to handle customers [55] and Anders Gronstedt, the founder of the digital training agency The Gronstedt Group, suggests training managers in VR while referring to the technology as "the ultimate empathy machine" because it allows users to experience situations from other individuals' perspectives [13].

Recent developments in the education domain also reflect VR applications' potential in transferring knowledge and practicing skills. Freina and Ott's literature review [18] showed that most studies in this area have investigated VR in higher and vocational education but focused on a very specific application domain [18]. Besides medical education [e.g., 40], VR has primarily found application in anatomy education [e.g., 24], engineering education [e.g., 2], and foreign language education [e.g., 9]. Some studies have also investigated the effects of VR on learners, suggesting that VR enables faster and more creative learning [1], increased motivation of learners [28], and better learning conditions for individual learners [5].

Although researchers have stressed VR's potential for constructivist learning [21] and the development of highly demanded 21st century skills [22] such as communication, collaboration, and problem-solving skills [14], educators have barely implemented VR into their curricula stating time constraints, shortage of support staff [20], and a lack of own digital skills [52]. As Chen argued, research needs to identify appropriate theories and models for the design of educational VR applications and investigate how these applications are able to support learning and how they affect learners [12]. Against this background, the design-science project described in this paper explores how to effectively design and use VR in higher education. The following section provides a theoretical foundation for the project.

### 2.2. Theoretical Background

Theories about learning either concern what learners learn or how learners learn. For the question what learners learn, different classifications for competences exist and the most popular classification is Bloom's taxonomy [8]. According to the revised version of Bloom's taxonomy, learners pass through the following levels: remembering facts, understanding facts, applying rules and concepts, analyzing connections among ideas, evaluating stands and decisions, and creating new knowledge [4]. Another classification is the skill-acquisition process, which consists of the declarative stage (remembering and understanding facts), the procedural stage (applying rules and concepts), and the self-regulatory stage (analyzing, evaluating, and experimenting) [3]. That is, learners first have to acquire knowledge, so they can then acquire actual skills. In the preliminary literature analysis, we followed the skill acquisition process model and distinguished between two broad types of knowledge—declarative and procedural knowledge—that are necessary to acquire skills [3] such as communication and collaboration skills and problem-solving skills that are relevant to higher education [16].

Considering how learners learn, a paradigm shift of educational designs took place around three decades ago—away from behaviorism (learning through consequences and reinforcement) and cognitivism (understanding cognitive processes) towards constructivism (constructing knowledge through experiences and social interaction) [15], which is the prevailing paradigm since then. Accordingly, research on VR in education builds primarily on constructivist learning assumptions [e.g., 21]. A common constructivist-learning theory is the discovery learning theory, which suggests that learners are most likely to remember facts that they have discovered themselves [11], so exploring and evaluating ideas are central elements of this theory. Another constructivist learning theory is the situated learning theory, which emphasizes the need to embed learning into authentic contexts in which learners collaborate on common objectives [27], so context and surroundings are central elements of educational designs that follow the situated learning theory.

While the discovery learning theory and the situated learning theory focus on certain aspects of educational designs (i.e. discovery and situatedness), the experiential learning theory considers learning a "[…] holistic process […] [that involves] thinking, feeling, perceiving, and behaving" [25, p. 194]. Consequently, the underlying aspects of both, discovery learning and situated learning, are present in experiential-learning designs as well. According to Kolb, the experiential-learning process has four iterative steps: concrete experience, reflective observation, abstract conceptualization, and active experimentation [26]. In other words, experiences lead to observations and reflections from which learners derive implications that they test, leading to new experiences.

Stieglitz et al. have developed a framework that specifies two dimensions that classify learning arrangements in virtual worlds: the degree of interaction and the degree of immersion (Figure 1) [45]. Against the background of the experiential learning theory, the framework suggests that only with high degrees of interaction and immersion can experiential learning take place. However, if the degree of both interaction and immersion is low, learning is primarily auditory and textual, and therefore passive. If interaction is high and immersion is low, as they are likely to be in virtual classrooms, we suppose that the minimum conditions for discovery learning are fulfilled. In contrast, if interaction is low and immersion is high, as they are likely to be in virtual tours, we suppose that the minimum conditions for situated learning are fulfilled.

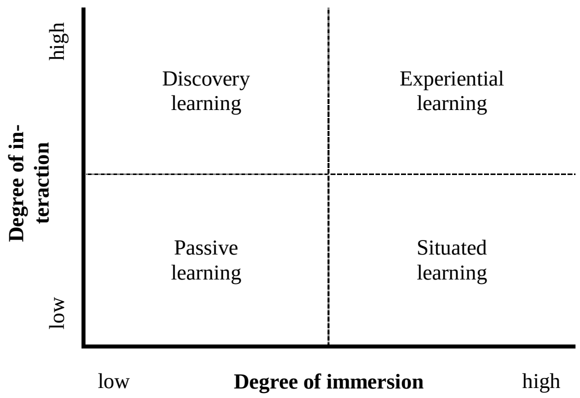


**Fig. 1.** Framework for virtual learning arrangements (adapted from [45])

Although Stieglitz et al. have developed their framework particularly for virtual worlds, the framework should also apply to other kinds of immersive systems, including VR. Accordingly, both Stieglitz et al.'s framework and the experiential learning theory provide the foundations for our design-science project.

## 3. Research Project Overview

In the course of our research project, we will follow the main phases of the design-science-research methodology proposed by Peffers et al. [31]. If necessary, each phase will undergo several iterations.

**Identify and motivate the research problem.** Any DSR process begins with the identification and motivation of the research problem [31]. Researchers have stressed the need for a systematic presentation and evaluation of VR in higher education [57], so we aim to emphasize this need through a thorough literature analysis, which is the focus of the present paper. Our literature analysis followed Webster and Watson's guidelines [58] and helped to identify VR design elements that have been used for educational purposes. Since the offers on the market are ahead of research, we plan to enhance our findings from the literature review with a market analysis, which will consist of an exploratory search for internet resources like whitepapers, newspaper articles, blogs, and product websites. We plan to synthesize our findings from the literature review and the market analysis using Stieglitz et al.'s framework.

**Define the objectives of the solution.** To identify the concrete objectives (i.e. target competences) and requirements for implementing VR in class, we will conduct three workshops, each at a different university, with six to eight lecturers form different faculties. These workshops will build on the workshop design proposed in the Joint Application Design (JAD) method [59]. In these workshops, we will present concrete scenarios identified from the literature review and market analysis, and the lecturers will evaluate their meaningfulness and feasibility. The lecturers will also derive target competences and requirements for the VR applications and evaluate their applicability in the lecturers' courses. We will pay particular attention to the requirements so the scenarios meet the conditions for experiential learning. Thus, the workshop will result in a set of scenarios that include target competences and requirements.

**Design and implementation.** The design and implementation phase contains two major steps. First, we will—together with the lecturers form the expert workshops—select six courses (i.e. two courses per university) that qualify for VR support. While we aim for a variety of subject areas, we will select the courses based on the implementability of VR, possibility to use experiential learning methods, and class size. Second, we will select existing VR applications for the courses based on the target competences and requirements that the lecturers have defined during the workshops. If necessary, VR-software developers will develop the applications together with the lecturers, as proposed by the JAD method [59]. At the end of this phase, we will derive a first version of the framework, which will be the main artifact of this DSR study.

**Demonstration and evaluation.** In the demonstration and evaluation phase, we will use the selected VR applications in class and conduct a series of field experiments [32], each with a 2x2 mixed factorial design [33, p. 84], to evaluate the framework. For each class, we will randomly assign students to four groups: Group A will have their lesson following a passive learning style in class; Group B will have the same lesson following a passive learning style in VR; Group C will have the same lesson following an experiential learning style in class; and Group D will have the same lesson following an experiential learning style in VR. Before and after the lessons, we will evaluate the students' competences with a pre-test and a post-test, which both are the same for the whole class. Based on whether VR lessons supported students at least as well in acquiring competences as compared to in-class lessons, we will evaluate the success of the selected scenarios and update the framework correspondingly. For ethical reasons, the lessons will not cover graded content.

## 4. Preliminary Results

To kick off the first phase of the DSR process, we conducted a literature review following Webster and Watson [58]. The literature search reported in this paper involved a keyword search on ProQuest, but we plan to extend the search in the further course of the project. We conducted our search by combining the search strings ("virtual reality" OR VR), (educat* OR learn* OR train*), and immers* using a Boolean AND operator. The keyword "immers*" was applied to all search fields, while the others were applied to title, abstract, and keywords only. The search results were limited to peer-reviewed scientific journal articles written in English and published after 2010. We decided to look for articles starting in 2010 because although HMDs became commercially available in 2016, an earlier explorative search revealed that several relevant articles were published between 2010 and 2015.

Our search in August 2018 returned 724 unique articles. Two researchers read those articles' titles and abstracts independently to separate relevant from non-relevant articles. We considered articles as relevant to our purposes only if they empirically investigated one or more VR applications for education, so we were able to extract the major design elements of these applications. As we did not want to omit any potentially relevant articles, we performed this activity generously by considering all articles that looked relevant to at least one of the researchers and eliminating only articles that were obviously irrelevant (e.g., articles about VR's technical features). After reviewing titles and abstracts 41 relevant articles remained. We read all 41 articles and eliminated another 15 that did not allow us to extract any design elements.

Using the final set of 26 articles, we created a concept matrix, as Webster and Watson proposed [58], that contained concepts related to competences and design elements. We coded four different competences: declarative knowledge, procedural knowledge, problem-solving skills, and communication and collaboration skills [3,16]. Declarative knowledge includes all kinds of facts that learners need to memorize like factual knowledge, abstract concepts, and scientific principles; procedural knowledge includes all kinds of tasks that foster practice and internalization of processes like steering a robot, playing an instrument, and performing a surgery; problem-solving skills include all kinds of skills that are related to complex tasks like solving business cases, performing risk assessments, and making complex decisions; and communication and collaboration skills include interaction with others in tense situations, presenting, and working on tasks collaboratively.

The design elements were obtained inductively in the process of reading the articles. (When our opinions about the design elements varied, we used a clinical approach and discussed until we reached consensus.) We found the following ten design elements in the articles: passive observation (i.e. virtual tours in which learners cannot intervene), exploration (i.e. moving around and interacting with virtual objects), interaction with other users (i.e. discussing and visiting other users' spaces), interaction with virtual agents (i.e. avatars that are steered by artificial intelligence, not by users), immediate feedback (i.e. immediate haptic, audio, and visual feedback), virtual rewards (i.e. badges, awards, and virtual relaxation areas), realistic surroundings (i.e. surroundings that simulate the learning context like laboratories), instructions (i.e. tutorials, audio guides, and textual instructions), repetition (i.e. practicing handles and processes), and assembling (i.e. provided set of objects so users can create or assemble new objects).

Table 1 maps the four competences with the ten design elements and shows the ratio of VR applications that targeted a certain competence using a certain design element. (For example, two out of seven applications that targeted declarative knowledge used passive observation, resulting in a ratio of 29 percent.) The analysis revealed that the most frequently used design elements with regard to the four competences are: exploration (71%), instructions (57%), and immediate feedback (57%) for declarative knowledge; instructions (77%) and realistic surroundings (69%) for procedural knowledge; realistic surroundings (86%) and interaction with other users (71%) for problem-solving skills; and realistic surroundings (83%) and interaction with virtual agents (67%) for communication and collaboration skills.

For three out of four competences—procedural knowledge, problem-solving skills, and communication and collaboration skills—realistic surroundings is one of the most important design elements, which includes all surroundings that simulate the learning context, such as laboratories and construction sites. Accordingly, realistic surroundings is a key indicator of a high degree of immersion and situated learning. For declarative knowledge, exploration and immediate feedback are among the three design elements implemented most frequently. While exploration allows learners to interact with virtual objects, immediate feedback simulates consequences of actions. Accordingly, exploration and immediate feedback are key indicators of a high degree of interaction and discovery learning. In contrast, passive observation, a key indicator of low degrees of interaction and immersion, rarely appears in the analysis.

**Table 1.** Mapping of competences and design elements

| | | **Competences** | | | |
|---|---|---|---|---|---|
| | | Declarative knowledge | Procedural knowledge | Problem-solving skills | Communication and collaboration skills |
| **Design elements** | Passive observation | 29% (2/7) | 23% (3/13) | 29% (2/7) | 17% (1/6) |
| | Exploration | **71%** (5/7) | 23% (3/13) | 43% (3/7) | |
| | Interaction with other users | 29% (2/7) | 23% (3/13) | **71%** (5/7) | 50% (3/6) |
| | Interaction with virtual agents | | 15% (2/13) | 29% (2/7) | **67%** (4/6) |
| | Immediate feedback | **57%** (4/7) | 46% (6/13) | | 17% (1/6) |
| | Virtual rewards | | | | 17% (1/6) |
| | Realistic surroundings | 43% (3/7) | **69%** (9/13) | **86%** (6/7) | **83%** (5/6) |
| | Instructions | **57%** (4/7) | **77%** (10/13) | 43% (3/7) | 17% (1/6) |
| | Repetition | | 46% (6/13) | | 33% (2/6) |
| | Assembling | 29% (2/7) | | 14% (1/7) | |

Most applications that target problem-solving skills and communication and collaboration skills focus on both, a high degree of interaction (interaction with other users/virtual agents) and a high degree of immersion (realistic surroundings), which are the conditions for experiential learning [45]. However, the results for applications that target declarative and procedural knowledge look different. For example, applications that target declarative and procedural knowledge seem to rely on action-feedback cycles rather than on interactions between other users or virtual agents. Accordingly, the results show that current applications that target complex skills follow an experiential learning approach, while applications that target knowledge fulfil only one of the two conditions for experiential learning. Nevertheless, the results confirm that most applications follow a constructivist learning approach and the sparse use of the design element passive observation strengthens this finding.

## 5. Summary and Outlook

VR is a young, but promising technology. Because it is highly versatile, VR offers a variety of promising applications, so VR is enjoying increasing popularity among practitioners, and various disciplines have started to study its potential. However, although IS researchers have identified research gaps related to the design and use of VR [e.g., 57], they have rarely investigated VR. In particular, only a few researchers have actually evaluated educational VR applications with regard to the acquisition of competences, whereas educators remain reluctant to use the technology—even though VR has much to offer, especially from a constructivist learning perspective. Thus, our research project pursues two goals: First, we will develop a framework for the design and use of VR in higher education, and second, we will evaluate the framework using a series of field experiments.

This research-in-progress paper presented preliminary results from the literature review, so it addresses the first goal of the research project. We conducted a literature search (in so far only one scientific database) to identify educational VR applications across different academic disciplines. The results show which design elements have been used to train and develop which competences. Accordingly, we not only identified the design elements that have been most commonly used and studied, but also the design elements that have not yet received much attention from researchers, so our results can also provide a foundation for future research. However, as this is research-in-progress, our results can only be considered preliminary, so we will perform a more comprehensive literature analysis using other scientific databases, such as the AIS electronic library, IEEE Explore, Science Direct, and Scopus. We will also revise our concepts by comparing them to related work and elaborate more on the theoretical classification of our findings.

In the further course of this research project, we will enhance our findings from the literature review with a market analysis and expert workshops, resulting in a set of VR application scenarios that include target competences and requirements. These target competences and requirements will determine which VR applications we will select for implementation in class. Together, the literature review, market analysis, and expert workshops will provide the foundation to develop the conceptual framework and experimentally test its usefulness in various educational settings at our universities. For educators, particularly those in higher education, the framework will offer guidance to integrating VR into classes in a feasible and meaningful manner. For researchers, particularly IS researchers, the research project will address the research gaps that other researchers have identified [e.g., 18,57] and add to the literature on the design and use of VR. In particular, future research might use the framework to evaluate the usefulness of one or more design elements to acquire certain competences.

## Acknowledgements

This research is part of the Erasmus+ project "Virtual Reality in Higher Education: Application Scenarios and Recommendations" funded by the European Union (Grant No. 2018-1-LI01-KA203-000107). This article reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

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