www.ijte.net

The Effects of a Constructively Aligned Virtual Reality Setting on Professionals' Knowledge, Motivation and Perceptions

Bo Sichterman
HU University of Applied Sciences Utrecht, The Netherlands

Stan van Ginkel
HU University of Applied Sciences Utrecht, The Netherlands

Melanie van Halteren
CoVince, The Netherlands

Richard van Tilborg
CoVince, The Netherlands

Omid Noroozi
Wageningen University & Research, The Netherlands

To cite this article:

Sichterman, B., van Ginkel, S., van Halteren, M., van Tilborg, R., & Noroozi, O. (2023). The effects of a constructively aligned virtual reality setting on professionals' knowledge, motivation and perceptions. *International Journal of Technology in Education (IJTE), 6*(4), 561-582. https://doi.org/10.46328/ijte.462

International Journal of Technology in Education
2023, Vol. 6, No. 4, 561-582 https://doi.org/10.46328/ijte.462

The Effects of a Constructively Aligned Virtual Reality Setting on Professionals' Knowledge, Motivation and Perceptions

Bo Sichterman, Stan van Ginkel, Melanie van Halteren, Richard van Tilborg, Omid Noroozi

Article Info

Article History

Received:
29 April 2023
Accepted:
15 September 2023

Keywords

Virtual reality
Constructive alignment
Artificial intelligence
Distance education
Professionals

Abstract

Although previous research on Virtual Reality (VR) demonstrated the effects of particular learning environment characteristics on learning, none of these studies constructed their virtual learning environment from a constructive alignment perspective. Therefore, this experimental study aims to investigate the impact of a constructively aligned virtual classroom setting, adopting an Artificial Intelligence (AI) training, on professionals' knowledge on AI. This experimental condition was compared with a control condition, consisting of a similar constructively aligned AI-training within a traditional face-to-face setting. Learning outcomes were measured using a pre-test post-test validated multiple-choice test. Additionally, motivation and perceptions, which are considered as crucial intermediate variables, were assessed using questionnaires. Results revealed significant improvements in learning from pre-test to post-test with no statistical difference between the conditions. Following the principle of constructive alignment, professionals perceived the VR classroom environment as motivating as the traditional setting. As a result, professionals perceived the VR classroom setting to the same extent as the traditional learning environment. These findings reveal that improvements in learning outcomes of professionals can be realized if environments are designed based on the principle of constructive alignment irrespective of the VR or traditional settings.

Introduction

Learning and development in the 21st century are considered to be fundamental for professionals (Cervero, 2000; Daley & Cervero, 2016). With rapid changes in society, continuing education has been considered crucial for professionals' performance and job satisfaction (Collin et al., 2012; Webster-Wright, 2009). Traditionally, professionals are trained by an expert in a face-to-face situation (Cervero, 2000). However, over the past decades, a trend has been observed in the so-called 'distance education'. This field is focused on effective teaching without the physical presence of the teachers and learners by making use of educational technologies (Sichterman et al., 2022; Zawacki-Richter & Naidu, 2016).

With the rapid development of Artificial Intelligence (AI) such as ChatGPT and powerful technology-enhanced learning environments, there is a shift from teaching and learning in the traditional classrooms into learning and collaborating in virtual settings to make learning processes more effective, efficient, and engaging (Banihashem et al., 2022; Farrokhnia et al., 2023; Noroozi, Järvelä and Kirschner, 2019). A revolutionary technology that supports distance education is Virtual Reality (VR). This technique enables users to learn in a virtual environment and collaborate with peers without being physically together (LaViola et al., 2017; Van Ginkel et al., 2020; Van Ginkel & Sichterman, 2023). Advances in VR, such as the significant increase in computational power and substantial reduction in costs, have led to extensive adoption in several professional and educational domains (Merchant et al., 2014; Radianti et al., 2020). Moreover, VR can support teachers in providing instructions or feedback in students' learning processes (Adubra et al., 2019). Additionally, VR offers logistical potentials for decreasing travel times and overcoming barriers of distance and physical constraints (Chau et al., 2013; Sichterman et al., 2021).

Several review studies have shown that learning (in terms of cognition, skills and attitudes) can be enhanced by VR within various professional and educational domains (Howard & Gutworth, 2020; Radianti et al., 2020). For example, Makransky *et al.* (2020) studied assessment strategies to measure students' ability to apply obtained knowledge in a laboratory-based VR environment and reported a significant impact on learning. Additionally, Fleming *et al.* (2009) demonstrated significant improvements in clinical skills in medical health care professionals after a VR intervention. Finally, Van Ginkel *et al.* (2020) revealed substantial increases in students' public speaking skills by facilitating immediate automated feedback during presentations in front of virtual audiences. Given these points, VR seems to have potentials to improve various aspects of learning processes and outcomes.

Scientific evidence claims that one must follow the principle of constructive alignment in order to fully obtain the potentials of VR for various aspects of learning processes and outcomes (McKenzie et al., 2020). To illustrate, following the principles of Biggs (1996), effective learning environments should include instructions, teaching/learning activities and assessment strategies in order to meet the criterion of constructive alignment (Banihashem & Farrokhnia et al., 2022; Biggs & Tang, 2011; Joseph & Juwah, 2012; Van Ginkel et al., 2015a). More specifically, the principle of constructive alignment starts from the perspective of the intended learning outcomes that, in turn, have to be systematically aligned with teaching/learning activities and assessment strategies (Biggs, 1996). However, VR studies in relation to various aspects of learning processes have not yet fully incorporated the principle of constructive alignment in their design.

Therefore, this experimental study aims to investigate the impact of a constructively aligned learning environment within a VR classroom on professionals' learning outcomes. The learning environment concerns an AI course aimed to acquire the basic principles of AI that are applicable in working practice. This topic is selected, since AI is expected to impact the tasks and careers of many professionals in the 21st century (Makridakis, 2017). In this study, the learning outcome is defined as the cognition towards understanding the basic principles of AI. Further, motivation and perceptions towards the characteristics of the learning environment and classroom setting are also adopted in this study, since learning is no longer seen as being only cognitive, but is seen as a complex process that is also motivational, social and emotional in nature (Biggs & Tang, 2011; Noroozi et al., 2019, 2020; Van Ginkel et al., 2019). The experimental condition consists of a fully fully-immersive multi-user VR classroom setting. The effects on learning are compared with a traditional face-to-face classroom setting, also constructed based on the principle of Biggs (1996).

Literature Review

The following sections outline recent scientific literature on the impact of learning environments in VR on learning outcomes that meet the criterion of constructive alignment (i.e. instructions, teaching/learning activities and assessment strategies). These learning environments involve particular learning environment characteristics (i.e. in isolation) and the combination of these characteristics (e.g. teaching/learning activities and assessment strategies). Based on discussions in literature, it is aimed to verify whether a concrete set of hypotheses can be formulated to guide this experimental study reported in this paper.

The Impact of Instructions, Learning Activities or Feedback in VR on Learning

Over the past decade, various studies have demonstrated the impacts of VR settings on learning of teaching/learning activities or assessment strategies in isolation. However, no studies have been found that solely focused on the implementation of constructively aligned VR settings. With regard to teaching/learning activities within VR, research has shown enhanced learning performances and increased learning outcomes after conducting these activities in VR environments (Alfalah et al., 2018; Graeser et al., 2014; Mohammadi et al., 2019; Rupasinghe et al., 2011). To illustrate, the implementation of a VR training tool within medical education – in which students could interact with 3D anatomical models - was considered to be effective for learning (Alfalah et al., 2018; Stepan et al., 2017). Interestingly, while results of one study showed that that learning activities within VR seem to be more effective for learning than traditional teaching approaches (Alfalah et al., 2018), others suggested that the VR simulation was as effective as traditional teaching (Stepan et al., 2017).

While the majority of studies have focused on the implementation of teaching/learning activities within VR, some scholars focused on assessment strategies in VR. For example, Van Ginkel et al. (2019) investigated the impact of computer-mediated delayed feedback on the development of students' presentation skills. Results of this study show increased presentation competences in students, without differences between the immersive VR environment and the face-to-face setting. Additionally, integration of formative feedback and assessment resulted in improvements in learning, intrinsic motivation and self-efficacy in a desktop VR laboratory setting (Makransky et al., 2020).

The Impact of a Comprehensive VR Learning Environment on Learning

While none of the studies particularly focused on the implementation of instruction in VR learning environments, some studies integrated the combination of instruction and teaching/learning activities in VR. Interestingly, one of these studies showed that learning in a desktop VR laboratory environment executed at home turned out to be as effective as in class since no differences in learning outcomes, intrinsic motivation and self-efficacy were determined (Makransky, Mayer, et al., 2019). However, other research studies demonstrated enhanced performance and improved creative thinking abilities after implementing instruction and teaching/learning activities within VR (Hu et al., 2016).

Regarding the combination of teaching/learning activities and assessment strategies within VR learning environments, various studies investigated their impacts on learning outcomes. The majority of these studies used VR simulators, e.g. in laparoscopic surgery or otolaryngology, and determined increased skill performance (Bhatti & Ahmed, 2015; Crochet et al., 2017; Palter et al., 2013). Additionally, increased conceptual and procedural knowledge in medication administration practice was determined while comparing a VR simulation with a lecture-based curriculum (Dubovi et al., 2017). Besides, others claimed increased self-efficacy and performance levels for students and professional experts after training with immersive VR (Wu et al., 2019).

Finally, other scholars incorporated different learning environment characteristics within VR, belonging to the components instructions, teaching/learning activities and assessment strategies (Biggs, 1996). Some researchers claimed that immersive VR resulted in increased behavioral performance, motivation and self-efficacy in comparison to a control condition that used conventional study materials (media and text) in a laboratory safety training. However, no difference was determined in basic knowledge retention between the control, desktop VR and immersive VR conditions (Makransky, Borre-Gude et al., 2019). Moreover, inconsistency in findings regarding the impact of VR on learning is observed since immersive VR also resulted in decreased learning compared to desktop VR (Makransky, Terkildsen et al., 2019). Furthermore, medical studies using simulations also reported inconsistent findings, since one study showed increased performances after collaborative learning (Khanal et al., 2014), while others reported no differences in practical performances, even though motivational levels were increased (Aeckersberg et al., 2019).

In brief, based on previous research, it can be stated that:

1. Previous studies on VR, while focusing on the effects of the learning environment, mainly studied instructions, learning activities and/or assessment strategies in isolation or two of these components combined. Although a minority of publications included learning environment characteristics belonging to all three mentioned categories, none of these studies designed their education from the perspective of aligning these learning environment characteristics according to the principle of constructive alignment (Biggs, 1996). This study, however, starts from the perspective of constructive alignment and empirically tests the impact of an aligned learning environment in VR on learning, motivation and perception.
2. Several scholars studied VR learning environments in which participants interacted with the VR modalities. However, little discussion focused on the impact of learning environments in VR, comparable with a traditional classroom situation, where participants conduct both individual learning activities as well as collaborative activities with their peers. Therefore, this study focuses on the impact of full-immersive multi-user VR on learning, motivation and perception by comparing this experimental group with a control condition consisting of a course in a traditional classroom setting.
3. Most studies adopted VR as a learning activity integrated in regular classroom situations. However, it remains questionable whether participants wearing VR-headsets - and following a full-immersive multi-user virtual learning trajectory - without being in the same physical environments as their teachers and peers, is effective for increasing learning outcomes and motivation. This study focuses on the latter by verifying whether

comprehensive VR learning environments are not only effective, but could also be more efficient (in terms of time constraints such as travel time) than traditional face-to-face education in the near future.

4. Previous studies tested the effectivity of the VR learning environments on various outcome variables. Further, several of these studies additionally incorporated perceptions of the participants, since these factors can be considered as crucial intermediate variables influencing learning outcomes. Therefore, this study includes items that directly correspond to the perceived motivation as well as the experience of the key learning environment characteristics as formulated by Biggs (1996) and the classroom setting.

In summary, taking the findings of recent literature together, there is no evidence for the impact of a constructively aligned learning environment in VR on learning outcomes in comparison to the effects of a traditional classroom setting. Therefore, the potential impact is studied here through explorative testing in a field experiment.

Methods

Participants

Twenty-seven Dutch adult participants, active in professional practice, were recruited for this experiment via online recruitment platforms. The sample consisted of eighteen males and nine females. Further, the majority of these professionals ranged from 24 to 56 years of age. With regard to their level of education, most of the participants obtained a Bachelor’s degree. Prior to the experiment, participants were informed about the intention of the study and all of them confirmed their informed consent. In addition, the Netherlands Code of Conduct for Scientific Practice was adopted to ensure research integrity and personal details were excluded from data analysis.

Context of Study

The training involved in this study was an one-day introductory AI course focused on the basic principles of AI and its impact on society and professional practice. The following subjects were included covering the topic of AI: (1) main principles of AI such as intelligent and automated behaviors; (2) classifications of AI referring to the extent of which the intelligence can be applied to any type of task; (3) areas as Machine Learning, Natural Language Processing, Computer Vision, and Robotics, (4) applications of AI in society, and (5) implications of AI for societal future directions.

The AI course was designed based on the principle of constructive alignment as described by Biggs & Tang (2011); Firstly, intended learning outcomes (ILOs) for declarative knowledge were formulated based on the SOLO taxonomy. Different levels of understanding were defined using appropriate ILO action verbs for both quantitative and qualitative phases. The quantitative phase focuses on increasing knowledge and included the action verbs *identify* and *describe*. The qualitative phase aims to deepen understanding and included the action verbs *explain* and *compare*. Secondly, in relation to these ILOs, various teaching/learning activities were created and incorporated in the course. Seeing that learning effectivity rapidly decreases after 15 minutes in class (Biggs & Tang, 2011), it was decided to implement three different action blocks of 15 minutes in the course where active learning was encouraged; (1) instructions about the ILOs were given and the trainer presented a multimedia

PowerPoint presentation about the different topics of AI; (2) group discussions with peers about statements that were designed based on the presented content were encouraged; (3) collaborative learning was encouraged where participants were challenged to work on a real-world scenario in which they had to apply their obtained knowledge. Thirdly, two types of assessment strategies were incorporated: (1) formative feedback was facilitated during collaborative learning where participants were encouraged to respond on each other and on questions of the trainer; (2) summative assessment took place directly after learning, which involved the completion of a test to establish learning outcomes. The assessment, aligned with the ILOs and teaching/learning activities, was mainly focused on basic levels of understanding.

Instructional Conditions

Participants were randomly assigned to either the experimental or control condition. In the experimental condition, participants (n=17) followed the AI course within a full-immersive multi-user VR classroom setting. The VR learning environment was identical to the learning environment of the control condition and both were constructed based on the principle of constructive alignment (Biggs, 1996). However, participants (n=10) in the control condition followed the AI course within a traditional face-to-face classroom setting, in line with Van Ginkel et al. (2019), who stated that in VR research face-to-face conditions can be considered as strong control conditions. Each training contained small groups of four to six participants. The trainer was an expert in the topic of the course and had a lot of experience with teaching and guidance of learners.

Prior to the experiment, participants of the experimental condition were welcomed in a face-to-face setting where they digitally had to complete demographic questions and the assessment for prior knowledge. After a brief introduction about the experiment, how to use VR and what to expect about the VR classroom setting and learning environment, participants were guided to separated rooms where the VR set up was installed. The set up consisted of a VR headset (Oculus Quest) with combined headphone and microphone that provided spatially enhanced voiced communication, lip synchronization and head movement.

The VR learning environment was created using photogrammetry and consisted of a realistic setting which included a U-shaped classroom arrangement and a TV screen in front of the room which was used for the presentation. Both participants and the trainer entered the VR learning environment as avatars and were able to move through the environment and sit on chairs using their controllers. During the course, they were able to ask questions and communicate with each other (e.g. during teaching/learning activities). After the course, participants completed the summative assessment within a different VR environment.

For the control condition, participant were welcomed in the identical face-to-face setting as the experimental condition and demographic questions and prior knowledge were completed via digital forms prior to the experiment. The experiment started with a brief introduction about the study and the traditional classroom setting and learning environment. This learning environment was identical to the experimental condition and participants were able to ask questions and communicate with each other during the teaching/learning activities. After the course, participants completed the summative assessment via a digital form.

Measurements

This study involves a pre-test post-test design to assess professionals' learning outcomes. Further, post-tests for motivation and perceptions towards the learning environment characteristics and classroom setting are incorporated.

AI-knowledge Test

Firstly, basic knowledge about AI was assessed using two similar multiple-choice tests. The first test was conducted before the course and aimed to assess prior knowledge (pre-test), while the second test was executed directly after the course to assess obtained knowledge (post-test). These tests contained six closed multiple-choice questions that were aligned with the ILOs and teaching/learning activities. An example of a question is: 'What type of learning is not supported by Machine Learning?' (A) Unsupervised Learning (B) Feedback Learning (C) Supervised Learning (D) Reinforcement Learning. Scores of these tests were established by summing the correct answers. Regarding validity, the following procedure was executed: To begin with, a concept test was created to elicit perceptions of the research group. After discussion with the researchers, a new concept version was created, which in turn was tested in a pilot study with three participants. Findings were evaluated in the research group, questions were adapted and final versions were created. Cronbach's alpha reliability coefficients have been calculated for both pre-test (0.65) and post-test (0.66).

Motivation Questionnaire

Secondly, motivation was assessed directly after the AI course (post-test only) using the Intrinsic Motivation Inventory (Ryan, 1982). The questionnaire contained five items in total including the following subscales: interest/enjoyment, pressure/tension and value/usefulness. These items were constructed on a 7-point Likert scale ranging from 1 ('I do not agree at all') to 7 ('I fully agree'). An example of an item is: 'I enjoyed doing this course very much'. Scores of these assessments were calculated by measuring the mean scores of the items for each of the subscales and reversed scores were taken into account (i.e. for the pressure/tension subscale). Cronbach's alpha reliability scores shows an adequate value of 0.85.

Perception Questionnaire

Finally, professionals' perceptions towards the learning environment characteristics and classroom setting were assessed (post-test only). The questionnaire contained six closed questions constructed on a 5-point Likert scale ranging from 1 ('strongly disagree') to 5 ('strongly agree'). These questions were related to the learning environment characteristics that were constructed based on the principle of constructive alignment (i.e. instructions, teaching/learning activities and assessment strategies) and the classroom setting. An example of a closed question is: 'The aim and intended learning outcomes of this course were made sufficiently clear'. Finally, evaluations towards the course were assessed with three open questions. These questions were related to major strengths and weaknesses of the course, as well as suggestions for improvements. Besides, two additional open questions were incorporated for participants in the VR classroom setting that were related to physical discomfort and whether participants would like to follow more similar courses in VR.

Procedure

Prior to the course, participants were asked to complete a digital multiple-choice form to assess their prior knowledge about AI (pre-test). Directly after the course, participants in the experimental condition had to accomplish the multiple-choice assessment of obtained knowledge (post-test) in a VR classroom setting that they could manage using their controller. For the control condition, assessment took place directly after the course via a digital multiple-choice form. Finally, participants in both experimental and control group conditions were asked to complete digital forms incorporating items about motivation and perceptions (see Table 1 for an overview of the experimental procedure).

Table 1. Overview of the Experimental Procedure

Phase	Items	Description
Pre-test	Demographic questions	
	Assessment prior knowledge AI	Multiple choice test AI-knowledge
	Plenary introduction	Brief introduction about the experiment and the classroom setting. Participants in the VR condition received an additional explanation about the use of VR.
Experiment	AI course; instructions, group discussion and collaborative learning	In groups of 4-6 participants within the (1) VR classroom setting or (2) traditional face-to-face setting
Post-test	Assessment obtained knowledge AI	Multiple choice test AI-knowledge
	Measurement motivation	Intrinsic Motivation Inventory Questionnaire (IMI)
	Measurement perception	Questionnaire about perceptions towards learning environment characteristics and classroom setting

Data Analysis

At first, paired samples *t*-test analyses were conducted to verify whether participants significantly developed their cognition towards the principles of AI (progress between pre-test and post-tests). Then, independent-sample *t*-tests were applied to determine potential differences in impact, between the experimental and control condition, on learning outcomes. Motivation and perception - assessed with closed questions - and differences between the two groups were analyzed using independent-sample *t*-tests. Regarding open questions about perception, inductive thematic analytical techniques were executed including descriptive statistics (Braun & Clarke, 2006). Substantial agreement (Cohen’s Kappa = 0.77) about the thematically coded responses of these open questions between two researchers was ensured.

Results

This section describes the results relating to the impact of the constructively aligned learning environment in the VR condition and traditional classroom condition on professionals' learning outcomes that is the AI knowledge. Further, motivation and perceptions of professionals relating to the learning environment characteristics and classroom setting are reported.

The Impact of the Learning Environment on Learning Outcomes

A paired-sample *t*-test revealed significant improvements in overall learning outcomes from pre-test (M = 2.33, SD = 1.44) to post-test (M = 3.74, SD = 1.02), $t(26) = 4.51$; $p < .001$. This significant improvement was observed across both conditions (see for details Table 2). Additional analysis showed no significant differences between these two groups, $t(25) = -0.22$; $p = .83$.

Table 2. Mean Scores, SDs and N related to Learning Outcomes for the Traditional and Virtual Reality Classroom Conditions

Variable	**Condition**	**Pre-test**	**Post-test**	**Mean difference**
Learning outcome	Traditional classroom			
	Mean	2.20	3.70	1.50*
	SD	1.75	1.16	1.90
	N	10	10	10
	Virtual reality classroom			
	Mean	2.41	3.76	1.35**
	SD	1.28	0.97	1.50
	N	17	17	17
	Total			
	Mean	2.33	3.74	1.41**
	SD	1.44	1.02	1.62
	N	27	27	27

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

The Impact of the Learning Environment on Motivation

Independent-sample *t*-tests showed no significant differences in motivation between conditions (see for details Table 3). Firstly, the interest/enjoyment subscale revealed substantially sufficient motivational outcomes for both the VR (M = 5.09, SD = 1.14) and traditional (M = 5.65, SD = 0.71) classroom setting, $t(24) = -1.38$; $p = .18$. Secondly, scores of the pressure/tension subscale revealed that participants in both the VR (M = 5.19, SD = 1.52) and traditional (M = 5.90, SD = 1.10) condition experienced no significant pressure/tension difference between the two groups, $t(24) = -1.29$; $p = .21$. Finally, the value/usefulness subscale showed no difference between VR and traditional settings. Both professionals in the VR (M = 5.09, SD = 0.97) and traditional (M = 5.00, SD = 1.05) classroom setting experienced the course as substantial valuable and useful, $t(24) = 0.23$; $p = .98$.

Table 3. Mean Scores, SDs and N related to Motivation for the Traditional and Virtual Reality Classroom Conditions

Subscales	**Traditional classroom**	**Virtual reality classroom**	**Difference between conditions**
Interest/enjoyment			
Mean	5.65	5.09	-0.56
SD	0.71	1.14	0.40
N	10	16	26
Pressure/tension			
Mean	5.90	5.19	-0.71
SD	1.10	1.52	0.55
N	10	16	26
Value/usefulness			
Mean	5.10	5.50	0.40
SD	1.05	1.00	0.41
N	10	16	26

Perceptions towards the Learning Environment Characteristics and Classroom Setting

Independent-sample *t*-tests for closed questions considering perceptions revealed no significant differences in perceptions towards the learning environment characteristics that were designed based on the principle of constructive alignment (i.e. ILOs, instructions, teaching/learning activities and assessment strategies) with substantially sufficient mean scores for each of these elements, see for details Table 4. However, professionals in the VR classroom setting experienced the setting as less pleasurable (M = 3.50, SD = 1.27) compared to professionals in the traditional classroom setting (M = 4.40, SD = 0.70), $t(24) = -2.33$; $p < .05$.

Thematically coded responses to open questions with regard to perceptions are represented in Table 5. Firstly, regarding major strengths of the course, eighteen professionals in total reported that the course was well-structured and instructions were clearly understandable. Additionally, several professionals in both conditions described their satisfaction about the group interaction (i.e. the interaction between peers and the interaction of the teacher with the group). Lastly, professionals in both conditions experienced the learning environment as satisfying and enjoyable. To illustrate, professionals in the VR classroom mentioned: “I experienced a sense of being in the virtual environment with my peers” and “The VR classroom setting was highly enjoyable”.

Secondly, according to questions about the major weaknesses of the course, many participants reported complications related to the setting. The majority of these participants were in the VR classroom setting and described issues as technical instability (e.g. audio problems and Wi-Fi connections) and unfamiliarity with the setting. Further, the minority of professionals of the VR classroom setting highlighted shortcomings related to features of VR (e.g. missing facial expressions) which affected perceptions of group interaction and the performance of group discussions. To illustrate, a quotation of a professional in the VR condition follows: “There were some moments that people started speaking at the same time, which also frequently occurs during online video conferencing. This slightly affected the group interaction at some moments during group discussions.”. Besides, one professional in the traditional classroom described a weakness related to the presentation of content.

Table 4. Mean Scores, SDs and N related to Perceptions for the Traditional and Virtual Reality Classroom Conditions

Items	**Traditional classroom**	**Virtual reality classroom**	**Difference between conditions**
1. The aim and intended learning outcomes of this course were made sufficiently clear.			
Mean	4.30	4.56	0.26
SD	0.82	0.63	0.29
N	10	16	26
2. Instructions were clearly understandable.			
Mean	4.60	4.50	-0.10
SD	0.52	0.52	0.21
N	10	16	26
3. The learning activities (e.g. case and statements) helped me to understand the course content.			
Mean	4.20	3.75	-0.45
SD	1.03	0.86	0.38
N	10	16	26
4. Questions in the assignment were clearly written and understandable.			
Mean	4.00	4.50	0.50
SD	0.94	0.52	0.29
N	10	16	26
5. Instructions, learning activities and assignments usefully complemented each other.			
Mean	4.50	4.38	-0.13
SD	0.53	0.81	0.29
N	10	16	26
6. I experienced the classroom setting as pleasurable.			
Mean	4.40	3.50	-0.90*
SD	0.70	1.27	0.39
N	10	16	26

* $p < .05$

Thirdly, suggestions for improvements included all different kinds of aspects. In line with reported complications due to the setting, the majority of professionals in the VR classroom condition described improvements related to these issues (e.g. facilitation of technical stability). Additionally, professionals in both settings reported improvements for group interaction and discussions. For the VR classroom setting, these improvements were related to VR features, such as incorporating hand movements and facial expressions, while others argued that interactivity of the learning environment could be improved. Besides, some participants in both conditions made suggestions for the presentation of content and duration of the course.

Table 5. Responses related to Open Questions about Perceptions for the Traditional and Virtual Reality Classroom Conditions

Evaluation questions	**Traditional classroom**	**Virtual reality classroom**
	Number of professionals	Number of professionals
What are the major strengths of this course?		
Well-structured course with clearly understandable instructions	6	12
Satisfying group interaction	3	4
Enjoyable and satisfying learning environment	2	5
What are the major weaknesses of this course?		
Complications due to the setting	3	14
Unsatisfying group interaction	0	3
Presentation of content	1	0
What improvements would you make for this course?		
The setting	3	11
Group interaction and interactivity	1	3
Presentation of content	1	3
Duration of the course	2	1
Did you feel any physical discomfort related to travel sickness during the course?		
No physical discomfort	-	14
Some physical discomfort	-	2
Would you follow more courses in virtual reality?		
Yes, but only when it is not possible to meet each other in person.	-	3
Yes, valuable due to (potential) features of VR and setting.	-	10
Yes, but only if it is used as an additional tool in education (no replacement of courses).	-	1
No, I prefer a face-to-face setting.	-	2

Finally, two additional questions were included for the VR classroom setting. One of these questions was related to physical discomfort associated with travel sickness. While the majority of participants did not report any physical discomfort, two of them experienced light headache and eye strain. The second additional question for participants in the VR classroom setting was about whether they would like to follow more course in VR. Ten of the participants explicitly agreed with this due to (potential) features of the VR technology and the setting (e.g. high efficiency concerning travel times). For example, it has been stated by one of the professionals that: "The course in this VR learning environment is very valuable within the context of professional practice. It almost felt like a real physical meeting." Others suggested that they are open to this, but only when it is not possible to meet each other in person (e.g. due to geographical barriers or in case of disease) or as an additional tool in current educational approaches. Lastly, a couple mentioned that they prefer a traditional face-to-face setting over the VR classroom setting.

Discussion and Conclusions

This field experiment aimed to explore the impact of an one-day introductory AI course, designed based on the principle of constructive alignment (Biggs, 1996), in a full-immersive VR classroom setting on knowledge, motivation and perceptions of professionals. Results of this study reveal improved learning outcomes for both the VR and traditional classroom setting from pre-test (before training) to post-test (after training) with no difference between the two conditions. Further, participants in both conditions showed comparable motivational outcomes towards following the course within the setting. Additional questions about perceptions towards the fundamental learning environment characteristics, that is instructions, learning activities and assessment strategies, showed that these elements are perceived by participants as highly positive and useful in both conditions. From a scientific perspective, this finding indicates that the principle of Biggs (1996) is effective for learning independent of classroom setting (VR or face-to-face). Additionally, based on professionals' perceptions, the constructively aligned learning environment might be further encouraged by making use of specific VR features. In order to increase the interactivity within the VR environment, professionals could, for example, - as a learning activity - verify whether a robot in VR behaves according to the tested AI formula by the learner (Segura et al., 2020). Another suggested improvement relates to increasing the degree of realism of nonverbal communication in VR by using devices aimed for facial expressions and hand movements that resemble human interaction (Li et al., 2019; Lou et al., 2020). From a societal perspective, adopting VR learning environments in future education seems to have promising practical benefits as participants highlighted the efficiency relating to travel times, geographical barriers and in case of disease. Besides these potentials of the VR classroom, a number of shortcomings regarding the setting need to be considered for practice and research, since professionals reported complications about technical instability, as network dropouts and audio problems, and unfamiliarity with the setting.

A fundamental finding of this study is the significant improvement in learning outcomes with no difference between the experimental and control condition. This result can be substantiated by several arguments. Firstly, the learning environment incorporated in this study was designed based on the principle of constructive alignment (Biggs, 1996). Earlier studies have shown that this principle is highly effective in traditional teaching approaches (Joseph & Juwah, 2012; Van Ginkel et al., 2015a). The present study confirms these findings with the established improvement in learning outcomes of participants in the traditional face-to-face setting. Moreover, seeing the lack of difference in learning outcomes between the two conditions, it is suggested that the implementation of the principle of constructive alignment in VR learning environments seems to be as effective as in traditional teaching.

This finding is supported by professionals' perceptions towards the learning environment characteristics that turned out to be more than substantial for both conditions.

Secondly, both the traditional and VR learning environments involved the presence of a teacher. According to previous literature, teachers have a crucial role in professionals and students' learning processes. For example, the teacher has been shown to play a fundamental role in providing instructions to professionals (Graeser et al., 2014; Khanal et al., 2014). Further, the expert has an essential impact on learning when providing verbal feedback (Van Ginkel et al., 2015b) and facilitating peer feedback (Van den Berg et al., 2006). Moreover, teachers are described to be a role model for students (Van Haaren & Van der Rijst, 2014). Concerning the role of the teacher in the present study, the expert fulfilled a similar function (i.e. presented instructions, provided verbal feedback and encouraged peer feedback during learning activities) in the experimental and control condition. As a consequence, the teacher might have encouraged professionals' learning processes – and as a result their learning outcomes – in both conditions similarly.

Thirdly, another argument concerns the motivational outcomes. Motivation is an intermediate psychological factor (Biggs, 1993) that positively influences learning in traditional (Biggs & Tang, 2011) and VR environments (Lee et al., 2010). In this study, professionals in both conditions were substantially motivated to follow the course within the setting, without a difference between the two groups. Based on this result, it is suggested that this intermediate factor might have driven similar learning processes in professionals resulting in comparable learning outcomes between conditions.

There are several limitations to this study. The first limitation concerns the small sample size. This field study demonstrated a significant impact on learning outcomes without a difference between the two selected conditions. Although the VR classroom can be considered as a promising setting in future learning arrangements, caution must be taken for interpreting these results given the small sample size. Therefore, research with larger sample sizes is recommended and may allow more substantiated conclusions about the impact of VR versus face-to-face environments.

The second limitation is professionals' unfamiliarity with using VR technology (Hew & Cheung, 2010; Van Ginkel et al., 2019). Based on the perceptions, several participants highlighted the lack of experience while learning in VR settings. This so-called unfamiliarity, as previously addressed by other studies on innovative technologies and learning (Hew & Cheung, 2010; Van Ginkel et al., 2019), could have influenced both the impact on learning outcomes and motivation as well as the perceptions towards the use of such an innovative technology. This finding corroborates with earlier studies suggesting that research and practice should focus more on training directed to familiarizing participants with the VR technology prior to their learning task (Makransky, Borre-Gude, et al., 2019; Van Ginkel et al., 2019). In retrospective, participants in this study only received a brief introduction about how to use VR and what to expect about in a VR setting. For future studies, it is recommended to incorporate training programs that sufficiently familiarizes participants with VR before entering the learning environment. Characteristics of such programs include: (1) instructions on VR, (2) practicing smaller learning tasks in such an environment and (3) how to provide feedback and conduct assessments on making use of these systems.

The third limitation concerns the lack of certain nonverbal communication aspects during collaborative learning tasks in VR. The present study actively incorporated several verbal and nonverbal communication aspects that play an essential role in social interaction in daily life as well as in VR. Examples refer to synchronous communication supported by lip synchronization (Laister & Kober, 2002) and postures (Smith & Neff, 2018). However, consistent with previous perceptions towards collaborative learning in VR (Šašinka et al., 2019; Smith & Neff, 2018), some participants of the VR classroom setting in this study described that the learning experience, especially for group interaction, might be improved by incorporating other nonverbal communication aspects such as facial expressions and hand movements. Another study that also failed to incorporate facial expressions and hand movements reported lower levels of social awareness compared to face-to-face interactions (Smith & Neff, 2018). However, it is unknown whether this might have negative consequences for participants' learning processes. Interestingly, Chan *et al.* (2019) developed a theoretical model about collaborative learning in VR environments that is focused on nonverbal communication features such facial expressions and hand movements. This research suggests that if these features are incorporated, it positively affects participants' perceptions which could potentially lead to enhanced motivation and higher learning outcomes (Chan et al., 2019). Further, follow-up experimental studies are needed to validate this theoretical assumption and evaluate whether additional nonverbal communications aspects, such as facial expressions and hand movements, will improve motivation and learning outcomes in collaborative learning environments.

To evaluate the quality of this research, reliability and validity have to be taken into account. Firstly, acceptable internal reliability scores of the instruments for learning outcomes and motivation have been determined in this study. Additionally, the interrater reliability was calculated for the thematically coded responses on open evaluation questions. This measurement turned out to be more than sufficient and therefore substantial agreement between researchers was ensured.

On the subject of validity, the following aspects are noteworthy to highlight for future studies including ecological validity, construct validity, internal validity and external validity. Firstly, the ecological validity in this study is high since the field experiment has been conducted in a realistic learning environment. Moreover, the training was designed based on the principle of constructive alignment that has been shown to be effective in teaching practice (Joseph & Juwah, 2012; Van Ginkel et al., 2015a). Secondly, construct validity in this study is ensured, because the items within the cognition and perception instruments are directly related to the principle of constructive alignment, i.e. the alignment between instructions, teaching/learning activities and assessment strategies (Biggs, 1996; Biggs & Tang, 2011). Further, the validity of the Intrisic Motivational Inventory has been reported by other researchers (McAuley et al.,1989). Thirdly, the internal validity in this study is strong. The present study incorporated a pre-test post-test design for learning assessment and post-tests for motivation and perception that were conducted directly before and after the training. This approach limits interference of variables (e.g. mental changes) in individuals over passage of time that could interact with the learning outcomes and motivation (Dimitrov & Rumrill, 2003). Further, the prevention of a potential bias between conditions was ensured by randomly assigning participants over both groups. As well, additional analysis revealed no differences in prior knowledge between the two conditions. Finally, with regard to the external validity of this study, it remains questionable to what extend the results can be generalized to other contexts. The present study has shown that participants can significantly develop their learning in the VR learning environment. However, it remains questionable whether the same progress in learning outcomes and substantial levels of motivation and perceptions are evident in VR settings at home. Another point concerns the extent to which the results of this study can be demonstrated in other contexts as well, such as higher education. Previous studies demonstrated the efficiency of VR learning environments in higher educational contexts (Alfalah et al., 2018; Makransky et al., 2020; Rupasinghe et al., 2011; Stepan et al., 2017; Van Ginkel et al., 2019). However, these studies only focused on particular learning environment characteristics. Therefore, it is recommended for future studies to determine whether a constructively aligned VR learning environment provides a similar effect on learning outcomes, motivation and perceptions in higher education.

Suggestions for Future Research

Based on the limitations, discussions and recommendations for future studies, several suggestions for new research directions are proposed. Firstly, it is recommended for future studies to investigate whether the implementation of VR features proposed by the professionals of this study, such as interactivity and nonverbal communication, enhance learning, motivation and perceptions. To start with, earlier studies showed that incorporation of learning activities with high levels of interactivity within a VR environment (i.e. the ability to interact and manipulate simulated biological mechanisms) significantly improve students' learning of science-related concepts (Lamb et al., 2018). In line with this, it might be interesting for future research to implement similar interactive learning activities covering the topic of AI (such as the ability to manipulate self-coded robots) within a constructively aligned VR learning environment (Segura et al., 2020). Besides, other studies should focus on VR features that include nonverbal communication aspects, as specifically addressed by participants in this study. Implementation of these nonverbal communication features has the potential to enhance the quality of interaction in learning activities (e.g. group discussions) and feedback strategies (e.g. peer feedback) in a constructively aligned learning environment (Li et al., 2019; Lou et al., 2020).

Secondly, it is recommended for future research to concentrate on the different demographic characteristics of learners. Previous studies have shown that there are differences between males and females in perceptions towards collaborative virtual worlds. For example, males experienced a stronger sense of physically being involved in the virtual environment compared with females (Felnhofer et al., 2014). Additionally, higher levels of engagement in social interactions within the collaborative environment were observed in males compared to females, which was related to differences in beliefs about the nature of the virtual world (Seo & DeNoyelles, 2012). However, perception is an intermediate variable in the learning process (Van Ginkel et al., 2015) and Seo and DeNoyelles (2012) claimed that the differences between males and females in perceptions affected learning. Moreover, it seems that differences in educational backgrounds also affect learning processes in VR (Belboukhaddaoui & Van Ginkel, 2019). Therefore, future studies should focus on different characteristics of learners (e.g. gender, age, background) that potentially affect perceptions and learning outcomes. Moreover, these insights might contribute to the development of personalized learning environments, which has been an observed trend in education (Xie et al., 2019).

Finally, it is proposed for future research to investigate the potentials of the replacement of teachers by artificial virtual experts to overcome educational challenges as time constraints and teacher shortages. Some researchers effectively replaced the teacher by a computer-driven agent within particular learning environment characteristics of teaching programs. For example, the replacement of a teacher by artificial virtual experts within the instructions of science-based study programs turned out to be effective for learning (Li et al., 2016; Makransky, Mayer, et al., 2019). Interestingly, it is suggested that the design of artificial virtual experts might be gender specific (Makransky et al., 2018). Besides, the delivery of computer-mediated feedback was as effective for learning as feedback provided by an expert (Van Ginkel et al., 2019, 2020). Even though the examples demonstrated a significant progress in learning while replacing the teacher by a computer-driven agent, these studies did not apply constructive aligned learning environments. Therefore, future research should focus on the replacement of a teacher by an artificial virtual expert in certain learning activities within a constructively aligned VR environment.

References

Adubra, E., Da Silva, I., Dhungana, B., Mohan, N., Saltsman, G., & Van Ginkel, S. (2019). Exploring the use of Artificial Intelligence to support teachers and teacher development. *UNESCO International Task Force on Teachers, 1*(19), 1-16.

Aeckersberg, G., Gkremoutis, A., Schmitz-Rixen, T., & Kaiser, E. (2019). The relevance of low-fidelity virtual reality simulators compared with other learning methods in basic endovascular skills training. *Journal of Vascular Surgery*, *69*(1), 227–235. https://doi.org/10.1016/j.jvs.2018.10.047

Alfalah, S. F. M., Falah, J. F. M., Alfalah, T., Elfalah, M., Muhaidat, N., & Falah, O. (2018). A comparative study between a virtual reality heart anatomy system and traditional medical teaching modalities. *Virtual Reality*, *23*, 229–234. https://doi.org/10.1007/s10055-018-0359-y

Banihashem, S.K., Farrokhnia, M., Badali, M., & Noroozi, O. (2022). The impacts of constructivist learning design and learning analytics on students' engagement and self-regulation. *Innovations in Education and Teaching International*, *59*(4), 442-452. https://doi.org/10.1080/14703297.2021.1890634.

Banihashem, S. K., Noroozi, O., van Ginkel, S., Macfadyen, L. P., & Biemans, H. J. A. (2022). A systematic review of the role of learning analytics in enhancing feedback practices in higher education. Educational Research Review, 37, 100489. https://doi.org/10.1016/j.edurev.2022.100489.

Belboukhaddaoui, I. & Van Ginkel, S. (2019). Fostering oral presentation skills by the timing of feedback: an exploratory study in virtual reality. *Research on Education and Media*, *11*(1), 25-31. https://doi.org/10.2478/rem-2019-0005

Bhatti, N. I., & Ahmed, A. (2015). Improving skills development in residency using a deliberate-practice and learner-centered model. *The Laryngoscope*, *125*, S1–S14. https://doi.org/10.1002/lary.25434

Biggs, J. (1993). From theory to practice: A cognitive systems approach. *Higher Education Research & Development*, *12*(1), 73–85. https://doi.org/10.1080/0729436930120107

Biggs, J. (1996). Enhancing teaching through constructive alignment. *Higher Education*, *32*, 347–364. https://doi.org/https://doi.org/10.1007/BF00138871

Biggs, J., & Tang, C. (2011). *Teaching for quality learning at university* (4th ed.). McGraw-Hill Education.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Cervero, R. M. (2000). Trends and issues in continuing professional education. *New Directions for Adult and Continuing Education, 86,* 3-12. https://doi.org/10.1002/ace.8601

Chan, J. K. Y., Wong, R. Y. M., & Cheung, C. M. K. (2019). How affordances of immersive visualization systems affect learning outcomes through aesthetic experience. *PACIS 2019 Proceedings.* Pacific Asia Conference on Information Systems.

Chau, M., Wong, A., Wang, M., Lai, S., Chan, K. W. Y., Li, T. M. H., Chu, D., Chan, I.K.W., Sung, W. K. (2013). Using 3D virtual environments to facilitate students in constructivist learning. *Decision Support Systems*, *56*, 115–121. https://doi.org/10.1016/j.dss.2013.05.009

Collin, K., Van der Heijden, B., & Lewis, P. (2012). Continuing professional development. *International Journal of Training and Development*, *16*(3), 155–163. https://doi.org/10.1111/j.1468-2419.2012.00410.x

Crochet, P., Aggarwal, R., Knight, S., Berdah, S., Boubli, L., & Agostini, A. (2017). Development of an evidence-based training program for laparoscopic hysterectomy on a virtual reality simulator. *Surgical Endoscopy*, *31*, 2474–2482. https://doi.org/10.1007/s00464-016-5249-3

Daley, B.J., & Cervero, R.M. (2016). Learning as the basis for continuing professional education. *New Directions for Adult and Continuing Education*, (151), 19-29. https://doi.org/10.1002/ace.20192

Dimitrov, D. M., & Rumrill, P. D. (2003). Pretest-posttest designs and measurement of change. *Work*, *20*(2), 159–165

Dubovi, I., Levy, S. T., & Dagan, E. (2017). Now I know how! The learning process of medication administration among nursing students with non-immersive desktop virtual reality simulation. *Computers & Education*, *113*, 16–27. https://doi.org/10.1016/j.compedu.2017.05.009

Farrokhnia, M., Banihashem, S. K., Noroozi, O., & Wals, A. (2023). A SWOT analysis of ChatGPT: Implications for educational practice and research. *Innovations in Education and Teaching International*. https://doi.org/10.1080/14703297.2023.2195846.

Felnhofer, A., Kothgassner, O. D., Hauk, N., Beutl, L., Hlavacs, H., & Kryspin-Exner, I. (2014). Physical and social presence in collaborative virtual environments: Exploring age and gender differences with respect to empathy. *Computers in Human Behavior*, *31*, 272–279. https://doi.org/10.1016/j.chb.2013.10.045

Fink, A. (2010). *Conducting research literature reviews: From the Internet to paper* (3rd ed.). Sage Publications.

Fleming, M., Olsen, D., Stathes, H., Boteler, L., Grossberg, P., Pfeifer, J., Schiro, S., Banning, J., & Skochelak. (2009). Virtual reality skills training for health care professionals in alcohol screeing and brief intervention. *Journal of the American Board of Family Medicine, 22 (4),* 387-398. https://doi.org/10.3122/jabfm.2009.04.080208

Graeser, K., Konge, L., Kristensen, M. S., Ulrich, A. G., Hornbech, K., & Ringsted, C. (2014). Airway management in a bronchoscopic simulator based setting An observational study. *European Journal of Anaesthesiology*, *31*, 125–130. https://doi.org/10.1097/EJA.0b013e328364395a

Hew, K. F., & Cheung, W. S. (2010). Use of three-dimensional (3-D) immersive virtual worlds in K-12 and higher education settings: A review of the research. *British Journal of Educational Technology*, *41*(1), 33–55. https://doi.org/10.1111/j.1467-8535.2008.00900.x

Howard, M. C., & Gutworth, M. B. (2020). A meta-analysis of virtual reality training programs for social skill development. *Computers & Education*, *144*, 103707 https://doi.org/10.1016/j.compedu.2019.103707

Hu, R., Wu, Y. Y., & Shieh, C. J. (2016). Effects of virtual reality integrated creative thinking instruction on students' creative thinking abilities. *Eurasia Journal of Mathematics, Science & Technology Education*, *12*(3), 477–486. https://doi.org/10.12973/eurasia.2016.1226a

Joseph, S., & Juwah, C. (2012). Using constructive alignment theory to develop nursing skills curricula. *Nurse Education in Practice*, *12*, 52–59. https://doi.org/10.1016/j.nepr.2011.05.007

Khanal, P., Vankipuram, A., Ashby, A., Vankipuram, M., Gupta, A., Drumm-Gurnee, D., Josey, K., Tinker, L., Smith, M. (2014). Collaborative virtual reality based advanced cardiac life support training simulator using virtual reality principles. *Journal of Biomedical Informatics*, *51*, 49–59. https://doi.org/10.1016/j.jbi.2014.04.005

Laister, J., & Kober, S. (2002). Social aspects of collaborative learning in virtual learning environments. *Proceedings of the Networked Learning Conference Sheffield* (pp. 1–7).

Lamb, R., Antonenko, P., Etopio, E., & Seccia, A. (2018). Comparison of virtual reality and hands on activities in science education via functional near infrared spectroscopy. *Computers & Education*, *124*, 14–26. https://doi.org/10.1016/j.compedu.2018.05.014

LaViola, J. J., Kruijff, E., McMahan, R. P., Bowman, D. A., & Poupyrev, I. (2017). *3D user interfaces: Theory and practice* (2nd ed.). Addison-Wesley

Lee, E. A. L., Wong, K. W., & Fung, C. C. (2010). How does desktop virtual reality enhance learning outcomes? A structural equation modeling approach. *Computers & Education*, *55*(4), 1424–1442. https://doi.org/10.1016/j.compedu.2010.06.006

Li, Y., Huang, J., Tian, F., Wang, H. A., & Dai, G. Z. (2019). Gesture interaction in virtual reality. *Virtual Reality & Intelligent Hardware, 1*(1), 84-112. https://doi.org/10.3724/SP.J.2096.2018.0006

Li, J., Kizilcec, R., Bailenson, J., & Ju, W. (2016). Social robots and virtual agents as lecturers for video instruction. *Computers in Human Behavior*, *55*, 1222–1230. https://doi.org/10.1016/j.chb.2015.04.005

Lou, J., Wang, Y., Nduka, C., Hamedi, M., Mavridou, I., Wang, F.Y., & Yu, H. (2020). Realistic facial expression reconstruction for VR HMD users. *IEEE Transactions on Multimedia*, *22*(3), 730-743. https://doi.org/10.1109/TMM.2019.2933338

Luppicini, R. (2014). Review of computer mediated communication research for education. *Instructional Science*, *35*(2), 141–185. https://doi.org/10.1007/s11251-006-9001-6

Makransky, G., Borre-Gude, S., & Mayer, R. E. (2019). Motivational and cognitive benefits of training in immersive virtual reality based on multiple assessments. *Journal of Computer Assisted Learning*, *35*, 691–707. https://doi.org/10.1111/jcal.12375

Makransky, G., Mayer, R., Nøremølle, A., Lopez Cordoba, A., Wandall, J., & Bonde, M. (2020). Investigating the feasibility of using assessment and explanatory feedback in desktop virtual reality simulations. *Educational Technology Research and Development*, *68*, 293–317. https://doi.org/10.1007/s11423-019-09690-3

Makransky, G., Mayer, R. E., Veitch, N., Hood, M., Christensen, K. B., & Gadegaard, H. (2019). Equivalence of using a desktop virtual reality science simulation at home and in class. *PLoS ONE*, *14*(4). https://doi.org/10.1371/journal.pone.0214944

Makransky, G., Terkildsen, T. S., & Mayer, R. E. (2019). Adding immersive virtual reality to a science lab simulation causes more presence but less learning. *Learning and Instruction*, *60*, 225–236.

https://doi.org/10.1016/j.learninstruc.2017.12.007

Makransky, G., Wismer, P., & Mayer, R.E. (2018). A gender matching effect in learning with pedagogical agents in an immersive virtual reality science simulation. *Journal of Compuer Assisted Learning, 35*, 348-358. https://doi.org/10.1111/jcal.12335

Makridakis, S. (2017). The forthcoming Artificial Intelligence (AI) revolution: Its impact on society and firms. *Futures*, *90*, 46–60. https://doi.org/10.1016/j.futures.2017.03.00

McAuley, E., Duncan, T., & Tammen, V. V. (1989). Psychometric properties of the intrinsic motivation inventory in a competitive sport setting: A confirmatory factor analysis. *Research Quarterly for Exercise and Sport*, *60*(1), 48–58. https://doi.org/10.1080/02701367.1989.10607413

McKenzie, S., Garivaldis, F., & Dyer, K.R. (2020). *Tertiary online teaching and learning: TOTAL perspectives and resources for digital education (1st ed.).* Springer Verlag.

Merchant, Z., Goetz, E. T., Cifuentes, L., Keeney-Kennicutt, W., & Davis, T. J. (2014). Effectiveness of virtual reality-based instruction on students' learning outcomes in K-12 and higher education: A meta-analysis. *Computers & Education*, *70*, 29–40. https://doi.org/10.1016/j.compedu.2013.07.033

Mohammadi, A., Grosskopf, K., & Kilingsworth, J. (2019). Workforce development through online experiential learning for STEM education. *Adult Learning*, *31*(1), 27–35. https://doi.org/10.1177/1045159519854547

Noroozi, O., Alikhani, I., Järvelä, S., Kirschner, P. A., Juuso, I., & Seppänen, T. (2019). Multimodal data to design visual learning analytics for understanding regulation of learning. Computers in Human Behavior, 100, 298-304. https://doi.org/10.1016/j.chb.2018.12.019.

Noroozi, O., Järvelä, S., & Kirschner, P. A. (2019). Multidisciplinary innovations and technologies for facilitation of self-regulated learning. Computers in Human Behavior, 100, 295-297. https://doi.org/10.1016/j.chb.2019.07.020.

Noroozi, O., Pijeira-Díaz, H. J., Sobocinski, M., Dindar, M., Järvelä, S., & Kirschner, P. A. (2020). Multimodal data indicators for capturing cognitive, motivational, and emotional learning processes: *A systematic literature review. Education and Information Technologies, 25*(6), 5499-5547. https://doi.org/10.1007/s10639-020-10229-w.

Noroozi, O., Weinberger, A., & Kirschner, P. A. (2021). Technological and pedagogical innovations for facilitation of students' collaborative argumentation-based learning. *Special Issue on Innovations in Education and Teaching International, 58*(5), 499-500. https://www.tandfonline.com/doi/full/10.1080/14703297.2021.1970439?src=.

Palter, V. N., Orzech, N., Keznick, R. K., & Grantcharov, T. P. (2013). Validation of a structured training and assessment curriculum for technical skill acquisition in minimally invasive surgery: A randomized controlled trial. *Annals of Surgery*, *257*(2), 224–230. https://doi.org/10.1097/SLA.0b013e31827051cd

Radianti, J., Majchrzak, T. A., Fromm, J., & Wohlgenannt, I. (2020). A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. *Computers & Education*, *147*. https://doi.org/10.1016/j.compedu.2019.103778

Rupasinghe, T. D., Kurz, M., & Washburn, C. (2011). Virtual reality training integrated curriculum: An Aircraft Maintenance Technology (AMT) Education Perspective. *International Journal of Engineering Education*, *27*, 778–788.

Ryan, R. M. (1982). Control and information in the intrapersonal sphere: An extension of cognitive evaluation theory. *Journal of Personality and Social Psychology*, *43*(3), 450–461.

Šašinka, Č., Stachoň, Z., Sedlák, M., Chmelík, J., Herman, L., Kubíček, P., Šašinková, A.

Doležal, M., Tejkl, H., Urbánek, T., Svatoňová, H., Ugwitz, P., & Juřík, V. (2019). Collaborative immersive virtual environments for education in geography. *International Journal of Geo-Information, 8*(3). https://doi.org/10.3390/ijgi8010003

Segura, R. J., del Pino, F. J., Ogáyar, C. J., & Rueda, A. J. (2020). VR-OCKS: A virtual reality game for learning the basic concepts of programming. *Computer Applications in Engineering Education, 28*(1), 31-42. https://doi.org/10.1002/cae.22172

Seo, K. K. J., & DeNoyelles, A. (2012). Inspiring equal contribution and opportunity in a 3d multi-user virtual environment : Bringing together men gamers and women non-gamers in Second Life. *Computers & Education*, *58*(1), 21–29. https://doi.org/10.1016/j.compedu.2011.07.007

Sichterman, B., Schipper, M., Verstappen, M., Waisvisz, P., & van Ginkel, S. (2021). The impact of computer-mediated delayed feedback on developing oral presentation skills: An experimental study in virtual reality. In A. Pucihar, M. Kljajic Borstnar, R. Bons, H. Cripps, A. Sheombar, & D. Vidmar (Eds.), Digital support: From crisis to progressive change (pp. 683–690). University Press.

Sichterman, B., Verstappen, M., Bonnes, A., ter Haar, D., & van Ginkel, S. (2022). Fostering students' engineering competence by adopting augmented reality: a proposed randomized controlled trial study. *2022 IEEE International Conference on Artificial Intelligence and Virtual Reality (AIVR)* (pp. 260-265).

Smith, H. J., & Neff, M. (2018). Communication behavior in embodied virtual reality. *Proceedings of the 2018 CHI Conference on Human Factors in Computing System* (pp. 1–12).

Stepan, K., Zeiger, J., Hanchuk, S., Del Signore, A., Shrivastava, R., Govindaraj, S., & Iloreta, A. (2017). Immersive virtual reality as a teaching tool for neuroanatomy. *International Forum of Allergy & Rhinology*, *7*(10), 1006–1013. https://doi.org/10.1002/alr.21986

Van den Berg, I., Admiraal, W., & Pilot, A. (2006). Design principles and outcomes of peer assessment in higher education. *Studies in Higher Education*, *31*(3), 341–356. https://doi.org/10.1080/03075070600680836

Van Ginkel, S., Gulikers, J., Biemans, H., & Mulder, M. (2015a). Towards a set of design principles for developing oral presentation competence: A synthesis of research in higher education. *Educational Research Review*, *14*, 62–80. https://doi.org/10.1016/j.edurev.2015.02.002

Van Ginkel, S., Gulikers, J., Biemans, H., & Mulder, M. (2015b). The impact of the feedback source on developing oral presentation competence. *Studies in Higher Education*, *42*(9), 1671–1685. https://doi.org/10.1080/03075079.2015.1117064

Van Ginkel, S., Gulikers, J., Biemans, H., Noroozi, O., Roozen, M., Bos, T., Van Tilborg, R., Van Halteren, M., & Mulder, M. (2019). Fostering oral presentation competence through a virtual reality-based task for delivering feedback. *Computers & Education*, *134*, 78–97. https://doi.org/10.1016/j.compedu.2019.02.006

Van Ginkel, S., Ruiz, D., Mononen, A., Karaman, C., De Keijzer, A., & Sitthiworachart, J. (2020). The impact of computer-mediated immediate feedback on developing oral presentation skills: An exploratory study in virtual reality. *Journal of Computer Assisted Learning*, *36*, 412–422. https://doi.org/10.1111/jcal.12424

Van Ginkel, S. & Sichterman, B. (2023). Constructing computer-mediated feedback in virtual reality for improving peer learning: a synthesis of the literature in presentation research. In: O. Noroozi, B. de

Wever. (Eds), *The power over peer learning. Social interaction in learning and development* (pp. 145-163). Springer. https://doi.org/10.1007/978-3-031-29411-2_7

Van Haaren, M., & Van der Rijst, R. (2014). Teaching talented students at a research-intensive university: In M. V. C. Wolfensberger, L. Drayer, & J. J. M. Volker (Eds.), *Pursuit of excellence in a networked society: Theoretical and practical approaches* (pp. 39–46). Waxman.

Webster-Wright, A. (2009). Reframing professional development through understanding authentic professional learning. *Review of Educational Research*, *79*(2), 702–739. https://doi.org/10.3102/0034654308330970

Wu, W., Hartless, J., Tesei, A., Gunji, V., Ayer, S., & London, J. (2019). Design assessment in virtual and mixed reality environments: Comparison of novices and experts. *Journal of Construction Engineering and Management*, *145*(9). https://doi.org/10.1061/(ASCE)CO.1943-7862.0001683

Xie, H., Chu, H.C., Hwang, G.J., & Wang, C.C. (2019). Trends and development in technology-enhanced adaptive/personalized learning: A systematic review of journal publications from 2007 to 2017. *Computers & Education, 140,* 103599. https://doi.org/10.1016/j.compedu.2019.103599

Zawacki-Richter, O., & Naidu, S. (2016). Mapping research trends from 35 years of publications in distance education. *Distance Education*, *37*(3), 245–269. https://doi.org/10.1080/01587919.2016.1185079

Author Information

Bo Sichterman
https://orcid.org/0000-0002-2698-5798
HU University of Applied Sciences Utrecht
Padualaan 99, 3584 CH, Utrecht
The Netherlands
Contact e-mail: *Bo.sichterman@hu.nl*

Stan van Ginkel
https://orcid.org/0000-0001-9520-4652
HU University of Applied Sciences Utrecht
Padualaan 99, 3584 CH, Utrecht
The Netherlands

Melanie van Halteren
https://orcid.org/0009-0008-8380-8043
CoVince
Utrechtseweg 33, 3704 HA, Zeist
The Netherlands

Richard van Tilborg
https://orcid.org/0009-0009-8742-6015
CoVince
Utrechtseweg 33, 3704 HA, Zeist
The Netherlands

Omid Noroozi
https://orcid.org/0000-0002-0622-289X
Wageningen University & Research
Hollandseweg 1, 6706 KN, Wageningen
The Netherlands