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Investigating the effect of pre-training when learning through immersive virtual reality and video: A media and methods experiment

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ABSTRACT

Immersive virtual reality (VR) is predicted to have a significant impact on education; but most studies investigating learning with immersive VR have reported mixed results when compared to low-immersion media. In this study, a sample of 118 participants was used to test whether a lesson presented in either immersive VR or as a video could benefit from the pre-training principle, as a means of reducing cognitive load. Participants were randomly assigned to one of two method conditions (with/without pre-training), and one of two media conditions (immersive VR/video). The results showed an interaction between media and method, indicating that pre-training had a positive effect on knowledge (d = 0.81), transfer (d = 0.62), and self-efficacy (d = 0.64) directly following the intervention; and on self-efficacy (d = 0.84) in a one-week delayed post-test in the immersive VR condition. No effect was found for any of these variables within the video condition.

1. Introduction

Virtual Reality (VR) is one of several technologies receiving attention for its potential use in education, with both the EU and USA launching initiatives for the large-scale implementation of digital technologies in the classroom (European Commission, 2018; U.S. Department of Education, 2017). VR in particular is expected to have widespread adoption within classrooms in the next two to three years (Freeman, Becker, & Cummins, 2017). Such attention is not unfounded, with several meta-analyses reporting positive educational outcomes with the use of digital technology, sometimes exceeding the outcome of traditional classroom instruction (Chauhan, 2017; Merchant, Goetz, Cifuentes, Keeney-Kennicutt, & Davis, 2014). While VR is defined as a digital technology, its educational potential has not been thoroughly investigated because it has only recently seen widespread consumer availability.

1.1. Defining virtual reality

Several attempts have been made at defining VR (e.g. Lee & Wong, 2014), and while they vary slightly, they all emphasize VR as being a way of digitally simulating or replicating an environment (Makransky & Lilleholt, 2018). VR can be accessed through different systems, with the most prominent being a desktop computer, a head-mounted display (HMD) and the cave automatic virtual environment (CAVE; Buttussi & Chittaro, 2018). Desktop VR typically refers to the virtual environment (VE) being projected on a

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desktop computer screen, with interaction typically taking place using a keyboard and mouse (Lee & Wong, 2014), while a HMD typically uses two screens, one in front of each eye, making depth perception possible through stereoscopic imaging (Makransky & Lilleholt, 2018). The CAVE has several screens facing the user, adjusting to the users position in the room; here the user wears 3D glasses in order to view 3D structures. These types of VR all offer different affordances to the user. One distinction typically made is contrasting high-immersion VR to low-immersion VR (Cummings & Bailenson, 2016; Makransky, Borre-Gude & Mayer, 2019). Cummings and Bailenson (2016) argue that immersion is an objective measure based on the vividness offered and the extent to which a medium shuts out the outside world. Makransky and Lilleholt (2018) further propose that the HMD and the intuitive interaction through head tracking typical in immersive VR is one factor that leads to increased measures of presence. Accordingly, VR through a HMD or CAVE is high on immersion and typically leads to a higher sense of presence (e.g., Makransky, Terkildsen & Mayer, 2019) and offers the user a way of interacting with the environment through bodily movements such as head movement. Desktop VR is in contrast low on immersion. It also allows for interaction, but only through more abstract means such as a keyboard and mouse. The unique affordances of immersive VR is of interest to the science of learning as its potential remains relatively unexplored, specifically, it's influence on both procedural and declarative knowledge. The former can be defined as embodied knowledge, ways of moving or 'doing', while the latter can be defined as factual knowledge such as remembering a specific name or concept. Prior research on learning in immersive VR has examined teaching methods incorporating physical training, and their effects on procedural knowledge (e.g., Bertram, Moskaliuk, & Cress, 2015; Çakiroğlu & Gökoğlu, 2019). Acquiring procedural knowledge has been shown to benefit from the higher immersion afforded by VR (e.g., Bertram et al., 2015). Meanwhile the less extensive body of research investigating immersive VR as a learning platform for acquiring declarative knowledge has found no apparent benefit of the medium (e.g., Makransky, Terkildsen, & Mayer, 2019; Moreno & Mayer, 2002; Parong & Mayer, 2018). In this study we investigate the effect of media on declarative knowledge, inasmuch as previous research has found higher extraneous cognitive load when using immersive VR as a learning platform for acquiring declarative knowledge (Makransky, Terkildsen, & Mayer, 2019b; Parong & Mayer, 2018).

1.2. The media effect

The media effect is used to describe the influence of a medium on instruction. The perspective that "the medium is the message" has long tradition in media research (McLuhan & Fiore, 1967) but is quite different than the theoretical approach typically taken in learning sciences. One prominent view in educational theory is that no media effect on learning exists, i.e. that a medium in itself cannot lead to increased learning, because the only relevant factor for learning is the instructional method (Clark, 1994; Parong & Mayer, 2018; Sung & Mayer, 2013). For example, when comparing traditional classroom teaching to a computer simulation wherein students are presented with 3D animations and can learn at their own pace, it is the difference in instructional method, not media, which leads to any difference in learning (Clark, 1994). Accordingly, media does "not influence student achievement any more than the truck that delivers our groceries causes changes in our nutrition" (Clark, 1983, p. 445).

This theory is grounded in the premise that no methodologically rigorous studies have shown a distinct media effect on learning without confounding it with instructional method (Clark, 1994). This view is mirrored in a large second-order meta-analysis summarizing 40 years of research comparing virtual-to non-virtual instruction (Tamim, Bernard, Borokhovski, Abrami, & Schmid, 2011). Although research comparing learning outcomes between two (or more) virtual media is more sparse, some studies have tested the media effect between modern virtual technologies, finding no media effect on learning (e.g. Makransky et al., 2019b; Moreno & Mayer, 2002; Sung & Mayer, 2013). Even though the theory has been criticized, most notably by Kozma (1994) who argued that certain media enables certain instructional methods and thus opposed a distinction between the two concepts, this central premise has not been refuted (Tamim et al., 2011).

The aim of this study is to investigate whether an instructional method has different cognitive outcomes between media. More precisely, whether the same method will result in a different outcome if nothing but the medium is changed.

1.3. Method interacts with media

Prior research investigating immersive VR has shown a media effect for motivational variables, but not for declarative knowledge (Makransky et al., 2019b; Makransky & Lilleholt, 2018; Moreno & Mayer, 2002; Parong & Mayer, 2018).

Makransky et al. (2019b) compared a science simulation in immersive VR to a desktop PC. They found participants using immersive VR to be more present (average effect size difference $d = 1.75$), and to rate the medium more favorably; but they scored lower on retention and transfer tests than those using the PC (average effect size difference $d = 0.625$ and $d = 0.245$ respectively). They also failed to find any main effects or interactions for the redundancy principle, which suggests that redundant information, such as the same information presented both as text and audio, leads to less learning. Moreno and Mayer (2002) did the most comprehensive study of the method interacts with media effect in immersive VR, likewise testing the redundancy principle. They compared the same simulation across desktop PC, HMD while sitting, and HMD while walking. They also varied the instructional method, with participants in each condition receiving instruction as narration, text, or both. Moreno and Mayer (2002) posited three hypotheses for their experiment: that *media affects learning*, that *method affects learning* and that *media enables method*. Only the method-affects-learning hypothesis was supported in their study, meaning that a difference was only found between instructional methods, with the narration condition learning the most.

Although we could not identify any comprehensive studies that have found evidence for a media effect, or interaction, in immersive VR, both of the previous studies investigated the redundancy principle. Therefore, it is important to investigate whether there is an interaction between method and media using other instructional design principles when comparing immersive VR to less immersive media. Several studies suggest that immersive VR's rich sensory environment can hinder learning because the increased amount of sensory information can lead to increased cognitive load (Makransky et al., 2019b; Richards & Taylor, 2015). In interpreting their results, Makransky et al. (2019b) suggest that immersive VR may not be an optimal medium for learning basic concepts and facts, but could have greater potential in helping learners develop schemas through 3D interactions once the students have a basic understanding of the material. They suggest that one way to decrease cognitive load when learning with immersive VR could be to provide pre-training.

1.4. The pre-training principle

The pre-training principle states that people learn more deeply from a multimedia message when they know the names and characteristics of the main concepts (Mayer & Pilegard, 2014). This lessens the cognitive load experienced when presented with novel concepts (Mayer & Pilegard, 2014). In their review of the current literature, Mayer and Pilegard (2014) found a medium effect size of pre-training ($d = 0.75$), while Mayer (2017) reports a more conservative effect size of d = 0.46. Most of the current research investigating the pre-training principle has been conducted in the context of slideshows or low-immersion video games. We have not been able to identify any studies investigating the effect of the pre-training principle in immersive VR.

In the present study, we investigate the interaction between media and method. We do this by comparing the learning and motivational potential of a lesson presented in either immersive VR or as a video. Furthermore, we investigate the effect of instructional method across the two conditions, by including pre-training for approximately half of the participants. Finally, we assess the outcomes in a post-test directly after the learning intervention, and in a one week delayed post-test in order to investigate the delayed effects of learning with immersive VR, as this has been identified as an important yet underdeveloped research topic (Makransky et al., 2019b).

2. Theory and predictions

2.1. Instructional method

The Cognitive Theory of Multimedia Learning (CTML) proposes several empirically based design principles for multimedia, with the goal of enhancing learning (Mayer, 2014). Consistent with Cognitive Load Theory (CLT; Sweller, Ayres, & Kalyuga, 2011) the CTML proposes that when cognitive processing exceeds the learners' capacity, essential overload is experienced, inhibiting learning (Mayer, 2017). CLT discriminates between two types of cognitive load. The first is intrinsic cognitive load, which is associated with the intrinsic nature of the material, such as its inherent difficulty. The other is extraneous cognitive load and is associated with the presentation of the material. For example, in an educational computer game the material to be learned is associated with intrinsic cognitive load, while the way the game is designed – and the medium chosen to present the information – is associated with extraneous cognitive load.

Intrinsic and extraneous cognitive load are additive (Mayer, 2017). This implies that essential overload can be experienced at low levels of intrinsic cognitive load if extraneous cognitive load is simultaneously high. Accordingly, previous research suggests that when a multimedia lesson is presented in immersive VR, learners experience essential overload more easily as compared to the same lesson in a less immersive format, inasmuch as extraneous load is higher due to the increased amount of sensory information (Makransky et al., 2019b; Richards & Taylor, 2015).

The pre-training principle is an instructional principle developed as a part of the CTML. The purpose of pre-training, according to the principle, is to reduce intrinsic cognitive load by familiarizing the learner with the material. In immersive VR, where extraneous load has been found to be higher than other media, pre-training could be more beneficial.

We therefore predict an interaction between media and method in which the group receiving a lesson in immersive VR will benefit significantly more from pre-training than the group receiving the same lesson as a video, when assessed with post-test measures of retention and transfer (Hypothesis 1).

2.2. Self-efficacy

In the current study we are also interested in assessing motivational factors, including self-efficacy and perceived enjoyment, in order to test the effect of both media and method. Previous research has shown that VR can have a particularly strong impact on these constructs (e.g. Cheng & Tsai, 2019; Makransky, Borre-Gude, & Mayer, 2019a,b; Parong & Mayer, 2018; Thisgaard & Makransky, 2017).

Self-efficacy is a concept from the social cognitive literature, which is defined as "the belief in one's abilities to organize and execute courses of action required to produce given attainments" (Bandura, 1997, p. 3). It is considered an important component in learning due to its association with positive outcomes such as academic achievement and persistence, and a large-scale meta-analysis by Richardson, Abraham, and Bond (2012) found self-efficacy to be one of the best predictors of students' grades. Self-efficacy is understood as a feedback loop; prior motivation, expectations, and feedback affect a learner's self-efficacy, which in turn affects current performance and experiences (Parong & Mayer, 2018). Several studies have found VR simulations (desktop and immersive VR) to be associated with a significant increase in self-efficacy compared with other methods of learning (Buttussi & Chittaro, 2018; Makransky, Thisgaard, & Gadegaard, 2016; Thisgaard & Makransky, 2017), ascribing this to the value VR simulations can have in allowing students to learn by performing activities in a high-fidelity environment and gaining relevant feedback. Self-efficacy is therefore an important measure when investigating the interactions between media and method.

The present study examines how pre-training will interact with self-efficacy in immersive VR. Pre-training gives the learner basic knowledge relevant to the multimedia lesson. During the multimedia lesson the learner will further recognize concepts from the pre-training, thereby providing the learner with positive feedback and a sense of competence in understanding the material. Since immersive VR has been shown to provide a higher sense of presence, but is expected to lead to a higher level of extraneous load compared to the video condition (Makransky et al., 2019b; Moreno & Mayer, 2002; Parong & Mayer, 2018), it is expected that learners' positive or negative experiences are more vivid in the immersive VR condition, thereby leading to greater differences in self-efficacy between pre-training vs. no pre-training conditions. We therefore predict an interaction between media and method in which the immersive VR condition will benefit significantly more from pre-training on measures of self-efficacy than the video condition (Hypothesis 2).

2.3. Enjoyment

Some of the appeal in using virtual simulations and games for learning lies in making learning enjoyable, affecting both engagement and motivation in education (Vogel et al., 2006). Positive emotions interact with each other and can serve as mediators between the multimedia lesson and learning outcomes (Pekrun, 2006). Studies are persistently associating VR with a higher self-reported perceived enjoyment, suggesting that such learning situations are enjoyable (Bertram et al., 2015; Makransky & Lilleholt, 2018; McLaren, Farzan, Adams, Mayer, & Forlizzi, 2017), with Makransky and Lilleholt (2018) and Mclaren and colleagues (2017) reporting an average effect size of $d = 0.94$ and $d = 0.95$ respectively. In the present study we predict a main effect of enjoyment in which the group receiving a lesson in immersive VR will score significantly higher on a post-test measure of perceived enjoyment than the group receiving the same lesson as a video (Hypothesis 3).

2.4. Delayed post-test

We have developed hypotheses based on each of the outcome variables independently. However, previous research shows that there is a complex relationship between learning and motivational variables when learning with VR (Lee, Wong, & Fung, 2010; Makransky & Lilleholt, 2018). Research has previously found changes in learning when comparing results of an immediate- and delayed post-test (e.g. Chang, 2017; Fyfe & Rittle-Johnson, 2017). For example, when comparing math instruction with and without immediate feedback, Fyfe and Rittle-Johnson (2017) found that the group receiving feedback scored highest on an immediate retention test, while the group without feedback scored highest on the one-week delayed retention test. Chang (2017), on the other hand, found that differences in retention measured in an immediate post-test weren't present when measured in a delayed post-test.

It is relevant to investigate the consequences of learning from immersive VR as compared to a video when assessed on a delayed post-test. A recent study by McLaren et al. (2017) shows that students who use an educational game score significantly higher on learning, both on an immediate post-test and a one-week delayed post-test, while also reporting significantly higher enjoyment, as compared to students who received a conventional computer-based approach. Chittaro and Buttussi (2015) likewise showed that participants using an immersive VR flight safety simulation retained significantly more knowledge than those reading a safety card with similar instructions. In both settings the superior learning outcomes were retained for at least one week.

In the current study we administer a one-week delayed post-test in order to investigate whether Hypothesis 1 through 3 hold when assessed a week later.

2.5. Simulator sickness

Investigating learning in immersive VR poses a possibility for participants to experience simulator sickness (Kennedy, Lane, Berbaum, & Lilienthal, 1993; Rupp et al., 2019). Symptoms resemble those of motion sickness although there are differences in term of severity and prevalence (Kennedy et al., 1993). Experiencing nausea or vertigo may interfere with the learning experience, and thus prevent participants from experiencing the simulation fully. Therefore, administering the Simulator Sickness Questionnaire (SSQ) designed by Kennedy et al. (1993) can provide additional information for how good an immersive VR simulation is for learning, by providing information for the number of people who were not in an acceptable state to receive learning.

3. Method

3.1. A priori power analysis

An a priori power analysis was performed in order to estimate the necessary sample size for the intended study design. Although a median effect size of $d = 0.75$ has been reported on studies comparing learning outcomes with pre-training or no pre-training (Mayer & Pilegard, 2014), we choose to use a more conservative effect size of $d = 0.46$, as reported in a more recent review (Mayer, 2017). With an alpha = .05 and power = .95, the projected total sample size needed with this effect size is approximately $N = 64$ (G*Power 3.1; Faul, Erdfelder, Lang, & Buchner, 2007).

3.2. Participants

The sample consisted of 118 participants (55 female) students at a large European University. Students were recruited using flyers that were handed out throughout campus and were hung up on campus notice boards where they were told that they would receive the equivalent of approximately 15 Euros to participate in a study about learning. Most participants (81%) were between the ages of 18 and 25, with only a few (4.2%) being older than 35. They were instructed to meet up in a classroom, in which the experiment took place. Here, the participants were randomly divided into four conditions: immersive VR without pre-training (n = 31), immersive VR with pre-training (n = 29), video without pre-training (n = 30) and video with pre-training (n = 28). The experiment was run multiple times, over several days, with 5–10 participants per session. This was done deliberately, mainly to keep the VR and video conditions separated in order to avoid distracting participants in either group.

3.3. Procedure

Participants were first given a pre-test including prior knowledge and demographic characteristics, and then were randomly assigned to one of the four training conditions. Participants receiving pre-training were asked to study the pre-training picture for 1 min and 30 s. All participants then either completed the immersive VR simulation or watched the video. Lastly, participants were given a post-test that included a retention test and a transfer test, as well as measures of simulator sickness, self-efficacy of learning, and perceived enjoyment in a controlled proctored setting. Finally, the participants were sent a delayed post-test one week after the intervention and were given a gift card worth approximately 15 Euros upon completing the delayed post-test. The delayed post-test was taken online, that is without a proctor, and 12 participants did not respond. The delayed post-test test was identical to the post-test, but didn't include a measure for simulator sickness.

4. Materials

4.1. The multimedia lesson

The learning intervention consisted of either the simulation *The Body VR: Journey Inside a Cell* (The Body VR, 2016), or a video of the simulation (pictures of the simulation are presented in Fig. 1). A science lesson about cells was chosen because it utilizes the affordances associated with VR. Specifically, it allows the student to 'be a part of' a vivid simulation of a cell, a phenomena not visible to the naked eye.

In the simulation, the player is shrunk down to cellular size. Finding themselves inside a vehicle of similar proportions, the player is transported along the bloodstream before shrinking even further down. The player then arrives at a single cell and enters it, in order to observe the inner workings. Finally, they arrive on the outside again where they witness a virus attack on the cell before the simulation ends. During the simulation information is provided through narration, with diagrams showing miniature versions of central parts, with their names written beside them.

The VR simulation was administered with a Samsung Galaxy S8 phone and stereoscopically displayed through a Samsung Gear VR HMD with headphones attached. Each participant was given their own HMD with instructions on how to put it on and use it. In order to start the simulation, the participants used the touchpad on the right side of the HMD. In the simulation the path is fixed, with no player control of the movement. Interactivity is available through movement of the head, allowing the player to control where they are looking in the 360° VE.

For the video condition the simulation was screen-captured, creating a video recording. An important consideration for the video was recording all the relevant information, in order for the participants to not miss any visual information. It was found that adopting a static camera angle for the entire simulation, with a single exception, allowed for all relevant information to be displayed. The video is therefore considered a recording of an optimal experience of the VR simulation. Participants watched the video on a 13-inch laptop with headphones attached. Both the VR simulation and the video took 10 min and 35 s to complete.

4.2. Pre-training material

The pre-training material used in this study consisted of the cross-section of a cell. The picture contained several key terms presented in the simulation in order to familiarize participants with the name, shape, and color of each part, as they would appear. It further served the purpose of providing a rough layout of the entire cell, making the participants familiar with the space before being presented with it in the simulation (the pre-training material is shown in Fig. 2). The current notion of what constitutes pre-training is rather unclear, and examples vary widely in how much of the learning material is explained in the pre-training (see Mayer and Pilegard, 2014 for examples). A 'barebones' approach was thus chosen in order to avoid blurring the line between pre-training and learning scenario.

4.3. Pre- and post-test participant questionnaires

The pre-and post-test were both administered in SurveyMonkey. All participants were provided with a 13-inch laptop with both the pre- and post-test open in Internet Explorer. Statistical analyses were conducted in IBM SPSS version 25. Furthermore, the validity of the scales used to measure the outcome variables was assessed according to their fit to the Partial Credit Rasch Model (PCM;

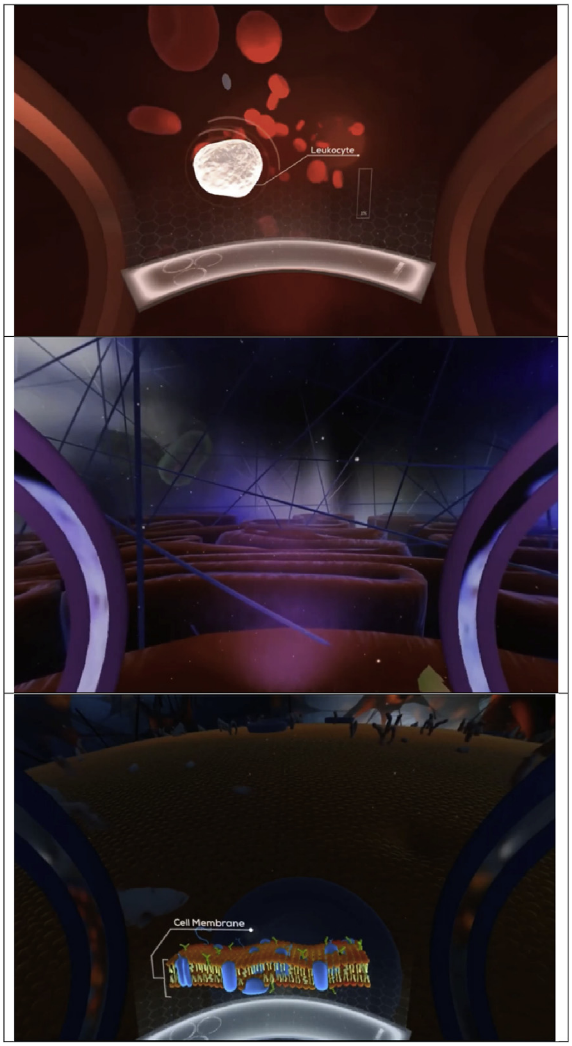

Fig. 1. Screenshots from the *Body VR: Journey Inside a Cell* simulation. The top panel shows the blood stream with red and white blood cells. The middle panel shows the rough endoplasmic reticulum, cytoskeleton and mitochondria. The bottom panel shows the cell membrane.

Masters, 1982) within the framework of Item Response Theory (IRT) using RUMM2030 (Andrich, Sheridan, & Luo, 2010). We report acceptable general fit to the model using the chi-square test statistic. Furthermore, we report reliability according to the person separation index (PSI) which can be interpreted similarly to Cronbach's alpha (see Pallant & Tennant, 2007 for an introduction to assessing fit according to the PCM).

The pre-test consisted of a prior knowledge test and demographic characteristics. The prior knowledge test contained six questions about cell biology (e.g. “Do you know what ribosomes are?”) with three of these questions containing a picture, accompanied by the question “Do you know what this is?”. The prior knowledge measure had a Cronbach's alpha reliability of 0.70.

The post-test consisted of The Simulator Sickness Questionnaire (SSQ), and measures of retention, transfer, self-efficacy and perceived enjoyment (see Appendix 1 for a list of items). The SSQ was adapted from Kennedy et al. (1993). The SSQ consists of 16 items measuring symptoms of discomfort (e.g. nausea, headache or vertigo) that participants had to rate (1. None, 2. Slight, 3. Moderate, 4. Severe). The SSQ had a Cronbach's alpha reliability of 0.84.

The self-efficacy of learning scale was adapted from the Motivated Strategies for Learning Questionnaire (MSLQ; Pintrich, 1991) in order to assess self-efficacy related to learning about cells. It consists of 5 items (e.g. I am confident that I understand the more complex concepts related to the cell). The scale had a Cronbach's alpha reliability of 0.87 and 0.90 and a PSI of 0.87 and 0.87 in the immediate and delayed post-tests respectively. Furthermore, the scale had good general fit to the PCM as evidenced by non-significant chi-square test statistics in the immediate $X^2_{(10)} = 7.85$, $p = .64$ and delayed post-tests respectively $X^2_{(10)} = 9.90$, $p = .45$.

The Perceived enjoyment scale was adapted from Tokel and İsler (2015). The perceived enjoyment scale consists of three items (e.g. I find using this kind of simulation enjoyable) and had a Cronbach's alpha reliability of 0.90 and 0.93 and a PSI of 0.89 and 0.90 in the immediate and delayed post-tests respectively. The scale also had good general fit to the PCM in the immediate $X^2_{(6)} = 2.77$,

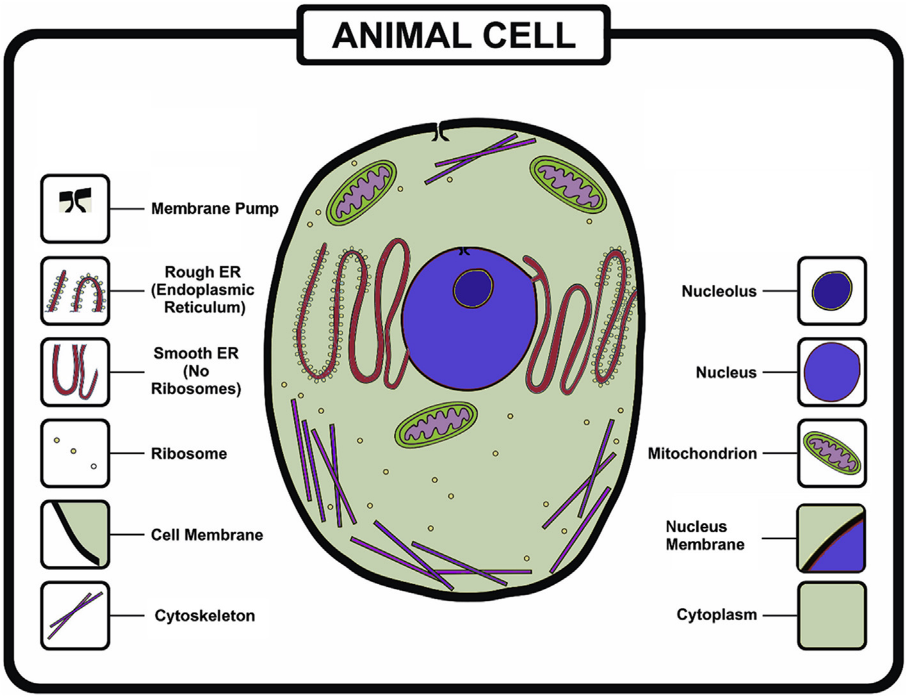

Fig. 2. The pre-training material.

$p = .84$ and delayed post-tests respectively $X^2_{(3)} = 6.49$, $p = .09$.

Both the self-efficacy and perceived enjoyment scales were rated on a five-point Likert scale ranging from (1), strongly disagree, to (5), strongly agree. The mean score for the items was used, meaning that learners could score between 1 and 5 on each scale. The fit to the PCM indicates that mean scale scores could be used on an interval level of measurement (Christensen, Kreiner, & Mesbah, 2013).

The retention test consisted of 30 multiple-choice items assessing participants' memory for the conceptual information presented during the training. One item (item 10) had a negative corrected item-total correlation in the immediate and delayed post-tests indicating that the item measured a different latent trait than the other 29 items, so this item was eliminated from the measure. The Cronbach's alpha reliability for the remaining 29 items was 0.86 and 0.86 in the immediate and delayed post-tests respectively.

The transfer test was designed to measure how well participants were able to use the knowledge from the lesson in a different context. The transfer test consisted of four questions presented on separate pages on the post-test: 1. Why does the cell not get flooded with all the various elements surrounding the cell? 2. "You are in a lab, looking at a blood sample where an infection has spread more that it should have. What could be the cause of this?" 3. "Why is the membrane that surrounds the nucleus important?" 4. "How does the cell keep functioning?". Participants were given three minutes to write down their answer to each question. Participants were scored from zero to three based on whether or not they fulfilled pre-defined criteria. Two independent raters blindly scored the transfer test items and the sum of their scores was used as a measure of transfer. The inter-rater correlation between the two raters' scores was 0.82.

The one-week delayed post-test consisted of the same scales as in the post-test with the exception of the SSQ (that is retention, transfer, self-efficacy, and perceived enjoyment). For the delayed post-test, participants were asked to spend at least three minutes on the transfer questions and to keep track of the time themselves.

5. Results

Before investigating the research questions, we investigated if the groups differed on basic characteristics and prior knowledge. One way ANOVAs indicated that the groups did not differ significantly on age ($F_{(3,114)} = 0.017$, $p = .997$), or prior knowledge ($F_{(3,114)} = 2.16$, $p = .096$). Furthermore, a chi-square test indicated that the groups did not differ significantly in the proportion of men and women, $X^2_{(N=118)} = 4.072$, $p = .254$. We conclude that there is no evidence of differences between the groups on age, gender, or prior knowledge before the start of the experiment.

The next step in the analysis was to investigate if there were differences between media and method on the symptoms of discomfort from the SSQ. The independent samples *t*-test showed that there was not a significant difference on the total SSQ score between those who had received pre-training and those who had not ($t_{(113)} = 0.962$, $p = .338$). However, the students who had used the immersive VR simulation scored significantly higher than the students who had used the video ($t_{(113)} = 2.351$, $p = .020$). Follow-up independent samples t-tests with a Bonferroni correction 0.05/16 = 0.003 were used to determine the specific items where

Table 1
Means and standard deviations for the dependent variables measured in the immediate post-test.

Pre-training	Immediate measures						
	Immersive VR		Video		Media	Method	Interaction
	With	Without	With	Without	p-value	p-value	p-value
Knowledge	21.28 (4.98)	16.98 (5.59)	18.82 (5.36)	20.30 (5.48)	.658	.155	**.004**
Transfer	6.66 (3.86)	4.29 (3.75)	5.07 (3.48)	5.97 (3.96)	.948	.294	**.021**
Self-efficacy	3.46 (0.73)	2.97 (0.79)	2.8 (0.91)	2.96 (0.76)	**.026**	.267	**.029**
Perceived enjoyment	4.06 (0.93)	4.33 (0.62)	3.12 (0.91)	3.51 (0.70)	< .001	**.026**	.705

differences existed. The results indicated that there were three items with significant differences between the groups including: general discomfort ($t_{(115)} = 3.127$, $p = .002$; d = 0.59), nausea ($t_{(116)} = 3.848$, $p < .001$, d = 0.78), and stomach awareness ($t_{(116)} = 3.041$, $p = .003$, d = 0.63). The results indicate that the immersive VR simulation had significantly higher negative symptoms of discomfort, with 5% of the sample reporting moderate or severe general discomfort (compared to 2% in the video condition), 12% reporting moderate, and 2% reporting severe nausea (compared to 2% reporting moderate nausea in the video condition); and 3% reporting moderate, and no students reporting severe, stomach awareness (compared to 0% in the video condition). Although a slightly higher discomfort score was found in the VR group, no participants were eliminated from the dataset on the basis of their SSQ score.

5.1. Hypothesis 1: there will be an interaction between media and method on the immediate outcomes of retention and transfer

Hypothesis 1 was investigated with two factorial ANOVAs with media (immersive VR vs. video) and method (pre-training vs. no pre-training) as independent variables, and immediate retention and transfer as the dependent variables. The results presented in the top portion of Table 1 indicate that Hypothesis 1 was partially supported. That is, there was a significant interaction between media and method for the outcomes of retention $F_{(1,114)} = 8.573$, $p = .004$; and transfer $F_{(1,113)} = 5.458$, $p = .021$.

Post-hoc independent samples t-tests run to investigate the source of the interaction indicated that within the immersive VR condition, the group that received pre-training (M = 21.28, SD = 4.98) scored significantly higher on the retention test than the group that did not receive pre-training (M = 16.98, SD = 5.59) $t_{(58)} = 3.145$, $p = .003$, d = 0.81 (see Fig. 3A). Similarly, the immersive VR group with pre-training scored higher on retention than the video group with pre-training, but the difference did not reach statistical significance $t_{(55)} = 1.792$, $p = .079$. There was no difference on the retention test between the pre-training and no pre-training groups in the video condition $t_{(56)} = 1.037$, $p = .304$. However, the video group without pre-training scored significantly higher on the retention test compared to the immersive VR group without pre-training $t_{(59)} = 2.350$, $p = .022$.

On the transfer test within the immersive VR condition, the group receiving pre-training (M = 6.66, SD = 3.86) scored significantly higher than the group that did not receive pre-training (M = 4.29, SD = 3.75) $t_{(58)} = 2.407$, $p = .019$, d = 0.62 (see Fig. 3B). There was no difference in the transfer test between the groups in the video condition $t_{(55)} = 0.904$, $p = .370$; and also no difference in the transfer test between the video and immersive VR groups who did not receive pre-training $t_{(58)} = 1.683$, $p = .098$. Similarly, no difference was found between the video and immersive VR groups who did receive pre-training transfer $t_{(55)} = 1.625$, $p = .110$.

The results indicate that the use of pre-training significantly increased knowledge and transfer in the immersive VR condition directly after the intervention, but it did not have a significant impact on learning or transfer in the video condition. This is a major empirical finding in this study.

5.2. Hypothesis 2: there will be an interaction between media and method on the immediate outcome of self-efficacy

Hypothesis 2 was also investigated with a two factorial ANOVA with media (immersive VR vs. video) and method (pre-training vs. no pre-training) as independent variables, and self-efficacy as the dependent variable. The results in Table 1 indicate that Hypothesis 2 was supported. That is, there was a significant interaction between media and method for self-efficacy $F_{(1,114)} = 4.869$, $p = .029$. A significant main effect across media was also identified indicating that students who used VR reported significantly higher self-efficacy than the groups who used the video $F_{(1,114)} = 5.105$, $p = .026$. Post-hoc independent samples t-tests run to investigate the source of the interaction indicated that within the immersive VR condition the group that received pre-training (M = 3.46, SD = 0.73) scored significantly higher on self-efficacy than the group that did not receive pre-training (M = 2.97, SD = 0.79) $t_{(58)} = 2.488$, $p = .016$, d = 0.64 (see Fig. 3D). The difference between the pre-training and no pre-training groups on self-efficacy was not significant for the video conditions $t_{(56)} = 0.730$, $p = .468$. The results indicate that pre-training significantly increases students' self-efficacy when learning in immersive VR, however this effect is not observed when learning through a video. This is another major empirical finding in this study.

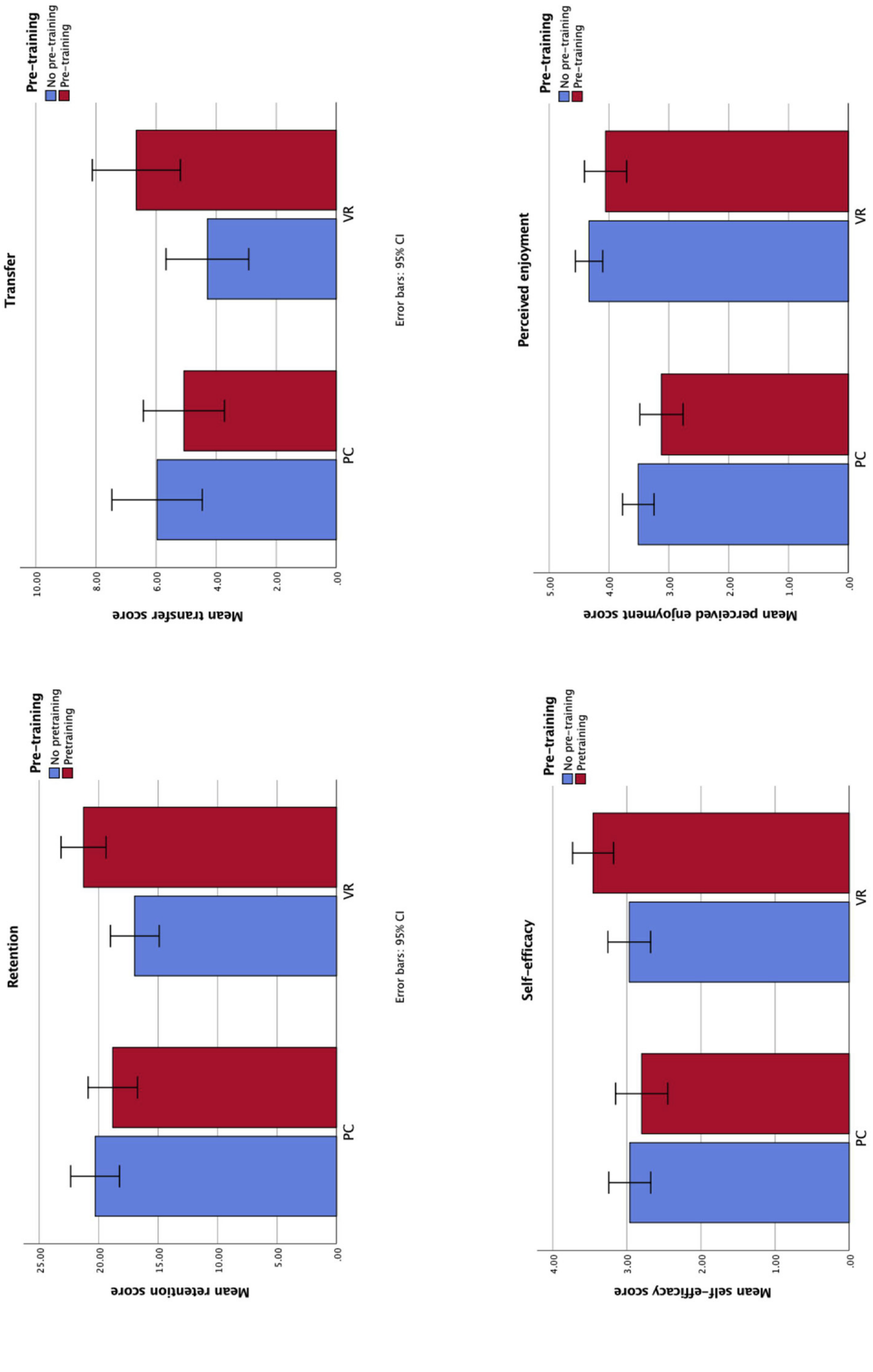

Fig. 3. *(from top left) A, B, C and D:* Bar charts showing the mean scores of all dependent variables as measured directly after the intervention.

Table 2
Means and standard deviations for the dependent variables measured in the delayed post-test.

Pre-training	Delayed measures (One week follow-up)						
	Immersive VR		Video		Media	Method	Interaction
	With	Without	With	Without	p-value	p-value	p-value
Knowledge	20.88 (6.02)	17.69 (5.68)	18.17 (5.88)	19.04 (5.61)	.553	.314	.079
Transfer	4.42 (3.60)	4.03 (3.09)	3.17 (2.99)	3.75 (3.01)	.224	.877	.442
Self-efficacy	3.25 (0.64)	2.66 (0.81)	2.63 (1.02)	3.10 (0.76)	.605	.647	**.001**
Perceived enjoyment	3.97 (0.80)	4.15 (0.70)	3.07 (0.88)	3.35 (0.64)	< **.001**	.127	.721

5.3. Hypothesis 3: there will be a main effect of perceived enjoyment across media

Hypothesis 3 was also investigated with a two factorial ANOVA with media (immersive VR vs. video) and method (pre-training vs. no pre-training) as independent variables, and perceived enjoyment as the dependent variable. The results in the final row of Table 1 indicate that Hypothesis 3 was supported. A main effect was found for perceived enjoyment $F_{(1,113)} = 35.530$, $p < .001$, d = 1.08 (see Fig. 3C). The results indicate that participants have significantly higher perceived enjoyment when using immersive VR (M = 4.20, SD = 0.79) compared to the video instruction (M = 3.77, SD = 0.91) independent of pre-training. Therefore, we conclude that learners enjoyed learning through the immersive VR simulation significantly more than the video. A significant main effect across method was also identified indicating a significantly higher perceived enjoyment for students who did not have pre-training compared to the students who had pre-training $F_{(1,114)} = 5.071$, $p = .026$.

5.4. Hypothesis 4: there will be an interaction between media and method for retention, transfer, and self-efficacy, and a main effect for media for perceived enjoyment on a delayed post-test

Hypothesis 4 was also investigated with two factorial ANOVAs with media (immersive VR vs. video) and method (pre-training vs. no pre-training) as independent variables, and retention, transfer, self-efficacy and perceived enjoyment as the dependent variables measured on a delayed post-test approximately one week after the intervention. Two factorial ANCOVA's where the score on the post-test was used as a co-variate for each of the four outcome variables were also conducted in order to investigate if there was a change on these variables after the intervention. Of the 118 learners who were in the study only 106 (89.8%) responded to the delayed post-test including: immersive VR without pre-training (n = 29), immersive VR with pre-training (n = 27), video without pre-training (n = 25) and video with pre-training (n = 25). The results in Table 2 indicate that hypothesis 4 was partially supported.

Although the same trend was seen as in the immediate post-test, the interaction did not reach significance for the delayed knowledge test $F_{(1,99)} = 3.152$, $p = .079$ (see Table 2). Furthermore, a two factorial ANCOVA where the post-test retention score was used as a co-variate resulted in the same conclusion $F_{(1,98)} = 1.134$, $p = .289$. The interaction between media and method was not significant in the delayed transfer test either $F_{(1,99)} = 0.595$, $p = .442$. Furthermore, accounting for the post-test transfer test as a co-variate resulted in the same conclusion $F_{(1,98)} = 1.456$, $p = .231$. Finally, there were no main effect for these variables (see Fig. 4A and B).

The bottom rows in Table 2 indicate that there was a significant interaction for self-efficacy $F_{(1,102)} = 11.352$, $p = .001$. Furthermore, a two factorial ANCOVA indicated that there was a significant interaction $F_{(1,101)} = 6.384$, $p = .013$ for self-efficacy at follow-up, after accounting for the post-test score as a co-variate. Post-hoc independent samples t-tests run to investigate the source of the interaction indicated that within the immersive VR condition, the group receiving pre-training (M = 3.25, SD = 0.64) scored significantly higher on self-efficacy than the group that did not receive pre-training (M = 2.64, SD = 0.82) $t_{(54)} = 3.083$, $p = .003$, d = 0.84 (see Fig. 4D). The differences were not significant for the video group $t_{(48)} = 1.823$, $p = .075$. Furthermore, there was a significant main effect for perceived enjoyment $F_{(1,102)} = 33.609$, $p < .001$, d = 1.14 where the immersive VR groups scored significantly higher (M = 4.07, SD = 0.75) than the groups using the video (M = 3.21, SD = 0.77) (see Fig. 4C). The two factorial ANCOVA indicated that the main effect across media remained in the follow-up test even after accounting for post-test perceived enjoyment $F_{(1,100)} = 7.908$, $p = .006$. Therefore, we conclude that there was the same pattern for the interaction between media and pre-training for knowledge and transfer; but the effect was no longer significant after one week. However, the interaction for self-efficacy was still significant in the delayed post-test. Finally, the main effect for perceived enjoyment favoring the VR groups was even stronger in the follow-up test compared to the post-test.

6. Discussion

6.1. Empirical contributions

The experiment was an investigation of media (immersive VR/video) and method (pre-training/no pre-training), where pre-training resulted in increased scores of retention and transfer only in the immersive VR condition. This shows an interaction between media and method which hasn't been present in previous studies with immersive VR (e.g. Moreno & Mayer, 2002; Sung & Mayer,

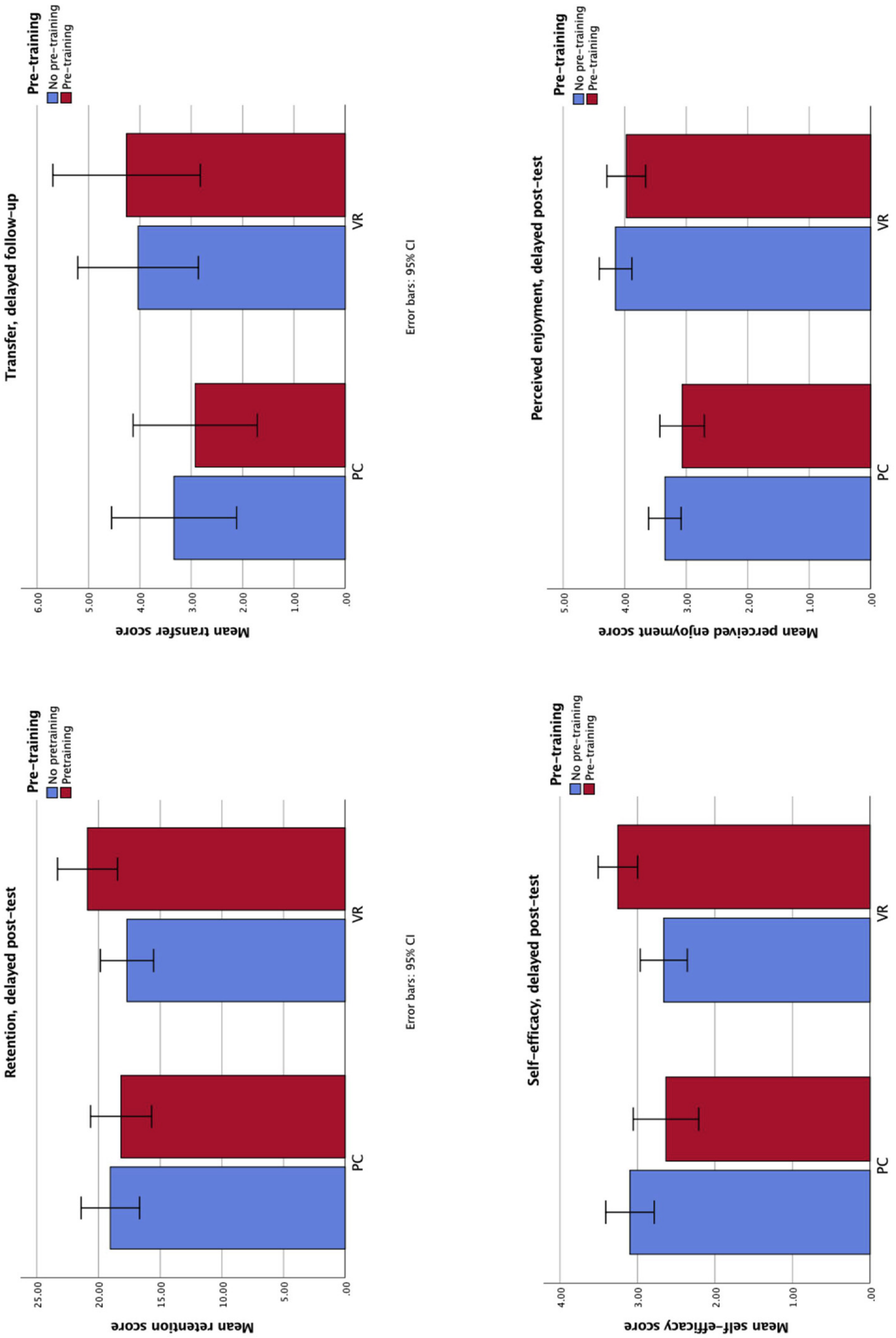

Fig. 4. *(from top left) A, B, C and D:* Bar charts showing the means scores of all dependent variables as measured one week after the intervention.

2013), and cannot be explained by the effect of instructional method alone.

The pre-training material did prove to be essential in the immersive VR condition. The group without pre-training, did not have sufficient prior knowledge of the content and even though this information was presented in the lesson, these learners seem to have been overwhelmed with sensory information and did not have resources available to effectively select, organize, and integrate information into long term memory. Even though the pre-training material was basic, this knowledge possibly helped the immersive VR group with pre-training to recognize important concepts and then use the experience of virtually "being in a cell" to develop a spatial mental map of the environment thereby aiding their learning and transfer.

No significant effect of pre-training was found in the video condition. This is inconsistent with most literature (Mayer, 2017); however, some previous studies have reported no effect of pre-training (Mayer & Pilegard, 2014), ascribing it to boundary conditions where pre-training might not be an effective tool. These include cases where learners possess pre-existing knowledge of the subject (Mayer & Pilegard, 2014), when it is more efficient to have the pre-training material presented simultaneously with the learning material; or cases where the material does not require sufficient mental effort to learn (Kester, Kirschner, & Van Merriënboer, 2004). In this experiment, the Body VR: Journey inside a Cell simulation was a self-contained lesson, which included all of the information necessary to understand the topic. Therefore, the pre-training material might not have provided a great learning advantage in the video condition where students had sufficient resources to select, organize, and integrate the new knowledge into long-term memory.

The design of the pre-training material might have influenced these results, as the pre-training material did not include information beyond key terms and their graphic representations, in order to avoid having the pre-training become a second learning scenario. While no consensus or best practice for pre-training exist, some previous studies have shown a large effect on knowledge when the pre-training included more extensive information on the subject taught in the learning scenario (Mayer & Pilegard, 2014).

A further result was that pre-training had an impact on self-efficacy in the immersive VR condition but not with the video. However, the differences between media on self-efficacy did not reach significance when there was no pre-training. Most previous studies that have compared simulations to more conventional learning methods report a positive main effect of media on self-efficacy (Makransky et al., 2016; Thisgaard & Makransky, 2017). The finding that there was an interaction between media and method on self-efficacy with the pre-training principle is a new finding in the context of learning with VR.

A main effect of media on enjoyment was also found, with participants using immersive VR scoring significantly higher than participants watching the video. These results are consistent with previous literature showing increased enjoyment in immersive VR when compared to other media (e.g., Bertram et al., 2015; Makransky et al., 2019b; McLaren et al., 2017; Thisgaard & Makransky, 2017). The results further showed that participants using immersive VR experienced more simulator sickness than those watching a video.

When measured again with a one-week delayed post-test, a trend of similar results was observed, but only self-efficacy and perceived enjoyment reached significance. While we expected significant differences in knowledge between video and VR in the one-week delayed post-test, the lack of results could possibly be due to the brief nature of the learning experience, in which case longer learning scenarios with more content might result in long-term differences between media. Another explanation could be the lack of relevance of the learning material to the participants' everyday life. Supporting this point is the fact that two of the studies cited above for reporting significant differences in a one-week delayed post-test (Fyfe & Rittle-Johnson, 2017; McLaren et al., 2017) integrated their design in the classroom activities of school children.

6.2. Theoretical implications

The major theoretical implication of this study is that the findings provide evidence for an interaction between media and method, which challenges the view that media cannot influence learning (e.g. Clark, 1994; Sung & Mayer, 2013). The interaction can be explained within the assumptions of CTML, CLT and motivation theory. CLT and CTML describe how learning with multimedia results in intrinsic cognitive load from the difficulty of the material, as well as extraneous cognitive load from the presentation of the material. Extraneous cognitive load can be detrimental to learning because it increases working memory load without being directly related to the learning material. Previous literature has found that high-immersion media can result in more extraneous cognitive load processing, which results in less learning (e.g. Makransky et al., 2019b; Parong & Mayer, 2018). Therefore, the finding that the pre-training principle was more effective in the immersive VR environment supports the fundamental assumptions of CLT and CTML.

What are the theoretical explanations for the immersive VR with pre-training condition outperforming the video with pre-training condition? Based on CTML it would be expected that the immersive VR simulation would provide a more realistic experience, which could foster generative processing (Makransky et al., 2019b). Furthermore, motivation theories such at the control value theory of achievement emotions (CVTAE; Pekrun, 2006) propose that positive emotions such as perceived enjoyment can have a positive influence on learning (Makransky & Petersen, 2019).

The theoretical implications of our study extend the understanding of the pre-training principle to the medium of immersive VR: pre-training resulted in higher retention and transfer in the immersive VR condition. While this study specifically deals with the pre-training principle, our findings might be generalizable to other instructional methods that currently serve a similar function of limiting intrinsic cognitive load (examples of these can be found in Fiorella & Mayer, 2016). The results further help provide a better theoretical understanding of the pre-training principle, including a more detailed understanding of when the effect works, and more knowledge about potential boundary conditions (such as those explored in Kester et al., 2004).

Furthermore, our results imply that pre-training interacts with the medium in an effective way not investigated fully in the literature. More specifically, when adhering to the pre-training principle, participants learned more in immersive VR than they did watching a video. The results thus add to the theoretical understanding of the media effect and how it may exist in multimedia learning with immersive VR. This has implications for understanding learning in immersive environments like VR, because the learning principles that have been developed based on less immersive media, might not generalize to, or may be even more important in, immersive VR.

The interaction between media and method was further evident in the measures of self-efficacy. Several studies have argued that VR simulations result in a significant increase in self-efficacy by allowing students to actively interact with the virtual environment (Makransky et al., 2016; Parong & Mayer, 2018; Thisgaard & Makransky, 2017; Thompson & Dass, 2000). The present study provides a more comprehensive understanding of this relationship, based on the finding that increased self-efficacy is dependent on both the medium (immersive VR) and method (pre-training). Accordingly, neither the immersion of the medium, nor pre-training as an instructional method alone explain the increase in self-efficacy. This prompts an expansion in the understanding of how self-efficacy develops when instruction is presented using different instructional design principles within different media.

6.3. Practical implications

The results imply that there is an interaction between pre-training and media, with pre-training playing a more important role for learning and self-efficacy in immersive VR, as compared to watching a video. Researchers should consequently be aware of these conditions if they are to further test the learning potential of the medium.

The definition of pre-training (Mayer & Pilegard, 2014) can refer to any presentation of relevant information prior to using the simulation. As VR is expected to have widespread application in classrooms in the coming years (Freeman et al., 2017), it is important that awareness is brought to the effects of pre-training or similar instructional strategies for reducing cognitive load. For example, a practical way of using pre-training could be to include it as part of the regular classroom teaching, where students are first taught about the relevant subject by the teacher, and secondly use immersive VR to gain a deeper understanding of the material and to enhance their self-efficacy (see Mayer & Pilegard, 2014, for further examples of pre-training in use). In this regard, pre-training is not necessarily domain specific to subjects within the natural sciences (as tested in this experiment), but could be applicable to any learning scenario in which complex or abstract information is to be conveyed in VR. As shown above, learning in immersive VR only works better than a video when the learners have important fundamental knowledge of the content before the lesson begins. Similarly, this practice can be applied as early as the instructional design phase, where pre-training can be incorporated into a VR simulation by presenting the core concepts to users before the main learning experience begins.

6.4. Future directions and limitations

Several of the points brought up in this discussion entail an understanding of immersive VR as a medium, which interacts with instructional methods differently than a video. As Moreno and Mayer (2002) and Makransky et al. (2019b) found no difference between media using the redundancy principle, more research is needed to determine the exact relationship of the interaction between media and method in immersive VR. One line of research could be to investigate if media influences methods when other learning principles from CTML are used.

As addressed above, the pre-training principle needs further clarification, as it is currently unclear where a line should be drawn between what constitutes pre-training and a separate learning scenario. The present study was an attempt to test the concept of pre-training while keeping the pre-training as simple as possible. Future research should have a similar distinction in mind, in order to avoid muddling the concepts. However, future research should also investigate the extent to which different pre-training material design impacts learning and motivational outcomes.

Pre-training is not the only way to reduce cognitive load. Parong and Mayer (2018) compared a VR simulation to a slideshow presentation, and found that the slideshow group performed better on factual questions ($d = 1.12$), but found no difference on conceptual questions. In a second experiment, they compared two groups using a VR simulation and found that, if given time to reflect between segments, scores increased on both factual ($d = 1.14$) and conceptual questions ($d = 0.66$). The authors argue that generative learning strategies such as summarizing can aid learning and limit cognitive load, while maintaining the motivational value of immersive VR learning environments. More research is needed to establish how different generative strategies dealing with cognitive load in immersive VR compare, and how these might interact with pre-training.

A main limitation of this study was that self-efficacy was not measured in the pre-test, meaning that we could not control for potential differences between the groups prior to the experiment on self-efficacy. A pre-test measure of self-efficacy was not included based on the perspective that pre-test measures of knowledge or self-efficacy could prime students in specific ways and thus influence the learning session and subsequent responses (Mayer, 2014). However, most previous articles that have investigated the impact of VR learning interventions on self-efficacy control for potential differences in self-efficacy prior to starting the experiment and then to assess if there is a change from prior to after the intervention (e.g Buttussi & Chittaro, 2018; Makransky et al., 2019b). We were able to investigate the issue in the one week follow-up test where we found a significant interaction with and without using the post-test self-efficacy score as a covariate, however our finding that there is an interaction between media and method on self-efficacy should be interpreted with caution and it needs to be investigated in future studies.

A further limitation is that the immediate post-test was conducted in a proctored setting, and the delayed post-test was conducted online. Therefore, the results of the delayed post-test could be positively biased due to the possibility of cheating on the knowledge and transfer test, or they could be negatively biased due to learners having less vested interest because they were taking the test at their own convenience rather than in a formal setting. This lower motivation might specifically have biased the transfer test, as there was a tendency for students to write less information than in the immediate post-test. More rigorous research is therefore needed to further determine whether the benefits of immersive VR persist after a delay in assessment.

Finally, we have shown that immersive VR has potential as an educational technology that increases objective learning outcomes and motivational states when utilizing pre-training as an instructional design principle, but work still needs to be done in determining how it can be adapted to a practical setting.

Acknowledgements

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Appendix. Questionnaire items & sources

Construct	Items	Source
Perceived enjoyment	1. I find using this kind of simulation enjoyable 2. Using this kind of simulation is pleasant 3. I have fun using this kind of simulation	(Tokel & İsler, 2015)
Self-efficacy	1. I am confident that I now understand the layout of the cell 2. I am confident that I understand the basic concepts of the cell 3. I am confident that I understand the more complex concepts related to the cell 4. I think I would be able to do well on a test on the materials I just learned 5. I am confident I could explain what a cell looks like to a friend	(Pintrich et al., 1991)
Simulator Sickness	1. General discomfort 2. Fatigue 3. Headache 4. Eyestrain 5. Difficulty focusing 6. Increased salivation 7. Sweating 8. Nausea 9. Difficulty concentrating 10. Fullness of the head 11. Blurred vision 12. Dizziness (open eyes) 13. Dizziness (closed eyes) 14. Vertigo 15. Stomach awareness 16. Burping	Kennedy, Lane, Berbaum & Lilenthal (1993)
Prior Knowledge	1. On a scale from 1 (very little) to 7 (a lot), how much do you know about cell biology? 2. Do you know what microfilaments are? 3. Do you know what cytoplasm is? 4. Do you know what ribosor 5. Do you know what ATP re 6. Do you know what this is? 7. Do you know what this is? 8. Do you know what this is? 9. Do you know what this is? 	
Retention	1. What are the three main cells in the bloodstream? a . Red (erythrocytes), white (leukocytes) and paleocytes (mesocytes). b. Red (erythrocytes), white (leukocytes) and platelets (thrombocytes). c. White (leukucytes), purple (opuscytes) and platelets (thrombocytes). d. Red (erythrocytes), platelets (thrombocytes) and striataler (striatocytes). 2. What kind of cell is most prominent in the bloodstream? a. Red blood cells (erythrocytes). b. Water (H2O). c. Red and white blood cells are equally prominent. d. White blood cells (leukucytes). 3. What is the purpose of white blood cells? a. To control and maintain the amount of other cells in the bloodstream. b. To protect the body against infection. c. To provide oxygen to cells around the body. d. To transport the red blood cells to their destination. 4. What is the function of the platelets (thrombocytes)? a. To attack foreign objects in the blood stream. b. To find and dissolve fat in the blood stream. c. To transport the red blood cells to their destination. d. To stop the bleeding at damaged blood vessels. 5. How do larger molecules pass through the cell membrane? a . They pas through the cell membrane freely. b. They cannot pass through, however receptors in the cell membrane can dissolve larger objects into vital components that can pass through the membrane. c. Small pumps in the cell membrane give access.	

d. They cannot pass through the membrane because it is made to prevent larger objects from entering the cell.
6. How do small atoms and molecules pass through the cell membrane?
a. Small pumps in the cell membrane give access.
b. They pass through the cell membrane freely.
c. They cannot pass through because the cell membrane Is made to keep all foreign molecules out.
d. They cannot pass through, however receptors in the cell membrane can dissolve larger objects into vital components that can pass through the membrane.
7. How does the cell membrane prevent larger molecules like viruses from entering?
a . Larger molecules never enter the cell.
b. The cell has its own immune system that attacks larger molecules that do not belong in the cell if they attempt to pass though the membrane.
c. A key is required to pass through the pumps in the cell membrane.
d. The cell membrane cannot prevent it and is therefore dependent on them being removed before reaching the cell.
8. What is cytoplasm?
a. The liquid that surrounds the cell.
b. A gel inside the cell that consists on mainly water.
c. A synthetic liquid that can be used to combat disease.
d. A gel that makes up the cell membrane.
9. What give the cell its structure/form?
a. The pressure from the cell's environment.
b. The cytoskeleton.
c. The accumulated mass of the cell (e.g. the nucleus, the mitochondria, the membrane).
d. The cell nucleus.
10. What is the cytoskeleton made up of?
a. Microtubules.
b. Intermediate filaments.
c. Microfilaments.
d. All of the above.
11. Which strand in the cytoskeleton is used for transport?
a. Mitosis filaments
b. Microfilaments
c. Microtubules.
d. Intermediate filaments.
12. What does kinesin motor protein do?
a. The motor protein contains large amount of energy and gets absorbed by the nucleus to keep the cell alive.
b. It helps the cell convey information from the nucleus to the small pumps in the membrane.
c. It transports larger molecules around the cell, by walking in the microtubules.
d. The protein binds with the small pumps in the membrane and helps them open and close.
13. How does kinesin motor protein gain energy for movement?
a. Each time it passes the mitochondria it absorbs and stores energy.
b. It is self-sufficient in regards to movement.
c. It absorbs energy from the molecules it transports through the cell.
d. It binds itself to energy in the cytoplasm (ATP).
14. What does the surface of the cell nucleus consist of?
a. A membrane similar to the one surrounding the cell.
b. Amino acids that protect the cell nucleus.
c. It consists only of cytoplasm.
d. Kinesin motor protein that transports energy inside the cell nucleus.
15. What is the role of the protein filaments that surround the nuclear pores?
a. To uphold the structural integrity of the pores.
b. They check that the molecules have the proper key to pass through the pores.
c. To facilitate the transport of the molecules to and from the cell nucleus
d. They have to specific role.
16. Where does the majority of the cell's DNA reside?
a . It is evenly distributed in the cell.
b. In the cell nucleus.
c. In the cytoplasm.
d. In the cytoskeleton.
17. What is the role of DNA?
a. It contains the instructions used for protein synthesis.
b. It decides how various molecules and atoms are prioritized in the cell nucleus at any given time.
c. It governs the entire functioning of the cell.
d. It plays no role.
18. What is RER an abbreviation of?
a. Redundant Electrolux Redox.
b. Red Enol Reagent.
c. Rough electropositive Rhodamine.
d. Rough Endoplasmic Reticulum.
19. What is RER?
a. A maze-like structure consisting of a flat membrane.
b. Larger molecules that will be bound by Kinesin motor protein.

	c. Energy in the cytoplasm. d. The name of the innermost parts of the nucleus. 20. Where are ribosomes mainly found? a. Attached to ADP. b. Attached to RER. c. Attached to DNA. d. Attached to ATP. 21. What do ribosomes do? a. They link together amino acids. b. They maintain the filaments in the membrane surrounding the nucleus. c. They govern the functioning of the cell. d. They control the production of energy in the mitochrondria. 22. How do ribosomes know which amino acids to link together? a. Through contacts with the RNA. b. Through contact with the DNA. c. They use the ones handed over by the kinesin motor proteins. d. None of the above. 23. What are the linked amino acids called? a. Protein. b. Nucleus. c. A1-glutamate. d. Leukocytes. 24. What is another name for the mitochondria? a. The battery of the cell. b. The cell controller. c. The powerhouse of the cell. d. The DNA storage. 25. In which process does mitochondria play an important role? a. ATP regeneration. b. ADP generation. c. Cell death. d. DNA Synthesis. 26. What is ATP an abbreviation of? a. Acetin triphenazine. b. Accelerant taurine pentoxide. c. Adenosine tannic phenyl. d. Adenosine triphosphate. 27. What role do antibodies play during a virus attack? a. They collide with the virus cells to throw them off course. b. They prevent virus cells from entering the cell by blocking the small pumps in the cell membrane. c. They mark the individual virus cells. d. They consume virus cells. 28. What is the role of white blood cells during a virus attack? a. They mark the virus cells. b. They collide with the virus cells to throw them off course c. They prevent virus cells from the entering the cell by blocking the small pumps in the cell membrane. d. They consume the marked cells. 29. How can viruses enter the cell? a . By using counterfeit keys. b. By attacking and degrading the cell membrane. c. They are small enough to freely pass through the cell membrane. d. By forcibly squeezing through the small pumps in the membrane.
Transfer	1. Why does the cell not get flooded with all the various elements surrounding the cell? 2. You are in a lab, looking at a blood sample where an infection has spread more than it should have. What could be the cause of this? 3. Why is the membrane that surrounds the nucleus important? 4. How does the cell keep functioning?

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