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Fostering science interests through head-mounted displays

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Abstract

Background: Research suggests that head-mounted displays (HMD) can spark situational interest when they are used to provide science learning experiences that are not possible in traditional classroom settings. However, few studies have investigated the lasting effects of using HMDs in an authentic instructional intervention.

Objectives: We investigated the effects of a one-time experience of a virtual field trip to Greenland in a sample of 105 middle school students.

Methods: Students used either a standard 2D video (video condition; N = 50) or an HMD (HMD condition; N = 55) as part of a six-lesson educational activity on the topic of climate change. Informed by social cognitive career theory (SCCT), we investigated the effects of the different conditions (video vs. HMD) on the outcomes of self-efficacy, outcome expectations, interest, and science intentions across three time points.

Results and Conclusions: The results showed that using the HMD-based virtual field trip, compared to the video, had a positive immediate effect on self-efficacy and interest, and total later effects on self-efficacy, outcome expectations, and interest an average of two and a half weeks after the virtual field trip. The results suggest that HMD-based virtual field trips can influence self-efficacy, outcome expectations, and interest more than a video-based virtual field trip when measured approximately two and a half weeks after the intervention.

KEYWORDS
climate change, head-mounted displays, immersive virtual reality, interests, self-efficacy, social cognitive career theory

1 | INTRODUCTION

A shift in teaching policies regarding science learning has focused on engaging students to participate in science as a practice. Thus, in ideal science teaching, the student is not a passive participant absorbing knowledge, but rather actively engaging with teachers and others (Dabney et al., 2013) in practices or partnerships while learning (Furtak & Penuel, 2019; National Research Council, 2011). Providing students with self-directed activities that are engaging and purposeful has been shown to increase interest in science (Blankenburg et al., 2016; Kass & MacDonald, 1999; White & Frederiksen, 1998). Thus, creating curricular activities that promote self-reflection and inquiry into meaningful scientific topics could enhance students' science interests and science intentions (i.e., the educational goals of science disciplines).

However, economic and practical constraints can restrict the scope of such activities (Tobin et al., 2001). One way of increasing the breadth of

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these interventions is by using technology such as immersive virtual reality (IVR; Ba et al., 2019). By using head-mounted displays (HMDs), educators can provide experiences that deal with phenomena that are not easily accessible in a traditional classroom setting (Meyer et al., 2019) to facilitate authentic scientific learning. By using HMDs, students can access a virtual learning environment and explore abstract, dangerous, or inaccessible phenomena in a way that feels realistic (Freina & Ott, 2015). This could include the inner workings of a virus (Jones et al., 2003), the phases of the moon in outer space (Bell & Trundle, 2008), or laboratory safety (Makransky, Andreasen, et al., 2020; Makransky, Petersen, & Klingenberg, 2020).

Recent studies investigating the effects of implementing HMDs in science education show promising results for increasing students' science interest and intentions (e.g., Makransky, Petersen, & Klingenberg, 2020; Petersen et al., 2020). However, several reviews highlight a major limitation in this research field. Namely, that the majority of these studies were based on short-term interventions. Hainey et al. (2016) conducted a systematic literature review of games-based learning in primary education and concluded that there was a lack of longitudinal studies in this area. Similarly, in a review of HMD-based education and training, Jensen and Konradsen (2018) reported that all except one of 21 studies focused on short-term interventions, and Mikropoulos and Natsis (2011) concluded a 10-year review of research on educational virtual environments by calling for more longitudinal evaluations. In a recent meta-review, Radianti et al. (2020) stressed the low maturity level of the field of IVR for educational purposes. This was based, in part, on their finding that most studies described experimental and development work rather than applications of IVR in actual teaching situations. Finally, guidelines in the field of educational technology recommend that virtual environments should be incorporated within a well-designed educational framework that follows a theoretical approach and has specific didactic goals (Barab et al., 2000; Kavanagh et al., 2017). Thus, there is a lack of studies that evaluate the long-term effects of HMD-based learning experiences integrated within well-designed education programs.

The aim of the current study was to investigate the long-term effects of an instructional intervention, which lasted an average of two and a half weeks and featured HMD compared to 2D video presentations, on students' interest in science. In particular, we investigated the effects when middle school students experienced a virtual field trip to Greenland through either 2D video (video condition) or HMD (HMD condition) as the first lesson of a six-lesson educational activity on the topic of climate change. The rationale behind choosing this topic was that its drivers and consequences resided mainly in the domain of science (Bråten et al., 2009; Meehan et al., 2018; Nussbaum et al., 2015). The theoretical framework was based on inquiry-based science learning (IBSL), which encourages students to learn through active engagement in the methods and practice of science (Furtak et al., 2012; McConney et al., 2014; Pedaste et al., 2015), and the social cognitive career theory (SCCT), which posits that learning experiences foster students' personal agency by enhancing their self-efficacy, outcome expectations, and, in turn, their interest and motivation for a given subject (Lent et al., 1994).

1.1 | Theory and background

1.1.1 | Inquiry-based science learning

Inquiry-based science learning (IBSL) is a didactic approach that aspires to mimic an authentic, scientific discovery process by encouraging students to learn through active participation and inquiry, in other words, by engaging in practices that make the student feel like a scientist (Jaber & Hammer, 2016). Studies have shown that IBSL leads to a more positive attitude towards science and more interest in science over time (Gibson & Chase, 2002). A meta-analysis conducted by Furtak et al. (2012) indicated that inquiry-based teaching and learning has an overall mean effect size of 0.50 larger than a control condition using traditional teaching methods. According to Pedaste et al. (2015), an inquiry-based learning framework can consist of five different phases: (a) *orientation*, when students are introduced to the topic in a way that aims to stimulate their curiosity and interest; (b) *conceptualization*, when students generate questions and hypotheses to understand concepts relevant to the topic; (c) *investigation*, when students explore, design experiments, and interpret results; (d) *conclusion*, where students address their original research questions to reach a general conclusion; and (e) *discussion*, where students communicate their findings to others and reflect critically on their inquiry process. In the current study, the six lessons in the educational activity were structured around this framework.

1.1.2 | Social cognitive career theory

Social cognitive career theory (SCCT) is a framework that seeks to explain the processes underlying career choices and behaviours (Lent et al., 1994). As a driver of career motivation and intentions, career-related interests are central to this framework (Lent et al., 2002). According to SCCT, career-related interests develop continuously throughout life, although many broad career interests, such as wanting to work with people or work in science, tend to stabilize by late adolescence or early adulthood (Lent et al., 2002). Therefore, interventions designed to increase interests and intentions in science should be particularly relevant for middle school students.

In SCCT (see Figure 1), learning experiences shape the individual's motivation for a particular topic area or subject. Specifically, learning experiences directly influence *self-efficacy* (SE; path a) and *outcome expectations* (OE; path b). Self-efficacy is understood as students' judgements of their own capabilities (Bandura, 1982; Bryan et al., 2011); outcome expectations refers to students' personal beliefs about probable response outcomes (i.e., the consequences of performing a certain behaviour; Lent et al., 1994). Self-efficacy influences outcome expectations (path c), and both self-efficacy (path d) and outcome expectations (path f) influence the development of interests, which are defined as "preferences to engage in activities, contexts in which activities occur, or outcomes associated with preferred activities that motivate goal-oriented behaviors" (Rounds & Su, 2014 p. 98). Finally, science intentions are affected by self-efficacy (path e),

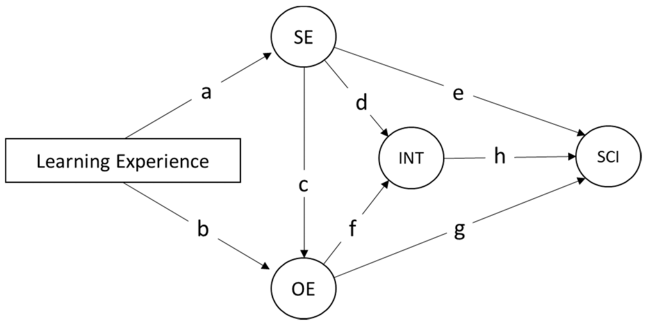

FIGURE 1 SCCT model (adapted from Lent et al., 1994). INT, interest; OE, outcome expectations; SCI, science intentions; SE, self-efficacy

outcome expectations (path g), and interest (path h). Science intentions are defined here as "one's intentions to engage in a particular activity" (e.g., to pursue a given academic major; Lent et al., 2002, p. 750).

In summary, SCCT posits that students are likely to form an enduring interest in activities in which they view themselves to be efficacious and from which they anticipate positive outcomes; and that these factors (SE, OE, and INT) shape their intentions to pursue a particular career (Lent et al., 1994). In this way, positive learning experiences in science influence students' science intentions indirectly through self-efficacy, outcome expectations, and interest. Therefore, in order to enthuse students to pursue science studies, and later a scientific career, it is important to foster their self-efficacy for scientific activities and develop an anticipation that they will do well if they engage in science learning.

1.2 | Immersive virtual reality through HMDs and interest development

SCCT specifies an indirect link between learning experiences (e.g., a learning intervention) and interests. This link is accounted for by learning experiences influencing the development of self-efficacy and outcome expectations (i.e., the underlying explanatory mechanisms), which, in turn, affect the intentions/behaviours enacted. In the following section, we describe how HMD-based learning experiences influence these links.

A number of recent studies that compared the relative effectiveness of different media for promoting educational outcomes emphasized the advantages of HMD-based lessons in developing students' interests. Parong and Mayer (2018) compared the relative effects of administering the same biology lesson in an HMD or as a slideshow on a desktop computer and found that students in the HMD group reported significantly higher ratings of motivation, interest, engagement, and positive affect than students who used the desktop computer. Meyer et al. (2019) compared the effectiveness of HMD versus video in a learning intervention on the topic of cells and found that students who used HMDs reported significantly higher self-efficacy and enjoyment than those who used video. Although Meyer and colleagues did not investigate interest, their findings are still relevant, as self-efficacy influences interest development. Makransky, Petersen, and Klingenberg (2020) also compared the effects of experiencing a science lesson through HMD to experiencing the same lesson via video. Students in the HMD condition reported higher levels of interest, self-efficacy, and physical and social outcome expectations when compared to students in the video condition. The authors suggested that the mechanisms of presence, feedback, agency, and enjoyment potentially accounted for the more favourable outcomes for students in the HMD group.

Immersive lessons accessed through HMDs can lead to a higher psychological presence, understood as the subjective sensation of "being there" (Lee, 2004; Makransky, Terkildsen, & Mayer, 2019). Increased psychological presence is one of the main affordances of learning through IVR instruction (Makransky & Petersen, 2021; Petersen et al., 2022). The experience of presence during a learning session can influence students' degree of self-efficacy, as the strongest source of self-efficacy comes from (personal) mastery experiences (Bandura, 2010; Usher & Pajares, 2006). Thus, students exposed to a virtual field trip via HMD are more likely to develop mastery as they can take a first-person perspective, compared to students who watch a video and thereby have a vicarious experience. Additionally, mastery experiences can influence outcome expectations as students experience the consequences of performing certain behaviours from a first-person perspective. Finally, the experience of presence during a learning session can influence the level of interest, as situational interest is initiated by environmental stimuli that are novel and intense in nature (Harackiewicz et al., 2016; Hidi & Renninger, 2006; Renninger et al., 2008). Thus, a way to trigger students' interest and follow-up intentions/behaviours is to structure learning activities so that they catch their attention.

In the current study, we investigated the direct and indirect effects of a field trip experienced though HMD compared to a video presentation, immediately after exposure and at the end of the full intervention, using the framework of SCCT. Based on the theory and research outlined above, we proposed the following research questions and hypotheses.

1.3 | Research questions

In our research questions, we distinguish between direct, indirect, and total effects. Direct effects refer to the direct impact of one variable on another (e.g., in Figure 1, path b, learning experiences directly affects outcome expectations). Indirect effects refer to the impact of one variable on another that is transmitted, or carried, by a third variable (e.g., in Figure 1, paths a and c, learning experience affects self-efficacy and this change in self-efficacy affects outcome expectations). Last, total effects refer to the total influence of one variable on another, which includes the direct effects plus the effects carried by any third variable (e.g., the total effect of learning experiences on outcome expectations is the sum of the direct effect and all of the indirect effects; in Figure 1, this is path b + path ac).

1.3.1 | Q1: What are the relative effects of the HMD and video virtual field trip experiences when students are assessed immediately after exposure?

According to SCCT, a learning experience will affect self-efficacy, outcome expectations, interest, and science intentions. Based on the IBSL learning approach and SCCT propositions, our first research question, regarding the immediate effects of the field trip exposure, stimulated the following three hypotheses:

The HMD-based virtual field trip, compared to the video presentation, will have a more positive, immediate (i.e., measured immediately after presentation of field trip) direct effect on self-efficacy (Hypothesis 1; path a in Figure 1); have a more positive direct (Hypothesis 2a; path b) and total effect (Hypothesis 2b; direct [path b] plus indirect effect via self-efficacy [path a + c]) on outcome expectations; and have a more positive direct (Hypothesis 3a) and total effect (Hypothesis 3b; direct plus indirect effect via self-efficacy and outcome expectations) on the outcome of interest.

1.3.2 | Q2: What are the relative effects of the HMD and video field trip experiences when students are assessed at the end of the full interventions?

We then evaluated if the long-term effects of the exposures on self-efficacy, outcome expectations, and interests differed between the two conditions at the end of the intervention. The three hypotheses here were:

The HMD field trip-based intervention, compared to the video, will have a more positive, later (i.e., students measured at the end of the intervention) direct (Hypothesis 4a) and total effect (Hypothesis 4b) on post-self-efficacy; have a more positive direct (Hypothesis 5a) and total effect (Hypothesis 5b) on post-outcome expectations; and have a more positive direct (Hypothesis 6a) and total effect (Hypothesis 6b) on the outcome of interest.

Finally, we explored the total indirect effects of the HMD field trip-based intervention, compared to the video, on science intentions measured at mid- and post-point.

2 | METHOD

2.1 | Sample

The sample consisted of 105 students (40 boys and 65 girls) from four different public schools each located in a different region in one European country. The age of the students ranged from 13 to 16 ($M = 14.12$, $SD = 0.68$). The schools were chosen to represent the diversity of the country regarding student demographics, and two teachers from each of the four schools participated in teaching and running the intervention.

2.2 | Procedure

The educational activity was based on a workshop and a follow-up pilot study conducted in collaboration with four educational experts and ten teachers and science educational advisors from five different regions of the country. Thus, it was a multidisciplinary co-creation activity. A manual with detailed descriptions of the six lessons was developed and the educational activity was integrated as part of the science education curricula in the four schools. The educational activity consisted of six lessons of approximately 50 minutes each. Three questionnaires – pre-, mid-, and post-test (see Figure 2 for overview of experimental procedure) – also were included. Teachers, who had participated in the workshop, were provided with the manual and were responsible for conducting all six lessons at their respective schools. In addition, several of the experimenters were present to assist with the random assignment and the HMD/video intervention in Lessons 1 and 2.

The total duration of the full intervention varied slightly across the schools, but ran an average of 18.51 days ($SD = 9.86$), with the specific distribution of lessons dependent on teacher scheduling. All students experienced the same six lessons, with the only difference being the experimental condition, which was either an HMD or a video version of a virtual field trip to Greenland. The students experienced the virtual field trip to Greenland as a one-time event either as a video projected on a screen in the classroom (video condition: $n = 55$, consisting of 22 boys and 33 girls, mean age $= 14.10$, $SD = 0.68$) or as a 360° HMD experience (HMD condition: $n = 50$, consisting of 18 boys and 32 girls, mean age $= 14.15$, $SD = 0.68$). All other factors were kept constant. The students were given a random number that assigned them to one of two experimental conditions. In one school, two classes were assigned to their condition prior to randomization due to a misunderstanding by the teachers, meaning that these students were assigned to condition based on class rather than random assignment.

In Lesson 1, *Introduction and Fake News Article*, students completed the pre-test questionnaire and were assigned to either the video or HMD condition. In each condition, students were further divided into work groups of three or four, where they stayed for the remainder of the interventions' six lessons. The teacher then facilitated a plenary discussion for the whole class around a fake news article, in which the author displayed a strong scepticism about climate change and appeared to be funded by the oil industry.

In the second lesson, *Scientific Method and HMD/Video Intervention*, the teacher presented general principles of the scientific method. Using this acquired knowledge, students then explored the consequences of climate change by participating in the virtual field trip to Greenland. For this, students either stayed in the classroom (video condition) or moved to another classroom (HMD condition). Immediately afterwards, all students completed the mid-test questionnaire.

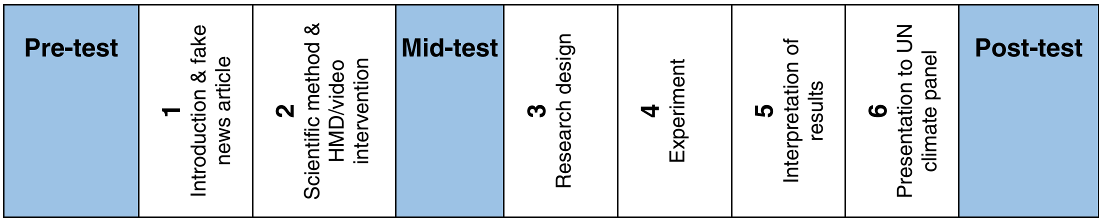

FIGURE 2 IBSL lessons and intervention assessment points

In Lesson 3, *Research Design*, the research groups (of 3 or 4 students) used their acquired knowledge and their observations in Greenland to formulate hypotheses and construct an experimental design that could explain the drivers of climate change. In the fourth lesson, *Experiment*, students conducted their chosen experiment, and interpreted the results in Lesson 5, *Interpretation of Results*. Last, in Lesson 6, *Presentation to UN Climate Panel*, all research groups presented their results to a fictitious climate panel consisting of the teachers and the rest of the class. All lessons except for Lesson 2, *HMD/Video Intervention* were provided for the whole class. The intervention concluded with all students completing the post-test. Both students and their parents agreed to the students participating in the experiment and ethical approval was obtained from the university that was responsible for the research.

2.3 | Materials

2.3.1 | The educational activity

The design of the educational activity was based on IBSL principles. Lesson 1, *Introduction and Fake News Article*, corresponded to the orientation phase, which aimed to stimulate students' curiosity and interest by highlighting the controversy around climate change through a plenary discussion of a fake news article. Lesson 2, *Scientific Method and HMD/Video*, corresponded to the conceptualization and investigation phases. Specifically, media in the form of an HMD or video, which involved students taking a virtual field trip to Greenland to explore and observe the consequences of the changing climate, were central to the investigation phase. In Lesson 3, *Research Design*, students generated hypotheses and constructed an experimental design to explain the drivers of climate change. Thus, Lesson 3 corresponded to the conceptualization and investigation phases. Lesson 4, *Experiment*, and Lesson 5, *Interpretation of Results*, both corresponded to the investigation phase of IBSL, where students conducted their chosen experiment and interpreted the results. Last, Lesson 6, *Presentation to UN Climate Panel*, corresponded to the discussion phase, when all research groups presented their results to a mock climate panel.

The intervention was aimed at enabling middle school students at all achievement levels to engage in the process of scientific inquiry and thereby promote their self-efficacy, outcome expectations, interest, and intentions in the field of science. To instill a sense of autonomy in the students and to ensure that students at all levels could engage in the educational activity, some aspects of the instructional design were left open (e.g., students could choose an experimental design that corresponded to their academic level and teachers could assist to varying degrees). Thus, the educational activity presented scaffolding for creating a middle school scientific research community by combining a detailed manual, teachers' pedagogical expertise, HMD- or video-based learning experiences, and students' active participation in research activities.

2.3.2 | The virtual field trip

The virtual field trip to Greenland was based on a documentary by Dennis and Strauss (2018), called *This is Climate Change: Melting Ice*. The students followed former US Vice President Al Gore on a trip to Greenland to explore the consequences of the changing climate. As a supplement to the virtual field trip, the experimenters had recorded a narration about climate change explaining concepts such as the greenhouse effect and albedo effect. With permission from the creators of the simulation, the narration, which was recorded using professional audio equipment (Yeti from Blue), was merged with the documentary video. All students experienced the same simulation. Those in the HMD condition experienced the virtual field trip as a non-interactive, 360° video administered through Samsung S7 or S8 headphones using Samsung Gear VR HMD; whereas, those in the video condition experienced the field trip projected onto a screen in the classroom.

2.3.3 | Questionnaires

The pre-, mid-, and post-test questionnaires included demographic questions (age, grade, and gender) and scales assessing: (a) self-efficacy (3 items: e.g., "I can easily understand the basic causes of climate change"; Makransky et al., 2016; Pintrich et al., 1991); (b) outcome expectations (3 items: e.g., "With an education in the area of environment, energy, and/or climate, I can do good things for society and mankind"; Makransky, Wandall, et al., 2019; Petersen et al., 2020); (c) interest (4 items, e.g., "I am interested in climate change"; Thisgaard & Makransky, 2017); and (d) science intentions (4 items, e.g., "Following high school, I intend to apply for an education within the natural sciences; e.g., geography, technology, engineering, mathematics"; Thisgaard & Makransky, 2017). All items were answered on a 5-point Likert scale with the following anchors ranging

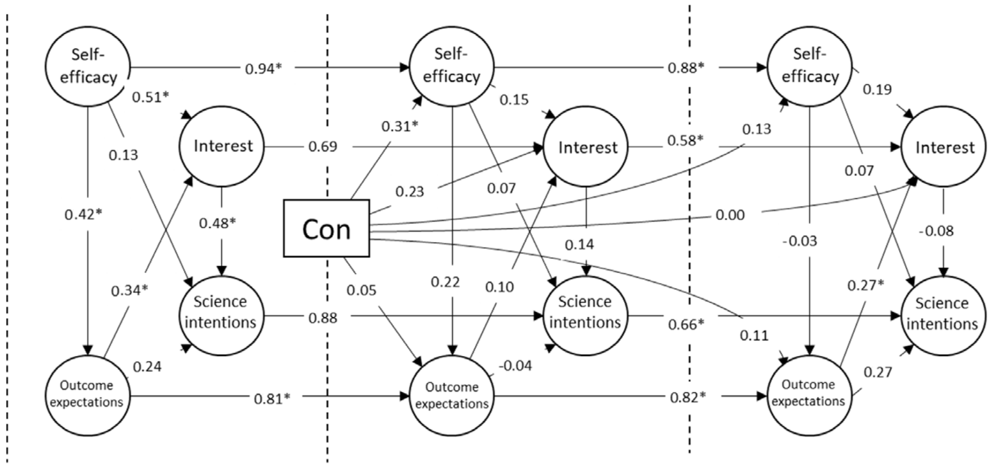

FIGURE 3 Structural equation model. Con, Condition. Individual items omitted from the figure, but included in statistical analysis. $^*p < 0.05$

from 1 = *strongly disagree* to 5 = *strongly agree*. A full list of items is provided in Appendix Table 1 and scale reliabilities for the measures are provided in Appendix Table 2.

To address the research questions, we assessed a model that included the pre-, mid-, and post-test responses (see Figure 3).

2.3.4 | Statistical analyses

We investigated the research questions by using structural equation modelling (SEM; Kline, 2011), which combines the methodologies of path analyses, confirmatory factor analysis, and structural regression. We examined a measurement model and then a structural model that included paths from the intervention to the outcome variable that were defined by the six hypotheses. We examined model fit using five fit indices, including the Chi-square test ($\chi 2$), Comparative Fit Index (CFI), Tucker Lewis Index (TLI), Root Mean Square Error of Approximation (RMSEA), and Standardized Root Mean Square Residual (SRMR). For both CFI and TLI, acceptable fit values are >0.95 (Hu & Bentler, 1999; Kline, 2011); for RMSEA and SRMR, acceptable values are <0.06 and 0.08, respectively (Hu & Bentler, 1999). We conducted all analyses using R statistical programming language (R Core Team, 2021) in the Lavaan package (Rosseel, 2012). Since the items were ordinal, we used the diagonally weighted least square estimation method (Li, 2016).

The strategy for the analyses was to test an SCCT-based model using data from all three time points that included direct paths (i.e., paths going directly from one variable to another) from the IVR intervention to self-efficacy (H1), outcome expectations (H2a), and interest (H3a) at mid-point, and to self-efficacy (H4a), outcome expectations (H5a), and interest (H6a) at post-intervention. Since all variables except self-efficacy at the second measurement point were also influenced by indirect paths (i.e., the impact of one variable on another variable that is transmitted by a third variable; note that there can be multiple indirect paths and more than one intervening variable), we also estimated the total effects (i.e., the sum of the direct path and all indirect paths). To assess the indirect paths (H2b-H6b), we used the bootstrapping procedure (Hayes, 2009), which generates the 95% bias-corrected confidence intervals (CIs; an indirect effect is present when the CIs for the indirect effect do not include zero; Preacher & Hayes, 2008). Last, to evaluate the full effect of the learning experience we also calculated the total effects (i.e., the direct effects plus the indirect effects). In the same manner, we estimated the total indirect effects on science intentions at the second and third measurement points. Since there were no direct effects on science intentions in the model, these consisted of the combined indirect effects only. Informed by SCCC and using SEM, we estimated the direct, indirect, and total effects (direct and indirect effects combined; see Appendix Figure 1 for a visual explanation of direct, indirect, and total effects). We also report the results for several ANCOVAs, as additional analysis.

3 | RESULTS

Preliminary analyses revealed pre-test differences between the experimental and contrast conditions on self-efficacy $t_{(103)} = 3.181$, $p < 0.001$, outcome expectations $t_{(103)} = 1.667$, $p = 0.048$, interest $t_{(103)} = 3.115$, $p = 0.001$, and science intentions $t_{(103)} = 1.755$, $p = 0.041$ (see Table 1). There also was a trend for increasing self-efficacy from pre- to mid-test, $t_{(104)} = 4.484$, $p < 0.001$, and from pre- to post-test, $t_{(104)} = 5.472$, $p < 0.001$; interest from pre- to mid-test, $t_{(104)} = 3.085$, $p = 0.001$, and from pre- to post-test, $t_{(104)} = 1.954$, $p = 0.027$; and science intentions from pre- to mid-test, $t_{(104)} = 2.311$, $p = 0.011$, and from pre- to the post-test, $t_{(104)} = 2.666$, $p = 0.004$. There was no increase in outcome expectations from pre- to mid-test, $t_{(104)} = 0.357$, $p = 0.361$, or from pre- to the post-test, $t_{(104)} = 0.957$, $p = 0.170$. Using ANCOVAs, we found no significant effect for condition on self-efficacy, outcome expectations, or interest at mid-test or post-test. However, as ANCOVAs do not account for indirect or mediated effects, which are central to the current study, we tested our SCCT model using SEM methodology as it allows for measurement models to be assessed and mediation to be tested in the model. In the SEM testing, we included pre-test variables

TABLE 1 Differences in dependent variables across conditions

	Pre-test		Mid-test		Post-test	
	M	*SD*	*M*	*SD*	*M*	*SD*
Self-efficacy video	9.87	2.50	10.53	2.66	9.69	2.37
Self-efficacy HMD	11.18	1.79	11.86	1.73	11.34	1.76
Outcome expectations video	9.62	3.09	9.85	3.12	9.71	3.38
Outcome expectations HMD	10.60	2.89	10.52	3.00	10.98	2.52
Interest video	12.95	4.68	13.71	5.17	13.49	5.38
Interest HMD	15.30	2.70	16.26	3.02	16.14	3.60

as predictors of mid-test target variables (i.e., self-efficacy at pretest predicts self-efficacy at mid-test and so on) to account for differences at pretest between the experimental and contrast conditions in self-efficacy, outcome expectations, and interest.

3.1 | Q1: The relative effects of HMD compared to video when assessed immediately after exposure

The SEM model (see Figure 3) showed acceptable fit for CFI (0.99), TLI (0.99), RMSEA (0.06), and SRMR (0.07). See Supplementary Material 2 for full details of SEM model. The results supported H1 as there was a significant path from the condition (HMD/video) to self-efficacy at mid-point ($\beta = 0.31$, $p = 0.005$, SE $= 0.18$), indicating that the condition (HMD/video) had a significant relationship with self-efficacy once all other relationships in the model had been accounted for. That is, the HMD field trip had a more positive effect on self-efficacy than the video.

There was no support for H2a, as the path from condition to outcome expectations at mid-point was not significant ($\beta = 0.08$, $p = 0.66$, SE $= 0.19$), nor was there support for H2b, that the HMD total effect was related more to outcome expectations than the video condition measured at mid-test (see Table 3). The sum of the total paths from condition to outcome expectations was not significant ($\beta = 0.24$, $p = 0.25$, SE $= 0.17$). Finally, the data did not support H3a, as there was not a significant path from condition to interest at mid-point ($\beta = 0.23$, $p = 0.41$, SE $= 0.28$), indicating that the HMD condition did not directly affect interest. However, the data supported H3b, the total effect from condition to interest was significant ($\beta = 0.28$, $p = 0.01$, SE $= 0.22$) at mid-point.

Thus, H1 and H3b, but not H2a, H2b, or H3a, were supported. From this, we concluded that experiencing the virtual field trip through HMD had a significantly stronger direct effect on self-efficacy than experiencing it as a video. This suggests that experiencing the HMD version of the virtual field trip leads to higher self-efficacy immediately compared to the same experience via video. Furthermore, experiencing the virtual field trip in HMD had a stronger total effect on interest than when it was experienced via video. This suggests that when we accounted for all direct and indirect effects, the HMD experience led to immediate higher interest than the video experience. However, there were no differences between experiencing the virtual field trip through HMD or video on outcome expectations, and no direct effect from condition to interest.

TABLE 2 Parameters and significance level for direct paths from condition to variable

	Estimate	Se	Standardized	*p*
SE Mid	0.50**	0.18	0.31	0.005
OE Mid	0.09	0.19	0.05	0.656
INT Mid	0.44	0.28	0.23	0.114
SE Post	0.22	0.15	0.13	0.149
OE Post	0.00	0.18	0.00	0.344
INT Post	0.21	0.22	0.11	0.990

Abbreviations: INT, interest; Mid, Measured at mid-test; OE, outcome expectancies; Post, measured at post-test; SE, self-efficacy; Se, standardized error.
**$p < 0.01$.

3.2 | Q2: Relative effects of HMD and video experiences at the end of the intervention

The results did not support H4a, as the path from condition (HMD/video) to self-efficacy post-intervention was not significant ($\beta = 0.13$, $p = 0.15$, SE $= 0.18$), indicating that HMD was not more strongly related directly to self-efficacy than the video condition when measured after taking part in all six lessons (see Table 2). The data did support H4b; that is, the total effect from condition to self-efficacy after the intervention was significant ($\beta = 0.40$, $p < 0.001$, SE $= 0.17$; see Table 3). Also, the results did not support H5a, as the direct path from condition to outcome expectations was not significant ($\beta = 0.11$, $p = 0.34$, SE $= 0.22$). However, the results supported H5b, that the total effect of condition on outcome expectations after the intervention was significant ($\beta = 0.20$, $p = 0.04$, SE $= 0.18$). Finally, there was no support for H6a, the direct path from condition to interest was not significant ($\beta = 0.01$, $p = 0.99$, SE $= 0.18$), but the results supported H6b, that the total effect of condition on interest after the intervention was significant ($\beta = 0.29$, p < 0.01, SE $= 0.19$, see Table 3).

In summary, these results did not support the direct effect hypotheses of H4a, H5a, H6a, but there was support for all total effects hypotheses of H4b, H5b, and H6b. We concluded that the HMD virtual field trip had a significant positive total effect on self-

TABLE 3 Parameters and significance level for Total effects from condition to variable

	Estimate	Se	B	p
OE Mid	0.20	0.17	0.24	0.249
INT Mid	0.55*	0.22	0.28	0.011
SE Post	0.69***	0.17	0.40	<0.001
OE Post	0.37*	0.18	0.20	0.039
INT Post	0.59**	0.19	0.29	0.002
SCI Mid	0.10	0.17	0.06	0.559
SCI Post	0.19	0.23	0.10	0.407

Abbreviations: INT, interest; mid, measured at mid-test; OE, outcome expectancies; Post, measured at post-test; SCI, science intentions; SE, self-efficacy; Se, standardized error.
*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

efficacy, outcome expectations, and interest compared to the video-based field trip when measured at the end of the intervention. This suggests that when we accounted for both direct and indirect effects over time, HMD was more effective than video for increasing self-efficacy, outcome expectations, and interest.

Apart from assessing the total effects, we also estimated the total indirect effects on science intentions measured at both mid- and post-point. However, the total indirect effects of condition on mid- ($\beta = 0.06$ $p = 0.56$, SE $= 0.17$) and post-science intentions ($\beta = 0.10$, $p = 0.41$, SE $= 0.23$) were not significant. Thus, examining the direct effects of the HMD condition, we found it affected self-efficacy measured at mid-test, supporting one out of our six hypotheses. However, when we accounted for the total effects (i.e., direct plus indirect effects), we found a significant effect for self-efficacy and interest measured at mid-test, as well as a significant effect on self-efficacy, outcome expectations, and interest measured at post-test, supporting five out of our six hypotheses.

4 | DISCUSSION

4.1 | Empirical contributions

The first contributions of this study were that the direct path from condition (HMD/video) to self-efficacy (H1) at mid-test, and the total effect from condition to interest at mid-test, were significant (H3b). Contrary to expectations, the direct and total effects of condition on outcome expectations at mid-test (H2a, b), and the direct path from condition to interest at mid-test (H3a), were not significant. This indicated that those experiencing the virtual field trip through HMD increased their self-efficacy and interest significantly more than those who experienced it through the video, when accounting for both direct and indirect paths. This finding is consistent with previous research that found that more immersive lessons led to higher levels of self-efficacy (Baceviciute et al., 2021; Makransky, Andreasen, et al., 2020; Makransky, Borre-Gude, & Mayer, 2019; Makransky & Lilleholt, 2018; Makransky, Petersen, & Klingenberg, 2020; Meyer et al., 2019) and interest (Makransky, Petersen, & Klingenberg, 2020; Parong & Mayer, 2018) than less immersive media.

What is novel about this study is the use of a longitudinal experimental design investigating the effect of different media, HMD versus video, within an educational intervention. The finding that the condition had a significant total effect on self-efficacy (H4b), outcome expectations (H5b), and interest (H6b) is a major empirical contribution, indicating that experiencing the virtual field trip though HMD can have positive carry-over effects on self-efficacy, outcome expectations, and interest compared to experiencing the virtual field trip as a video. However, the direct effects of condition on self-efficacy (H4a), outcome expectations (H5a), and interest (H6a) were not significant. This means that by including the theoretically-driven intervening explanatory mechanisms of self-efficacy and outcome expectations, we were able to identify the value of the HMD-based presentation, which led to higher levels of self-efficacy and outcome expectations, which, in turn, were related to stronger interests.

The results suggest that the immersive virtual field trip to Greenland, in the framework of an IBSL climate change intervention, was more effective than the video field trip to Greenland in terms of self-efficacy and interest, both immediately after the experience and at the end of the intervention, and for outcome expectations at the end of the intervention. The longitudinal finding represents an important contribution to the growing literature that has investigated IVR in climate change education (e.g., Fauville, Queiroz, & Bailenson, 2020; Fauville, Queiroz, Hambrick, et al., 2020; Markowitz et al., 2018; Petersen et al., 2020) as it suggests that these effects are observable over a longer period of time and occur after controlling for initial levels of the constructs of interest. The result is consistent with social learning theory (Bandura, 1982), which proposes that the best way to develop self-efficacy is through mastery experiences. As the added immersion in HMD potentially leads to more psychological presence (Makransky & Petersen, 2021), it is reasonable to conclude that students perceived their experiences as tangible rather than hypothetical, which can facilitate experiential learning (Dalgarno & Lee, 2010) and increase self-efficacy and ultimately interest.

4.2 | Practical implications

Our results suggest that an HMD-based virtual field trip embedded within the exploration phase of an IBSL intervention can lead to increased self-efficacy, outcome expectancies, and interest in relation to science, compared to experiencing the same virtual field trip through a 2D video. The implications of these findings are that middle school students might benefit from immersive learning experiences in this phase of an IBSL intervention. However, no differences were found for outcome expectations measured at mid-point. One possible explanation for this is that students in the virtual field trip did not specifically encounter a virtual mentor who they could relate to easily. Therefore, a practical implication is that future interventions should use specifically designed virtual field trips that engage students by having them interact with relatable role models in the virtual environment who can model successful outcomes for them. This is relevant because a major barrier for IVR adoption is the lack of available high quality content (Glegg & Levac, 2018; Laurell et al., 2019). This was apparent in preparing for the design workshop for this study where it was difficult to find relevant and affordable scientific content for HMDs, and a tailored solution needed to be developed. Other barriers are related to teacher and student acceptance of the technology, which can also include demographic factors (e.g., gender; Falk & Needham, 2013; Voyles et al., 2008). Finally, a potential barrier influencing HMD-based lessons is the availability and cost of HMDs. Although this remains a barrier for many teachers, recent reports highlight the rapid increase in use of HMDs, where the number of regular VR users in the U.S. increased from 30.6 million to 45.3 million from 2018 to 2019, and was projected to reach 55.3 million in 2020 (Artillery Intelligence, 2020), suggesting that more students and teachers will have access to the technology in the future.

4.3 | Limitations and future research

According to SCCT, a learning experience is also influenced by external factors, such as predisposition, gender, race-ethnicity, disability, health status, as well as other contextual affordances (Lent et al., 2002). These factors were not included in the current study and future research might address these as they replicate this study in different samples and lessons in other subject matter. Many factors can influence the outcomes of experiments in real educational environments over time, and future research is needed to investigate the generalizability of these results and the potential boundary conditions when using HMDs in science education. Furthermore, recent developments in the field point to several affective and cognitive factors relevant for the process of learning with immersive technology, which were not included in this study (e.g., cognitive load; Makransky & Petersen, 2021).

A further weakness of the study was the difference between the experimental and contrast conditions at pretest. While true randomization is difficult to achieve in field experiments (Eden, 2017), future studies should attempt to achieve closer approximations of this. We dealt with pre-test differences by controlling for them statistically when testing our SCCT SEM model, but having more closely matched conditions would strengthen our results. Related to this, it was not possible to conduct the study in a blinded manner, as all students, regardless of condition, participated in lessons 3–6. Thus, teachers in the study were aware of the pupils' experienced condition, which might have unintentionally influenced the results. Pupils also spent limited time using the HMDs. If learning with immersive technologies is to become an everyday experience assessing the exposure effect will be important. Thus, future studies might explore the effects of longer experience with HMD and investigate the consequences of using several HMD exposures within different lessons in an intervention and include measures of learning.

5 | CONCLUSION

We used a field experiment to investigate the consequences of administering a virtual field trip within the investigation phase of a six-lesson, IBSL, climate change intervention in middle school using either HMD or a video. The results suggested that the HMD-based virtual field trip led to higher levels of self-efficacy and interest than a video, measured both immediately after the field trip and at the end of the intervention (∼two and a half weeks after the virtual field trip), when accounting for both direct and indirect effects. The results also suggested that the condition had a total effect on outcome expectations when measured at the end of the intervention; that is, when accounting for all indirect paths as well as the direct path, the result suggested that the HMD condition led to higher levels of outcome expectations. These results have important practical implications, as they suggest that immersive lessons that facilitate mastery experiences can have positive longitudinal consequences for self-efficacy and interest beyond any immediate effects. When students find interest and enjoyment in the material they will engage more deeply in the learning material (cf. interest theories; Dewey, 1913; Renninger & Hidi, 2016). The results did not support direct effects for media on outcome expectations or science intentions, suggesting that the virtual field trip did not directly influence these outcomes. As the results did not support direct effects for media on outcome expectations or science intentions, suggesting that the virtual field trip did not directly influence these outcomes. Finally, the results also provide partial support for the relationships outlined in the SCCT, suggesting that this is a meaningful framework for understanding how immersive learning experiences can influence interest and science intentions.

PEER REVIEW

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DATA AVAILABILITY STATEMENT

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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