Immersion and Learning: Cognitive and Affective Outcomes of Immersive Virtual Reality Learning Experiences

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Abstract

This study aimed to compare the effects of immersive virtual reality (IVR) videos and 2D educational videos on cognitive (i.e. conceptual knowledge) and non-cognitive (i.e. self-efficacy) learning outcomes. Fifty-three students from an all-girls middle school learned about humans' impact on the ocean through either IVR videos, using a virtual reality (VR) headset, or through 2D videos, using a computer monitor. Results replicate previous findings suggesting that conceptual knowledge gains between IVR and desktop learning experiences is not significant. Also, results show that participants who watched IVR videos reported higher self-efficacy scores and expressed higher feelings of presence than participants who watched the same videos using a computer monitor. Finally, further analyses revealed that the feeling of presence mediated both cognitive and non-cognitive learning outcomes.

Keywords: virtual reality, self-efficacy, immersive virtual reality videos, conceptual knowledge, learning

Since the first virtual reality (VR) head-mounted displays (HMDs) were built in the 1960s (Sutherland, 1968), there has been an interest in using immersive VR (IVR) technology for learning (Dede, 2010). However, IVR's commercial availability has only increased considerably in the last decade (Parong & Mayer, 2018) and is now becoming affordable to the general public. Consequently, more attention is now being drawn to possible IVR applications in schools as well as research on the impact of IVR within the context of learning. (Blascovich & Bailenson, 2011; Parong & Mayer, 2018).

Most of the IVR systems work by replacing the perceptual input of the real world with perceptual input from the virtual environment in real-time. This is accomplished by blocking out visual, auditory, and haptic feedback from the physical world, the continuous tracking of the user's head and body movements, and the immediate rendering of the virtual environment in response to the user's movements and behaviors. Thus, one of the unique affordances of IVR systems, is their ability to immerse users in virtual environments and elicit feelings of *presence.* Presence is a subjective experience and "refers to the phenomenon of behaving and feeling as if we are in the virtual world created by computer displays" (Sanchez-Vives & Slater, 2005, p. 332). Previous research in this area has found that increased *immersion*, defined as the "extent to which the computer displays are capable of delivering an inclusive, extensive, surrounding, and vivid illusion of reality to the senses of a human participant" (Slater & Wilbur, 1997; p. 3), increases feelings of presence (Sanchez-Vives & Slater, 2005).

Glenberg (2018) argued that the second most important affordance of IVR systems within the context of learning relates to embodiment and the subsequent agency associated with being able to manipulate virtual content in three dimensions and in real-time. According to Glenberg (2018), manipulating objects in three-dimensional space gives learners increased personal control (agency) over the learning environment. Even though there are multiple ways of activating agency into immersive learning environments using IVR technology (e.g., eye gaze), Glenberg (2018) reasons that gestures play a special role because in these virtual learning environments since they activate larger portions of the sensory-motor system and may improve memory. Given students are in control of where they look and for how long, they can monitor their interest and curiosity, which gives them a sense of control and empowerment over their own exploration (Glenberg, 2018). This may in turn improve students' self-efficacy (i.e., feelings of being able to succeed at a given task) and increase their motivation to learn.

There are two main categories of IVR experiences, namely computer generated (CG) and immersive 360-Degree videos, also known as IVR videos (Li, Bailenson, Pines, Greenleaf & Williams, 2017). In CG experiences, users are immersed in an artificial, three-dimensional world that is generated by computer graphics. Much like video games, CG experiences allow users to move around the environment, be represented by different kinds of avatars, interact with objects and virtual characters, and control virtual content at their leisure. In IVR videos users are fully immersed in a virtual sphere that plays a panoramic video that surrounds the users. More specifically, users are placed inside a sphere and are able to use their head movement to change their viewing angle as real-world footage plays around them, similarly to the users' agency in real environments. In contrast to CG experiences, users watching IVR videos with a VR headset are not able to move around the virtual environment and they are only able to watch the video from the perspective of the camera. Both types of experiences are considered immersive, yet they differ in terms of interactivity and perceived user control.

Given IVRs ability to immerse users in virtual environments, elicit feelings of presence, and allow users to manipulate virtual content in real-time, IVR has the potential to not only be an effective educational tool across different subject matters, but to help students' chances of success by increasing self-efficacy. The feeling of presence is of particular interest to developers of IVR learning applications since higher feelings of presence have been correlated to higher user engagement with the content (Bailenson et al., 2008; Cummings & Bailenson, 2016; Parong & Mayer, 2018). However, the literature shows mixed results when it comes to the effectiveness of IVR learning experiences compared to less immersive media (Jensen & Konradsen, 2018; Parong & Mayer, 2018; Queiroz, Nascimento, Tori & Leme, 2018). Moreover, most of the research examining these relationships has used CG experiences, thus the effect of IVR videos on learning outcomes has been underexplored. Within this context, the goals of this study are 1) to compare the effectiveness of watching IVR videos using a VR headset versus watching 2D videos on a desktop, 2) to compare the effects IVR and desktop learning experiences on students' perceived self-efficacy and motivation to learn, and 3) empirically assess the role, if any, that presence plays in the relationship between the level of immersion and learning outcomes as well as the relationship between immersion and self-efficacy.

Virtual Reality and Learning

IVR has shown different effects on the three learning domain defined by cognitive psychology theory, namely cognitive, affective and psychomotor (Krathwohl & Anderson, 2009). Two systematic literature reviews investigating the use of IVR in education have found similar results about IVR effects on learning outcomes in different domains of learning (Jensen

& Konradsen, 2018 and Queiroz, Nascimento, Tori, & Leme, 2018). Queiroz and colleagues (2018) reviewed 24 studies focusing on IVR use in K-12 education while Jensen and Konradsen (2018) reviewed 21 studies focusing on IVR in K-12, higher education and training.

Those reviews suggested that IVR, when compared to other learning methods, positively impacts the affective (e.g. feelings and emotions) and psychomotor (e.g. motor skills) domains of learning. Results from Queiroz and colleagues (2018) indicated that students using IVR reported higher affective outcomes, such as perception of topic relevance, greater confidence and more satisfaction in learning compared to other settings. All studies reviewed by Jensen and Konradsen (2018) investigating learners' attitudes towards IVR reported that students perceived IVR as useful, exciting and interesting. For the cognitive domain, both reviews reported paucity of studies investigating the effects of IVR in learning and not enough evidence about IVR effectiveness compared to other media, particularly regarding conceptual learning.

Bloom (1956) proposed a hierarchical taxonomy emphasizing the cognitive objectives of learning. Mayer, Paul, Raths, and Wittrock (2001) reviewed Bloom's taxonomy and proposed six levels of cognitive processes dimensions, in crescent order: remembering, understanding, application, analyzing, evaluation and creation. These levels are described as follows: remembering refers to information recall, while understanding refers to comprehension and the ability to translate what was learned to students' own words; application is related to the ability to use the knowledge in new situations that were not taught directly; analyzing relates to the ability to break down an information and discuss its elements; evaluation refers to the ability to make judgements about something, using some criteria; and, creation is considered the highest cognitive level and refers to inductive thinking and the ability to create based on what the student already knows. This taxonomy is particularly useful when planning and evaluating learning activities, helping to assess lower and/or higher cognitive processes levels involved in using IVR, for example.

Results from studies comparing conceptual learning outcomes from IVR to other media vary significantly. On one hand, some studies have reported significant positive learning outcomes of IVR compared to other media (Alhalabi ,2016; Webster, 2015). On the other hand, some studies have shown significant lower learning outcomes when using IVR (Dede, Saltzman and Loftin, 1997; Parong and Mayer, 2018). This points out the need of further research about IVR usefulness and effectiveness for learning, particularly when considering its use at scale.

In spite of inconclusive results favoring IVR, there are some suggestions that IVR may favor learning due to its unique features such as motivation, sense of control given by presence and other factors (Glenberg, 2018). As it will be examined in the next section, it may be that the sense of control given by IVR can positively impact learning because of the sense of self-efficacy, feelings of presence and control present in the situation.

Self-efficacy

Self-efficacy, a concept coined by Bandura (1977) in light of the Social Learning Theory, is defined as “people’s judgments of their capabilities to organize and execute courses of action required to attain designated types of performances” (Bandura, 1986, p. 391). In other words, self-efficacy refers to people’s beliefs that they can succeed in a specific task, topic, or environment. Relevant to this concept is the idea that “expectations of personal mastery affect both initiation and persistence of coping behavior” (Bandura, 1977, p. 193), which highlights the importance of self-efficacy to understanding peoples’ behaviors, achievements, and even life outcomes.

According to Bandura (1977), people's perceived self-efficacy determines how much effort they will put into a particular activity and how long they will persist in succeeding at that activity. Usher and Pajares (2008) suggested that when people perceive themselves as being able to learn and master some activity, they will face challenges more positively and will be more persistent at mastering that activity than people who perceive themselves as not capable of attempting or mastering the same activity. This is an important ability considering the demands of our current society. Learning new professions and how to face and cope with new economic, social, or cultural changes are crucial to succeed in our constantly changing environment (Bandura, 1995).

Because the importance of self-efficacy in driving behavior, it has been extensively researched and applied to educational settings (Schunk, 1995; Schunk & DiBenedetto, 2016). In general, self-efficacy has been considered a predictor of students' academic performance and career choices (Maddux, 2016; Zimmerman, 1995). More specifically, self-efficacy influences students' career choices by influencing the type of environments and activities they engage with. Students tend to avoid environments they believe they won't be able to cope with. Self-efficacy operates by guiding the selection of the environments and social networks people choose to engage with throughout their lives (Bandura, 1995).

According to Bandura (1997), the four main sources of students' self-efficacy are: 1) enactive mastery experiences, 2) vicarious experiences (observation), 3) social persuasions, and 4) physiological states. The author states that enactive mastery experiences (i.e. performance accomplishments) produce the highest and most generalized increase in perceived self-efficacy as they provide genuine and immediate evidence that students can succeed on the task at hand (Bandura, 1997). After receiving that evidence and interpreting the results, students tend to develop beliefs about their own performance. In the literature, those beliefs are thought to impact students' self-efficacy. The second most powerful source of students' self-efficacy are vicarious experiences through which students interpret their own capabilities by observing others and making comparisons (Schunk, 1987). Bandura (1997) argued that although enactive mastery experiences show higher impact on self-efficacy, students who are uncertain of their capacities or have little mastery experience are more sensitive to the influence of vicarious experiences.

In the literature, many studies highlight the role of teachers, parents and schoolmates on students' self-efficacy (Schunk, 1995; Usher & Pajares, 2008). However, because of the increased technological adoption by students both inside and outside of schools, particularly in the course of the last two decades, recent research has started to focus on the bidirectional relationship between technology and self-efficacy (Huang & Mayer, 2019; Kuo, Walker, Schroder, & Belland, 2016; Meyer, Omdahl & Mackranki, 2019; Sun & Rueda, 2014). More specifically, given IVR's potential to tap into students' non-cognitive dimensions of learning, more attention has been drawn to understand how IVR impacts self-efficacy.

Previous studies have shown a positive relationship between the increased level of immersion and self-efficacy. For example, Meyer, Omdahl and Makranski (2019) compared the effect of pre-training on learning about human body cells using IVR versus a 2D video. A 2x2 repeated measures design was used and participants were randomly assigned to either IVR or video condition, with or without a pre-training session. Results showed that the pre-training session significantly increased knowledge and transfer in the IVR condition but not in the video condition. Results also showed that participants in both IVR conditions reported higher self-efficacy than participants in the video conditions. Moreover, the pre-training session was found to significantly increase students' self-efficacy when learning in IVR, but not when using a video.

In a different study, Makransky, Borre-Gude and Mayer (2019) compared the motivational and cognitive effects of an IVR simulation, a desktop VR simulation, and a conventional safety manual for laboratory safety training. Although results indicated no significant difference on immediate retention test between conditions, they did show a significant difference for transfer to physical world problem solving, motivation, enjoyment, and self-efficacy between IVR and the text conditions, with participants in the IVR condition reporting higher scores on these measures.

Since self-efficacy has been found to affect academic performance and influence professional choices, Multon, Brown, and Lent (1991) argued that it is crucial to find new ways to support positive self-efficacy perception in educational, professional and personal environments. Thus, understanding how teaching methods and in-classroom tools impact self-efficacy plays an important role in improving students' chances for success. Focusing on IVR in particular, given its recent and increasing adoption in formal and informal learning environments, it is necessary to understand its role in fostering self-efficacy. Moreover, it is important to note that most of the studies assessing the relationship between immersive media and self-efficacy have only used CG virtual environments and the relationship between IVR videos and self-efficacy is still unclear.

Present Study

The present investigation compared the effects of watching educational IVR videos using VR headset or watching 2D videos using a desktop monitor on both cognitive and non-cognitive learning outcomes. A long line of research investigating the effects of IVR and education has reported significant learning increase after using IVR educational experiences (Alhalabi, 2016; Dede, Saltzman, & Loftin, 1997; Jensen & Konradsen, 2018; Markowitz, Laha, Perone, Pea, & Bailenson, 2018; Parong & Mayer, 2018; Queiroz, Nascimento, Tori & Leme, 2018; Webster 2015). However, when comparing learning gains from IVR or desktop computer, results from previous studies vary significantly, with some studies reporting higher learning gains from using IVR and others reporting the opposite (Jensen & Konradsen, 2018; Parong & Mayer, 2018). Considering these results, we hypothesized that both participants watching IVR videos using a VR headset and participants watching the same content using a computer monitor will show similar learning gains.

Past research examining the impact of IVR on self-efficacy has shown that increased immersion has a positive effect on self-efficacy (Makransky, Borre-Gude, & Mayer, 2019; Meyer, Omdahl & Makranski, 2019). Still, it is important to note that, to date, there are only a few studies comparing these effects between IVR videos and desktop set ups. Taking these findings into consideration, we hypothesized that participants who watch an IVR video report higher self-efficacy (as it specifically relates to learning science) compared to participants watching the same content on a desktop monitor.

Based on previous findings suggesting that increased levels of immersion result in higher feelings of presence (Sanchez-Vives & Slater, 2005), we hypothesized that participants watching IVR videos in a VR headset will report higher feelings of presence than participants watching 2D videos on a desktop monitor. In addition, to the best of our knowledge, no published study has investigated the causal mediation effect of presence on both learning gains and self-efficacy when watching IVR videos. Makransky and Lilleholt (2018) aimed to understand how the level of immersion impacts perceived learning and found that presence had a mediation effect on perceived learning outcomes. However, their design did not measure actual learning gains. Thus, as presence has been found to mediate the effect between immersion and perceived learning, and past researches suggest significant positive correlations between the level of immersion and engagement with learning content (Bailenson et al., 2008; Parong & Mayer, 2018), between engagement and self-efficacy (Bandura & Cervone, 1986; Linnenbrink & Pintrich, 2003), and between presence and emotions (Riva et al., 2007), we predict that presence will mediate both self-efficacy and learning gains.

Method

Procedures and materials in this study were approved by the Institutional Review Board at REDACTED University. Written parental consent forms and assent forms were obtained from all participants and their parents/legal guardians. Researchers worked with the participants' science teacher to define the logistics of the experiment and the wording of the questionnaires used. The entirety of the study occurred before participants covered any relevant or closely related material in their coursework.

Participants

Participants were recruited from an all-girls middle school in the United States. Participation was entirely voluntary. An initial sample of 55 female 8th grade students answered the pre-test using a MacBook Air computer. Two students failed to complete some part of the study and were excluded from analysis. The final sample consisted of 53 female participants.

Materials & Apparatus

The instructional material consisted of two videos: *The Crystal Reef* and *Coral Compass*. Both of these videos are narratives depicting how human actions have been negatively affecting the ocean. *The Crystal Reef* focuses on ocean acidification (OA) and how carbon dioxide (CO_2) from human emissions negatively impacts the ocean. The video presents a female scientist diving into the Mediterranean Sea at a site where natural vents from the ocean floor emit CO_2 into the water. The high concentration of CO_2 in the water decreases the water pH, resulting in more acidic water and reduced biodiversity. *Coral Compass* focuses on how human activities have been impacting the coral reefs in Palau, a small island in the western Pacific. The video is narrated by a male scientist and presents how tourism and land practices have been affecting the health of the coral reefs and shows how the country's government has been acting to reduce negative impact on the ocean. Both videos suggest actions that can be taken to reduce humanity's negative impact on the ocean.

Depending on which condition participants were randomly assigned to, they either watched both videos on the flat screen of a Mac-Book Air Pro (desktop condition) or watched the IVR version of the videos using a Lenovo Mirage Solo VR headset (IVR condition). Participants in both conditions listened to the audio using headphones. The 2D versions of each IVR video were created using a screen capture software (Fraps^{TM}). The sounds and narrative were exactly the same in both the IVR and desktop conditions. Each video is about 5 minutes long.

Design & Procedure

Participants were invited by their science teacher to participate in this study. Participants who accepted and received consent from their parents answered a pre-test questionnaire on Qualtrics during their science class. Three weeks later, the researchers visited the school to conduct the treatment sessions during which participants were randomly assigned into the IVR condition (n = 28) or the desktop condition (n = 25).

In the IVR condition, participants watched the IVR video versions *The Coral Reef* and *Coral Compass* using a VR headset while participants in the desktop condition watched the 2D versions of the videos on a laptop in a separate room. The treatment sessions and post-test took place during a 90-minute science class period. To account for order effects, half of the participants in each condition watched *The Crystal Reef* first while the other half started with *Coral Compass*.

In an effort to mitigate fatigue, after participants watched the first video, the researcher asked students to answer three questions assessing presence, three open-ended questions and three multiple-choice questions assessing learning outcomes on a laptop computer. When participants finished that survey, the researcher helped put the headset on the participants again and started playing the second video. After the second video, participants answered again the three questions assessing presence, three open-ended questions and three multiple-choice questions assessing learning as well as additional three questions about environmental concern, knowledge about OA and twelve questions to measure self-efficacy.

Finally, after all students completed the experiment they were debriefed about the study and researchers answered students' questions.

Measures

Presence. Three items assessing feelings of presence using a 5-point Likert scale (*1= not at all, 5 = extremely*) were adapted from Nowak and Biocca (2003). These items were: "To what extent did you feel like you were inside the virtual experience?"; "To what extent did you feel immersed in the virtual experience?" and "How much did it feel as if you visited another place?" Participants answered these three questions during the post-questionnaire immediately after watching each of the videos.

Open-ended learning assessment questions. Six open-ended questions were created based on the critical thinking theory and revision of Bloom's taxonomy for learning assessment (Krathwohl & Anderson, 2009; Mayer, Paul, Raths, & Wittrock, 2001). The questions designed to assess participants' understanding about the topic were: "Explain what you know about how human activities change the ocean chemistry" and "Palau's coral reefs are considered to be one of the 'Seven Underwater Wonders of the World'. What actions is the Palau government taking to reduce damages to the coral reefs?" The questions designed to assess participants' ability to apply knowledge gained were: "Describe ways that could help reduce ocean acidification" and "How could the Palauan government actions to protect the coral reefs be applied to other environmental issues, for example, the fast erosion of South California beaches?" The questions designed to assess participants' creation cognitive processes were: "Propose strategies to increase engagement of the general public with ocean acidification" and "Considering the Palauan government efforts to protect the coral reefs, think about one issue from your community that needs immediate attention. Propose an action plan that could help address this issue". Blind coders rated each of the participants answers using a range of 0 to 5 points using a rubric developed according to Saxton, Belanger and Becker (2012). Agreement average rate between researchers was 89.27% in pre-test and 88% in post-test. When researchers had an initial disagreement on the scoring, they looked for a consensus score, that was the one considered. A score for each participant was created by averaging the scores they received by coders for each question.

Multiple-choice learning assessment. Four questions about OA and coral reefs were adapted from the International Ocean Literacy Survey (Fauville, Strang, Cannady, & Chen, 2018) and two questions about Palauan government actions regarding coral reefs were created.

Participants were given a point for every correct answer and received zero points for incorrect answers. Participants' final score was the sum of all of their correct answers.

Concern about the ocean. Participants were asked how concerned they were about the health of the ocean using a 5-point Likert scale (*1 = not at all, 5 = extremely*). The question used was "How concerned, if at all, are you about the health of the ocean?" and it was adapted from Capstick et al., (2016).

Knowledge about OA causes. Participants were asked to complete the following statement "Do you think that the increased amount of carbon dioxide in the atmosphere was caused…" by selecting one of the following answers: "mostly by things people did"; "mostly by natural causes" or "equally by things people did and natural causes". This question was designed specifically to assess participant's knowledge about what causes OA and evaluate in the extent to which the level of immersion could impact participants' knowledge about the causes of OA.

OA Seriousness. Participants were asked to answer the question "How serious of a problem do you think the increased amount of carbon dioxide in the atmosphere is for the health of the ocean?" using a 5-point Likert scale (*1= not at all serious, 5 = extremely serious*). This question was used to assess participants' opinion about OA seriousness.

Self-efficacy and motivation to learn science. Twelve questions from Tuan, Chin and Shieh (2005), Pekrun, Goetz and Perry (2005) and Pekrun, Goetz, Frenzel, Barchfeld and Perry (2011) were adapted to assess participants self-efficacy and motivation to learn using a 5-point Likert scale (1= *strongly disagree*, 5 = *strongly agree*). Negatively framed questions were reverse coded. The exact wording of the questions in the self-efficacy questionnaire can be found in Appendix 1.

Results

The feelings of presence were measured at post-test and therefore a Welch Two Sample t-test was performed to compare results between conditions. Knowledge about the causes of OA was a nominal categorical variable, and a Chi-squared test was performed (Campbell, 2007) to compare the proportions between conditions at pre- and post-test.

A linear growth curve model with fixed-effect of condition (desktop vs. IVR) and time (pre- vs. post-test) was used to analyze most of the variables (except for feeling of presence and knowledge about OA causes). Random effect of individuals on the intercept and the slopes were also included in the models (Bates, Mächler, Bolker, & Walker, 2014). Given the pre- and post-test experimental design, growth curve modeling analysis was chosen since it accounts for inter-participant variability (between) and intra-participant (within) patterns of change over time, thus accounting for pre-test differences between conditions and between participants (Winter, 2013).

All the analyses were carried out using RStudio Version 1.1.463 as well as the *lme4* and *mediation* package. Means and standard deviations of each dependent variable are shown in Table 1.

Table 1. Means and standard deviations for variables by condition and time.

Even though participants were randomly assigned to each condition, significant differences between conditions were found at pre-test for the multiple-choices learning assessment ($t(50.69) = 3.16$; $p < 0.01$; 95% Confidence Interval (CI) [0.36, 1.59]) as well as self-efficacy ($t(44.49) = 2.27$, $p < 0.05$, 95% CI [3.52, 3.2]). No significant difference between conditions was found at pre-test for the open-ended questions learning assessment ($t(42.37) = -0.36$; $p > 0.5$; 95% CI [-0.26, 0.18]), concern about the ocean ($t(48.71) = 1.28$; $p > 0.1$; 95% CI [-

0.14, 0.67]), OA seriousness ($t(50.42) = 0.96$; $p > 0.1$; 95% CI [-0.18, 0.52]), and knowledge about OA (X^2 (1)= 4.6^{-31}, $p > 0.5$, 95% CI [-0.18, 1.0]).

Presence. Feelings of presence were measured during the post-test, right after participants watched each of the videos regardless of condition. There was a significant difference in participants' feelings of presence between conditions (t (43.55) = -9.593; $p < 0.001$; 95% CI [-2.23, -1.45]), with participants in the VR condition reporting significantly higher feelings of presence than participants in the Desktop condition.

Open-ended learning assessment questions. There was a significant effect of time in learning gains based on the open-ended learning assessment questions with both conditions showing a significant increase in score between the pre and post-questionnaires. ($\beta = 1.51$, $t(53) = 14.64$, $p < .001$, 95% CI [1.30, 1.71]). There was no interaction effect of condition and time on open-ended questions (X^2 *(1)* = 0.3721, p = 0.542, 95% CI [0.87, 1.27]).

Regarding each cognitive process measured according to Bloom's taxonomy (Krathwohl & Anderson, 2009; Mayer et al., 2001), both conditions showed a significant increase in score at post-test. This effect of time was significant for both conditions and for each cognitive process as follows: understanding ($\beta = 1.60$, $t(53) = 12.58$, $p < .001$, 95% CI [1.01, 1.55], *std.* $\beta = 1.25$, *std. SE* = 0.13); application ($\beta = 1.33$, $t(53) = 10.23$, $p < .001$, 95% CI [1.53, 2.09], *std.* $\beta = 1.32$, std. *SE* = 0.13); creation ($\beta = 1.58$, $t(53) = 11.90$, $p < .001$, 95% CI [1.32, 1.85], *std.* $\beta = 1.46$, *std. SE* = 0.12). These results indicate that over time, participants in both conditions demonstrated a significant increase in each of the cognitive processes. There was no significant interaction effect of condition and time on understanding (X^2 (1) = 0.5946; $p = 0.440$, 95% CI [0.68, 1.24]), knowledge application (X^2 (1) = 0.0055; $p = 0.938$, 95% CI [0.50, 1.10]) or creation (X^2 (1) = 0.3638; $p = 0.545$, 95% CI [1.25, 1.83]).

Multiple-choice learning assessment questions. There was a significant effect of time on score, indicating that participants in both conditions scored significantly higher during the post-test (β = 2.11, $t(53)$ = 13.65, p < .001, 95% CI [1.80, 2.42]).There was no significant interaction effect of condition on multiple-choice score over time (X^2 (1) = 0.6023; p = 0.438, 95% CI [1.87, 2.73]).

Concern about the ocean. There was no significant effect of time on participants' concern about the health of the ocean in both conditions (β = 0.04, $t(53)$ = 0.41, p = 0.766, 95% CI [-0.15, 0.22, *std.* β = 0.05, *std. SE* = 0.13). Also, there was no significant interaction effect of condition in participants' concern about the ocean over time ($X^2(1)$ = 0.6373; p = 0.424, 95% CI [3.58, 4.10]). These results indicate that participants' concern did not significantly increase after watching the videos regardless of condition.

Knowledge about OA causes. None of the participants attributed OA to mostly natural causes in either the pre-test or the post-test. The percentage of participants answering that OA is caused "mostly by things people did" increased from 89.3% in pre-test to 96.4% in post-test for the VR condition, while it decreased from 92% to 76% for the Desktop condition (Figure 1). There was no significant difference between conditions on the proportion of participants attributing OA to "mostly by things people did" before treatment (2.7% difference, X^2 (1)= 4.6^{-31}, p = 0.5, 95% CI [-0.18, 1.0]). However, a significantly higher proportion of participants in the VR condition attributed OA causes to "mostly by things people did" than participants in the desktop condition after treatment (20.4% difference, X^2 (1) = 3.19, p = 0.037, 95% CI [0.014, 1.0]).

Figure 1. Percentage of answers about OA causes.

OA seriousness. There was a significant effect of time on OA seriousness indicating that participants' perception of OA seriousness increased after treatment regardless of condition (β = 0.38, $t(53) = 3.51$, $p = 0.003$, 95% CI [0.16, 0.59]). There was no significant interaction effect of condition and time on perceptions of OA seriousness (X^2 (1) = 0.8205; $p = 0.365$, 95% CI [3.92, 4.34]).

Self-efficacy and motivation to learn science. There was no significant effect of time on self-efficacy and motivation to learn (β = -0.08, $t(53) = -1.07$, p = 0.289, 95% CI [-0.22, -0.07]). However, there was a significant interaction effect of condition on self-efficacy perception and motivation to learn over time (X^2 (1) = 4.2718; $p = 0.039$, 95% CI [2.96, 3.44]), with increase in score for participants in the VR condition, and a decrease in score for in the desktop condition after treatment (Figure 2).

Figure 2. Self-efficacy and motivation to learn score means at pre- and post-test

Mediation Analysis. The preconditions to run a mediation analysis are that the predictor variable (participants' condition) is associated with the outcome variable (in this case self-efficacy and learning gains) and with the mediating variable (presence) (Hayes, 2017; Tingley, Yamamoto, Hirose, Keele & Imai, 2014). Additionally, the mediating variable needs to be associated with the predictor variable and the outcome variable (Jose, 2013). These criteria were met considering condition as a predictor variable and presence as mediating variable for: multiple-choice learning assessment, self-efficacy and motivation to learn, and concern about the ocean. The mediation and outcome models considered the score change between pre- and post-test for each variable (MacKinnon, 2008). The explanatory variables of the outcome model included the mediator (presence) and condition (considering the desktop group as control and IVR group as treatment).

The causal mediation analysis showed that presence partially mediated the multiple-choice score ($p = 0.024$) and self-efficacy outcomes ($p = 0.002$) but not the concern about the ocean ($p = 0.480$). Coefficients are shown in Figure 3 and Figure 4.

Figure 3. Presence mediation on multiple-choice learning assessment

Figure 4. Presence mediation on self-efficacy

Discussion

This study compared the effects of IVR videos and 2D educational videos on cognitive (i.e. conceptual knowledge) and non-cognitive (i.e. self-efficacy) learning outcomes. Fifty-three students from an all-girls middle school learned about humans' impact on the ocean through either IVR videos, using a VR headset, or through 2D videos, using a computer monitor.

Research so far has been inconclusive about the IVR impact on conceptual learning gains compared to other media, thus its usage for cognitive skills' learning purposes-only should be taken with caution. However, positive outcomes beyond conceptual knowledge, such as gains in non-cognitive domains (for example, affective and perceived self-efficacy), have been correlated with long-term positive effects on learning, academic and professional performance (Bandura 1986; Plass & Kaplan, 2016; Pekrun, 2006; Zimmerman, 2000). For these non-cognitive domains of learning, the impacts of IVR has been shown to be positive. Although research has been inconclusive about IVR impacts on conceptual knowledge gains, findings from studies investigating IVR impacts on self-efficacy seems to be more consistent, and positively correlates IVR use with increased self-efficacy perception (Makransky, Borre-Gude, & Mayer, 2019; Meyer, Omdahl & Makranski, 2019).

The present study found a significant difference in self-efficacy scores between conditions over time. Participants in the IVR condition reported significantly higher perceived self-efficacy and motivation to learn after treatment than participants in the desktop condition. Moreover, given there was no significant effect of condition on learning outcomes, our findings replicate Makransky, Borre-Gude and Mayer's (2019) study, which compared IVR, desktop VR simulation and a text-based safety manual. Their results also showed no significant difference between conditions on immediate multiple-choice retention test but showed a significant difference favoring the IVR group for intrinsic motivation and self-efficacy.

This positive impact of IVR on self-efficacy may be due to the positive effects that IVR has shown in non-cognitive aspects of learning such as engagement and enjoyment (Bailenson et al., 2008; Makransky & Lilleholt, 2018; Parong & Mayer, 2018). Those aspects are known to influence self-efficacy (Bandura, 1995) and therefore may mediate the positive impact of IVR on self-efficacy. Also, as pointed out before, feelings of greater control of the situation can also be held responsible for the higher self-efficacy perception in IVR (Glenberg, 2018; Hite et al., 2019). Agency and the intention to act have been shown to involve causal efficacy (David, Newen & Vogeley, 2008; Schlosser, 2012) and may have contributed to increase self-efficacy in the IVR condition. These are aspects to be considered in future research.

Although studies investigating IVR impact on self-efficacy are still scarce, these findings shed light on the potential of IVR impacts on affective domains of learning. As Bandura (1977; 1995) stated, self-efficacy has a direct influence on people's choices of activities and settings and directly affects how much effort people will put in and how long they will persist. Also, given self-efficacy's positive correlation with academic and professional achievements (Zimmerman, 2000), educational approaches enhancing students' self-efficacy are of great value.

As predicted, participants in IVR group reported higher feelings of presence than participants in the desktop condition. Considering the inconclusive results on the literature about the impact level of immersion on learning (Jensen & Konradsen, 2018; Parong & Mayer, 2018; Queiroz, Nascimento, Tori, & Leme, 2018) and to better understand how presence impacts affective and cognitive domains of learning, we ran an analysis considering presence as a mediator of the following variables: concern about the ocean, self-efficacy, learning. Results show that presence mediated participants' score on the multiple-choice questions and on self-efficacy. Although some studies have reported correlations between IVR, presence, learning and self-efficacy, to the best of our knowledge, this is the first study that assesses the role of presence as a mediator within the context of IVR videos and learning.

Although there was no significant main effect or interaction effect of condition and time on participants' concern about the ocean, the level of immersion significantly impacted participants' knowledge about the causes of OA. More participants in the VR group attributed the causes of OA to human activities after treatment than participants in the desktop condition, while the proportion of participants in the desktop condition attributing the causes of OA to mostly human activities decreased after treatment. Given past research has shown that the general population is not aware of OA (Capstick et al, 2015; Capstick et al., 2016; Mossler, Bostrom, Kelly, Crosman, & Moy, 2017), these results offer cogent evidence suggesting that VR can be more helpful than traditional media (e.g. 2D videos) at increasing people's awareness about human's activities impact on the environment.

A significant effect was found between pre- and post-test for perceived seriousness of OA, but no interaction effect was found between conditions. Although the level of immersion did not impact participants' perceived seriousness of OA, the message of the video *The Crystal Reef* seems to have impacted it. Learning about the causes and consequences of OA could have increased their perception of its seriousness.

Comparing participants’ scores on multiple-choice learning assessment between conditions showed no significant interaction effect of the condition, corroborating previous studies that compared learning outcomes between IVR and desktop (Parong & Mayer, 2018; Stepan et al., 2017; Moreno & Mayer, 2002). Also, the level of immersion did not impact the different cognitive processes measured (understanding, application and creation), corroborating Allcoat and Mühlenem (2018). However, the videos used showed to be effective for conceptual learning, as a significant increase in open-ended and multiple-choice questions’ scores between pre- and post-test in both IVR and desktop conditions was observed.

Our findings are aligned with previous studies investigating the level of immersion impact on non-cognitive domains of learning and our study is novel in showing the mediation effect of presence in both cognitive and non-cognitive dimensions of learning. These findings are important in light of a changing society in which technology use is increasing at a fast pace and devices continue to augment the level of digital immersion.

Limitations and future directions

Although results from this study yielded encouraging findings, there are some limitations. First, even though participants were randomly assigned to each condition, there was significant difference between conditions at pre-test for some of the variables measured. A statistical method that consider pre-test differences was selected in order to properly analyze the data. However, it doesn’t rule out the possibility of interference of this pre-test difference at post-test results.

Second, the sizes and particularities of the samples limit the generalization of the results. Although our samples sizes are considered acceptable (25 participants in the desktop condition and 28 in the IVR condition), they limit the findings' generalization. Also, participants were only female students from a school placed in an affluent neighborhood. Hence, these findings should be taken with care when considering other populations.

Finally, assessing learning through multiple-choices and open-ended questions have some inherent limitations. Although multiple-choices questions are considered common practice in learning assessments, it may bring some inaccuracy due to students' excessive training in answering this kind of questions. Some students' score can be impacted by their ability to identify the most probable correct answer more than their learning about the content presented. To reduce this impact, we also used open-ended questions to assess learning. However, even open-ended questions have limitations, particularly because they ultimately rely on subjective scoring. An objective rubric was developed, and blind score ratings were used as an attempt to reduce the subjectivity of this assessment.

Despite these limitations, these findings provide encouraging evidences of IVR impacts on cognitive and non-cognitive domains of learning. Future studies should consider larger samples, a more diverse population, multiple IVR exposures, and use multiple learning assessment methods in order to improve the generalizability of these findings.

Conclusion

The present study found an interaction effect of the level of immersion on participant's perceived self-efficacy. Participants watching IVR videos scored significantly higher on self-efficacy after the video exposure than participants watching the same videos on a desktop monitor. We also found a causal mediation of presence between the condition and the learning gains measured on multiple-choices questions and as a causal mediation between the condition and the self-efficacy perception. The results of this study give evidences of the positive impact of an increased level of immersion on cognitive and non-cognitive domains of learning, particularly conceptual knowledge and self-efficacy.

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Table 1

Means and standard deviations for variables by condition and time.

	IVR Condition			
Measures	**Pre-test**		**Post-test**	
	Mean	*SD*	*Mean*	*SD*
Presence	-	-	4.05	0.58
Open-ended questions learning assessment	1.06	0.32	2.62	0.51
Multiple-choice learning assessment	3.21	1.23	5.21	0.92
Concern about OA	4.14	0.71	4.25	0.59
OA seriousness	4.25	0.65	4.54	0.51
Self-efficacy and motivation to learn science	3.52	0.43	3.65	0.5

	Desktop Condition			
Measures	**Pre-test**		**Post-test**	
	Mean	*SD*	*Mean*	*SD*
Presence	-	-	2.21	0.79
Open-ended questions learning assessment	1.1	0.46	2.54	0.87
Multiple-choice learning assessment	2.24	1.01	4.48	1.26
Concern about OA	3.88	0.78	3.84	0.62
OA seriousness	4.08	0.64	4.56	0.58
Self-efficacy and motivation to learn science	3.2	0.57	3.12	0.71

Figure 1

Percentage of answers about ocean acidification causes at pre- and post-test

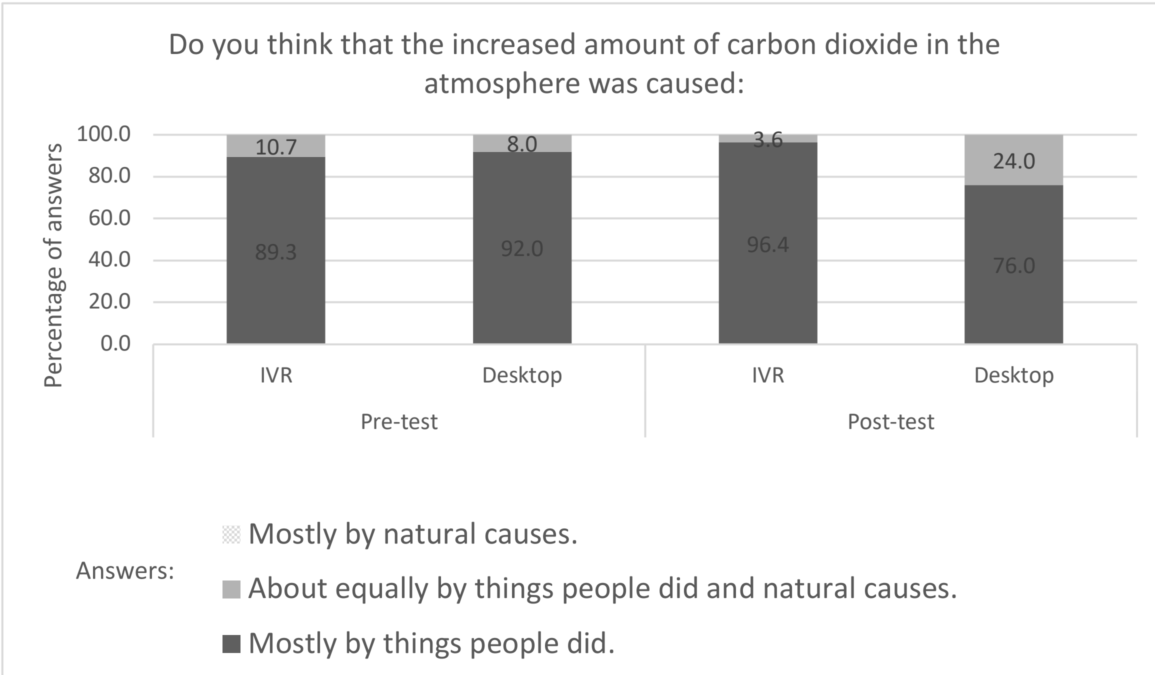


Figure 2

Self-efficacy and motivation to learn science means at pre- and post-test, per condition

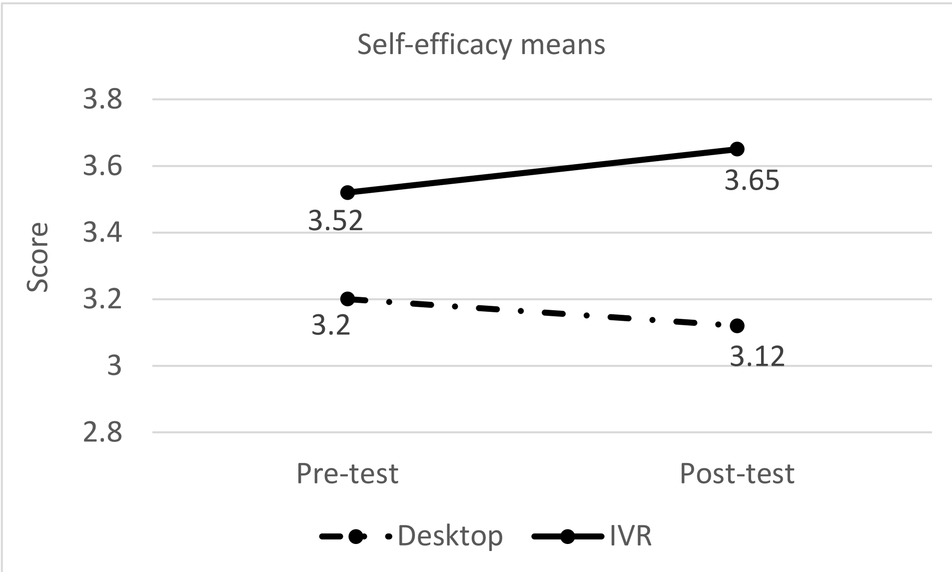


Figure 3

Mediation coefficients of presence as a function of condition on multiple-choice assessment outcome

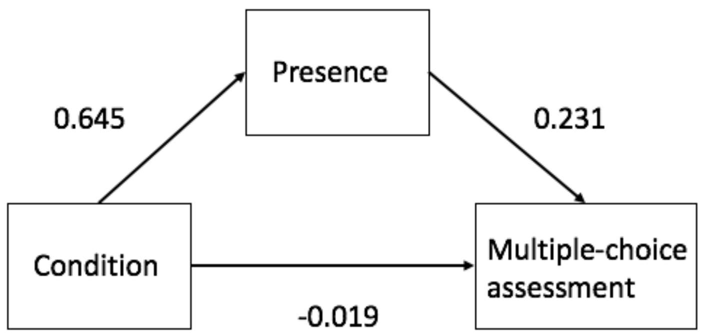
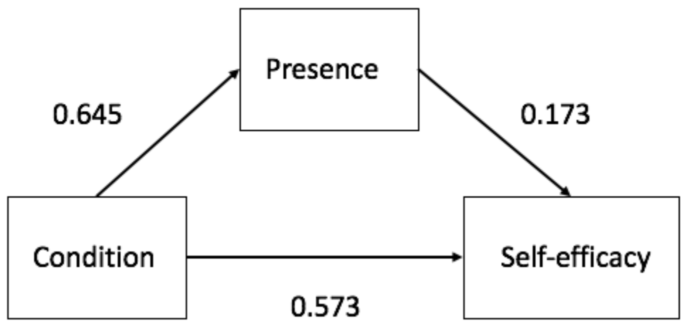


Figure 4

Mediation coefficients of presence as a function of condition on self-efficacy outcome



Appendix 1

Self-efficacy and motivation to learn questionnaire

Participants were asked to express their agreement to each statement below, in a 5-point Likert scale (1= *strongly disagree*, 5 = *strongly agree*):

1. I think that I can be proud of what I know about this subject.
2. I think that learning science is important because I can use it in my daily life.
3. No matter how much effort I put in, I cannot learn science. (-)
4. It is important to have the opportunity to satisfy my own curiosity when learning science.
5. Whether the science content is difficult or easy, I am sure that I can understand it.
6. I am not confident about understanding difficult concepts. (-)
7. I study more than required because I enjoy it so much.
8. When science activities are too difficult, I give up or only do the easy parts. (-)
9. I am willing to participate in this science course because the content is exciting.
10. The subject scares me since I don't fully understand it. (-)
11. I am so happy about the progress I made that I am motivated to continue studying.
12. This subject is so enjoyable that I am motivated to do extra readings about it.