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The Effects of Virtual Reality News on Learning about Climate Change

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ABSTRACT

Promoting public knowledge about climate is important for garnering support for climate-change policy, and researchers have begun to study the effectiveness of new technologies as learning tools. News organizations are increasingly producing immersive journalism, including virtual reality (VR) and augmented reality (AR), and this study tests whether VR news can be an effective tool for learning about climate change. Based on results from a controlled, in-person laboratory experiment comparing an immersive VR news story to 360°-video and text-with-images versions, we find no main effects on the learning outcomes. However, we do find indirect effects on cognitive elaboration, which are conditional on preexisting knowledge about climate change. Results are discussed in light of their implications for theory about learning in multimedia environments, as well as their implications for the science of science communication.

Scientific issues such as climate change are at the forefront of politics and policy making in democratic societies around the world, and particularly in the United States, where public opinion about climate change is divided, and climate denial has become a full-blown political stance for one of the two major parties (Funk & Kennedy, 2020). In this context, increasing knowledge about climate change and other scientific issues is important

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for garnering public support for climate policy. While knowledge itself is likely not sufficient to garner such support, it is critical to the formation of attitudes and perceptions that are related to policy support (Simis et al., 2016; Sturgis & Allum, 2004), and learning is therefore an important part of promoting public engagement with scientific issues (Xenos, 2017).

Scholars have investigated virtual reality technologies as potential learning tools, both in educational settings (Herrington et al., 2007; Parong & Mayer, 2018) and in the context of news and public affairs information (Shin & Biocca, 2018; Sundar et al., 2017). News organizations such as CNN and the *New York Times* are investing in and producing immersive journalism, including virtual reality (VR), augmented reality (AR), and 360° video. These immersive technologies afford users a first-person experience with the news (Jones, 2017; De la Peña et al., 2010), and scholars have theorized that this kind of experience could have important effects on learning about public affairs issues (e.g., Sundar et al., 2017).

Yet, prevailing theory on learning in immersive VR environments suggests that the technology may inhibit learning if it overloads its users with extraneous information (Mayer, 2005; Parong & Mayer, 2018), and, therefore, learning is more likely where the cognitive load—that is, "the cognitive processing capacity needed to handle [. . .] information" (Sweller, 1988, p. 261)—required to process VR content is reduced. But most of this research examines learning from detailed and complex educational modules. In contrast, news stories are communicated at a basic level, designed to engage a broad array of people (Chaffee & Frank, 1996). Thus, news requires less cognitive processing than educational modules, and VR news may therefore prove effective for learning when compared to other news-delivery formats.

This study tests the learning effects of immersive VR news about climate change. Using a real VR news story featured on CNN's app for Oculus devices, we compare the immersive virtual reality format to both 360° video and an adapted text-with-images story in a controlled, in-person laboratory experiment. Results are discussed in light of their implications for theory about learning in multimedia environments, as well as for the use of VR news as a tool to educate the public about scientific issues such as climate change.

Public engagement with climate change

The traditional "deficit model" of science communication (e.g., Miller, 1983) assumes that a lack of knowledge is the primary cause for a lack of support for various policy initiatives surrounding scientific issues such as climate change (Simis et al., 2016). But recent scholarship has found that engendering public support for policies is more complex than this model assumes. For example, research has shown that support for nanotechnology is unrelated to knowledge, but rather more closely related to partisanship (Yeo et al., 2015) or risk perceptions (Brossard et al., 2009). Based on studies such as these, some scholars have criticized the traditional deficit model for being overly simplistic (Simis et al., 2016; Sturgis & Allum, 2004), and others have forwarded alternative models that emphasize public engagement in social networks in which experts and peers can interact (Akin & Scheufele, 2017; Nisbet & Scheufele, 2009).

But while there is consensus for the need to move beyond the deficit model of science communication, understanding how to reduce knowledge gaps about scientific issues remains a primary goal, and there is increasing recognition that learning can occur in a variety of online environments (Xenos, 2017). This observation fits with recent calls by science communication researchers to move "beyond the choir" to reach different segments of the public (Scheufele, 2018), and it raises the question of whether immersive VR can be used to increase scientific knowledge in new segments of the public. In particular, news apps, such as CNNVR or the New York Time's "Immersive," are increasingly available on VR devices (Jones, 2017; De la Peña et al., 2010), and prior research has demonstrated that VR news has some promise as tool for engaging the public (Shin & Biocca, 2018; Sundar et al., 2017), and therefore it also has the potential to close knowledge gaps about scientific issues, including climate change.

Theoretical approach

This paper draws on the cognitive theory of multimedia learning (CTML), which is interested in increasing learning in multimedia environments (Mayer, 2005), to make predictions about the learning effects of virtual reality news. Building on cognitive load theory (Sweller, 2011), the CTML assumes that certain elements of multimedia environments can create cognitive overload, which occurs when an individual's capacity to process information is lower than the threshold required by the information and/or its delivery format, thus inhibiting rather than enhancing learning (Meyer et al., 2019). Previous research has identified two forms of cognitive load: intrinsic, which is related to the nature of the materials to be learned, and extraneous, which is associated with the presentation of the material (Sweller, 2011). These different kinds of cognitive load are cumulative (Mayer, 2005; Meyer et al., 2019), and therefore high levels of each kind of load can create cognitive overload and inhibit learning.

Some scholars have asserted that immersive technologies generate a "believable space" for users (Greenhalgh, 2002), which potentially enables users to create lasting connections between immersive and real-world experiences (Bian et al., 2016; Suh & Prophet, 2018), and consistent with this assertion, some studies have found that VR may increase learning (Herrington et al., 2007; Sundar et al., 2017). However, other studies have found it to be less effective than other media modalities because immersive VR increases the amount of extraneous processing required, resulting information overload (e.g., Makransky et al., 2020; Makransky & Petersen, 2019; Makransky et al., 2019b; Meyer et al., 2019; Parong & Mayer, 2018). For example, several studies have compared the learning outcomes of reading from a slideshow, watching a video, desktop VR (i.e., 360° video), and immersive VR. These studies find that participants had worse learning outcomes in posttests than the participants who used less immersive technologies (Makransky et al., 2020; Meyer et al., 2019; Parong & Mayer, 2018), because of the greater cognitive load required to process the extraneous stimuli in immersive formats. The effects of this extraneous stimulation on active learning may be lessened by increasing the immediacy of control the user has over the stimuli (Lee et al., 2010), giving users the ability to reduce extraneous processing, or by pre-training participants (Meyer et al., 2019), reducing the intrinsic processing required to learn.

Applications to virtual reality news

Most studies on learning in immersive media environments have focused on educational modules about complex scientific subjects, such as cell anatomy (Meyer et al., 2019; Parong & Mayer, 2018), forensic DNA collection (Makransky et al., 2020), and genetics (Makransky & Petersen, 2019). These kinds of modules require a high amount of intrinsic processing—careful attention to detail is necessary to comprehend the materials. In contrast, the present study utilizes a news story produced for a general audience. Compared to science learning modules, news stories should present lower levels of intrinsic cognitive load, requiring lower levels of detailed cognitive processing and making it more likely that individuals learn from news.

Journalists write news stories at a more basic level so a general audience can understand them without prior knowledge of events or issues. Prior research suggests media use is related to attention, elaboration, and knowledge in political learning (Lo & Chang, 2006). In particular, research shows that television news use improves learning outcomes, especially for young adults (Chaffee & Frank, 1996; Lo & Chang, 2006), in part because it is a rich medium allowing for more vivid and affective connections to the learning process (Chaffee & Frank, 1996). Likewise, VR and 360°-video technologies are also rich media that allow for vivid and affective connections to the content, enhancing their potential as tools for learning. Therefore, even while this study does not directly test whether VR news produces cognitive overload, we base our first hypothesis on the idea that news presented in an immersive virtual reality format will not create cognitive overload in comparison to news presented in other formats, and therefore we expect to find significant learning effects of VR news across several learning outcomes to account for both recall and *depth* of learning (Makransky et al., 2019a).

H1: Subjects in the virtual reality condition will score higher than subjects in the 360° video and text-with-images conditions on **(a)** free recall, **(b)** cued recall, and **(c)** cognitive elaboration.

Cognitive and affective pathways to learning

Research on learning from immersive technologies has been slanted toward the study of cognition (Picard et al., 2004). Yet, recent research has taken a more nuanced approach by delineating an affective pathway to VR learning that is reliant in part upon the concept of presence to go along with the cognitive path which revolves around understanding and application (Makransky & Petersen, 2019). Makransky and Lilleholt (2018) identified a distinct affective pathway where VR immersion was found to be related to learning outcomes indirectly through increased presence, as well as a cognitive mechanism where immersion was associated with learning through cognitive benefits, such as improved understanding and perception. Therefore, in the current study we consider both cognitive and affective pathways to learning, including via presence, flow, and cognitive absorption.

Presence

The concept of presence has been theorized and operationalized to include elements of interaction, "being there," and realism (e.g., Brautović et al., 2017; Kim & Biocca, 1997; Sheridan, 1992; Shin & Biocca, 2018). Lee (2004) defined presence as a mental state in which virtual objects are experienced as real. While some level of "presence" may be experienced from a variety of media formats (Kim & Biocca, 1997), immersive technologies have a unique ability to create this physical and spatial perception for its users (Ke et al., 2016).

Immersive VR promotes a greater sense of presence in users than normal video, including both immersive journalism videos (Shin & Biocca, 2018; Sundar et al., 2017) and nature videos that feature scientific and/or environmental issues (Breves & Heber, 2020; Filter et al., 2020). But while experimental participants tend to report greater enjoyment and more "fun" as a result of increased presence under conditions of VR immersion (e.g., Diemer et al., 2015; Lee et al., 2010; Parong & Mayer, 2018), they do not learn more from these experiences, enjoyable though they may be (Makransky et al., 2020). In particular, high-immersion VR results in higher presence than the low-immersion set, but participants tend to learn less in comparison (Makransky et al., 2019b). That said, some studies have observed that higher presence and enjoyment can increase motivation of users to stick with the material (Parong & Mayer, 2018), in some cases leading to better learning outcomes (Lee et al., 2010; Sundar et al., 2017). Research has also found that presence plays a mediating role leading to learning when taking into account other variables such as intrinsic motivation and self-efficacy (Makransky & Lilleholt, 2018; Makransky & Petersen, 2019). Perhaps for this reason, some research on VR news has documented significant effects of presence on indicators of learning, such as story recall (Sundar et al., 2017). Therefore, we expect to find that VR will produce higher levels of presence, and that presence will mediate the effects of VR on indicators of learning.

H2: Subjects in the virtual reality condition will score higher in presence than subjects in the 360° video and text-with-images conditions.

H3: Presence will mediate the positive effects of virtual reality news on **(a)** free recall, **(b)** cued recall, and **(c)** cognitive elaboration.

Flow

In addition to presence, immersive media also increase flow for many users (Brautović et al., 2017; Hsu, 2017), and users in a flow state have been shown to be more interested in learning (Bachen et al., 2016; Bodzin et al., 2021). While presence refers to affective immersion through a technological medium, flow refers to cognitive immersion in an activity via deep concentration (Csikszentmihalyi, 2014; Shin, 2018). These mental states co-occur: as presence increases, users are more likely to enter a flow state (e.g., Shin, 2018). In a flow state, users' experiences heightened attention (Chang et al., 2014; Csikszentmihalyi, 2014) and interest in learning (Bachen et al., 2016; Bodzin et al., 2021), which is perhaps why some research shows that flow and learning are interrelated (Chang et al., 2014; Guo & Ro, 2008; Van Schaik et al., 2012). Additionally, Hsu (2017) suggests that this learning enhancement occurs because flow makes it easier for people to process difficult task-based information (Van Schaik et al., 2012) or large amounts of information (Hsu, 2017). Therefore, we hypothesize that:

H4: Subjects in the virtual reality condition will score higher in flow than subjects in the 360° video and text-with-images conditions.

H5: Flow will mediate the effects of virtual reality news on **(a)** free recall, **(b)** cued recall, and **(c)** cognitive elaboration.

Cognitive absorption

Different from presence or flow, cognitive absorption refers to the engagement with and involvement in learning experiences (Agarwal & Karahanna, 2000; Kurt & Emiroğlu, 2018), rather than sensory experiences with technology or deep concentration on an activity. Because immersive media blur the boundary between the virtual and real environments, Csikszentmihalyi (1996) considered cognitive absorption to be an important aspect in the immersive learning experience, as it is the point at which nothing matters besides the experience itself. Previous studies show that cognitive absorption increases learning because it amplifies inquisitiveness (Konradt & Sulz, 2001; Kurt & Emiroğlu, 2018) and attention to information (Magni et al., 2013). Several recent studies found the cognitive process and absorption of information are essential to predicting perceived learning outcomes from VR simulations (Makransky et al., 2019a; Makransky & Lilleholt, 2018). Based on this prior research, we hypothesize that:

H6: Subjects in the virtual reality condition will score higher in cognitive absorption than subjects in the 360° video and text-with-images conditions.

H7: Cognitive absorption will mediate the effects of virtual reality news on **(a)** free recall, **(b)** cued recall, and **(c)** cognitive elaboration.

Preexisting knowledge as a moderator

Preexisting knowledge about a particular concept or topic can help to lessen cognitive load even in interactive environments, as this knowledge is integrated into developed schemas (Meyer et al., 2019). Therefore, an additional factor to consider is the idea of pre-training learners on a concept or topic before VR immersion (Mayer & Pilegard, 2005). Prior research suggests that receiving training before engaging in a virtual task can improve performance (Bertram et al., 2015). Used in this manner, pre-training assists in overcoming limitations in cognitive processing of rapid presentation of stimuli, as it develops preexisting knowledge about the concepts in the message (Mayer & Pilegard, 2005). With the increased cognitive load produced by the immersive VR environment, pre-training can therefore be an essential component of VR learning interventions (Meyer et al., 2019).

Again noting the caveat that the present study does not observe cognitive load directly, these insights suggest that individuals with higher levels of preexisting knowledge about climate change should learn more from immersive VR. This logic implies conditional indirect effects— the indirect learning effects of virtual reality news via presence, flow, and cognitive absorption will be conditional on an individual's preexisting knowledge, such that the indirect effects will be stronger among those who know more going into the study. Therefore, we expect to find:

H8: The indirect effects of virtual reality news on free recall via **(a)** presence, **(b)** flow,and **(c)** cognitive absorption will be stronger among subjects with higher levels of preexisting knowledge about climate change.

H9: The indirect effects of virtual reality news on cued recall via **(a)** presence, **(b)** flow, and **(c)** cognitive absorption will be stronger among subjects with higher levels of preexisting knowledge about climate change.

H10: The indirect effects of virtual reality news on cognitive elaboration via **(a)** presence, **(b)** flow, and **(c)** cognitive absorption will be stronger among subjects with higher levels of preexisting knowledge about climate change.

Methods

Experimental design and procedure

Following the example of Sundar et al. (2017), the experimental design is a pre/posttest design with three conditions: virtual reality (VR), 360° video (360°), and text-with-images (TWI). The experiment was conducted in person in a university laboratory space using a double-blind procedure, relying on three blind research assistants to administer the study. The study ran from May 21-December 6, 2019.[1] Subjects first completed an informed consent form and a short pretest questionnaire measuring their preexisting knowledge about climate change. They were then randomly assigned to one of the three conditions. Subjects in the VR condition were exposed to a news story about climate change in the CNNVR app on an Oculus Rift headset powered by a gaming laptop computer. Subjects in the 360° condition viewed the same story in 360°-video format on CNN's website using a desktop computer. Subjects in the TWI condition viewed the same story,

[1]The study was approved by the Institutional Review Board at the University of Alabama (#19-OR-125) on May 8, 2019.

adapted by the study team to text-with-images format, in a web browser on a second desktop computer. After viewing the story, subjects completed a paper-and-pencil posttest questionnaire. They were then debriefed and thanked for their participation. A detailed description of the experimental procedure can be found in the online supplement (Appendix A).

Participants

Subjects were communication students at a major university in the Southeastern United States. They were recruited via the university's online study recruitment platform, which described the study as "an experiment about climate change." Subjects were offered extra credit for their participation. In all, 134 subjects participated in the study, but one dropped out of the study due to dizziness and/or disorientation. This left 133 participants for analysis, with 41 subjects in the VR condition, 46 in the 360° condition, and 46 in the TWI condition.[2]

Stimulus materials

The stimulus was a real CNN story about the effects of climate change in Greenland entitled "Global Warming: Artic Melt." This particular story was selected because of (a) its topical focus, (b) its inclusion of discrete facts about climate change that could be included in recall tests, and (c) its adaptability to text format. The story is available in the CNNVR app for Oculus Rift, and online in 360°-video format at https://www.cnn.com/2017/11/29/vr/climate-change-greenland-arctic-vr/index.html. The story was adapted by the study team to a text-with-images format, which is included in the online supplement (Appendix B). The images are screenshots from the 360°-video story that were chosen based on their representativeness of the story. The text story was based on a transcript of the 360°-video version, with some minor changes made to fit with the conventions of text-based journalism.

Measures

Dependent variables

Three indicators of learning were measured in the posttest: *free recall, cued recall*, and *cognitive elaboration*. Question wording, measurement scales, reliability, and descriptive statistics are reported in the online supplement (Appendix C).

[2]Data supporting the analyses are available at http://dx.doi.org/10.17632/sk9hmp4mxx.1.

Following Sundar et al.'s (2017) example, the free recall question asks subjects to list up to five facts from the story. For each of the five items, three trained coders assessed whether the fact listed was in the story or not in the story. The team counted only accurate factoids included in the story, and discounted inaccurate factoids or factoids not included in the story. Intercoder reliability was assessed at the item level for each of the five binary items. Once acceptable reliability was obtained for all items, an index was created by summing correct responses.

Also based on Sundar et al.'s (2017) example, the cued recall question asked subjects to complete five phrases that appeared in the story. The first word in the phrase was provided for them, and they were asked to provide the remainder of the phrase. Three trained coders assessed whether each response was correct or incorrect based on information in the story. Intercoder reliability was obtained for each of these five binary items. After obtaining intercoder reliability for all items, an index was created by tallying correct responses.

Cognitive elaboration was measured using the thought-listing method (e.g., Petty et al., 1981). Subjects were provided with eight text boxes in which to list their thoughts about the story. Three trained coders recorded whether each response contained a relevant thought. Coders counted answers relevant to climate change, and discounted answers relating to the production value of the story, which were common. Intercoder reliability was assessed for each of the eight items. Once intercoder reliability was obtained for all items, the relevant responses were tallied.

Mediator variables

The mediator variables—*presence, flow*, and *cognitive absorption*—are based on prior literature (Brautović et al., 2017) and were measured in the posttest. Presence was measured with five questionnaire items on a 5-point scale, which were averaged for each respondent. Flow was measured with seven items on a similar scale, which were also averaged for each respondent. Cognitive absorption was measured with eight items on the same scale, which were likewise averaged for each respondent.

Moderator variable

Climate change knowledge was measured in the pretest. Five items taken from an online quiz on the U.S. Department of Energy website (https://www.energy.gov/articles/quiz-test-your-climate-change-iq). Correct responses were summed to create an index.

Covariates

Two covariates were included, *virtual reality use* and *climate change attitudes*, and both were measured in the pretest. The virtual reality use items were adapted from survey questions measuring social media news use (Gil de Zúñiga et al., 2012), and it relied on six items measured on 7-point scales, which were averaged for each respondent. Research suggests that attitudes and knowledge may be interrelated (Sturgis & Allum, 2004), and our measure of climate change attitudes was based on prior literature (Corner et al., 2012). It comprises four items measured on 5-point scales, which were then averaged for each respondent.

Analysis and results

Our expectations about the direct, indirect, and conditional indirect effects of the experimental treatment on the mediators (presence, flow, and cognitive absorption) and learning outcomes (cued recall, free recall, and cognitive elaboration) are illustrated in Figure 1.

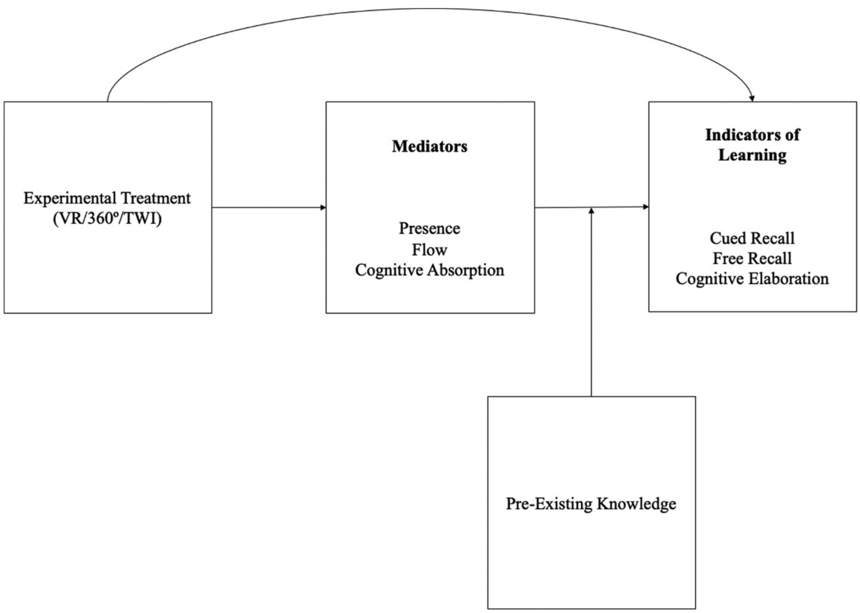

Figure 1. Conceptual model illustrating expected relationships among the experimental treatment, mediators, and learning outcomes.

Manipulation checks were performed before testing main effects and mediation models. Most (87%) subjects[3] correctly identified the medium through which they viewed the story (VR, 360°, TWI), and 90% of subjects correctly identified the news source (CNN). As a final check, subjects were asked "How immersive do you feel the story was?" (1 = Not very immersive, 5 = Very immersive). Subjects in the VR condition rated the story as the most immersive *(M* = 4.57), followed by subjects in the 360° condition *(M* = 3.98), and then subjects in the TWI condition *(M* = 3.46). All of these means are significantly different from one another (alpha = .95) according to Tukey post-hoc tests (omnibus F (2, 135) = 25.64, p < .001).

Main effects on learning outcomes (Table 1) were tested in a one-way MANCOVA, including the same covariates and accounting for correlated outcomes. No main effects are observed for the learning outcomes. Subjects in the VR condition scored the lowest on free recall *(M* = 2.87) and the second lowest on cued recall *(M* = 3.32). By contrast, they scored highest on cognitive elaboration *(M* = 5.29). Subjects in the TWI condition, meanwhile, scored the highest on the recall outcomes *(M* = 3.39; *M* = 3.63) and the second lowest on elaboration *(M* = 4.16). However, none of the omnibus tests are statistically significant (free recall: F (2, 127) = 1.24, p = .29; cued recall: F (2, 127) = 1.09, p = .34; cognitive elaboration: F (2, 127) = 2.08, p = .13). These results show no direct effects of VR on learning about climate change, and do not support H1.

Main effects on the mediators (Table 2) were tested with a one-way MANCOVA, including VR news use, climate change knowledge, and climate change attitudes as covariates while estimating effects on presence, flow, and

Table 1. Mean differences in learning outcomes by experimental condition.

Experimental Condition	Free Recall *M* (*SE*)	Cued Recall *M* (*SE*)	Cognitive Elaboration *M* (*SE*)
Virtual Reality	2.87 (.23)	3.32 (.20)	5.29 (.46)
360° Video	3.20 (.21)	3.26 (.18)	4.13 (.42)
Text w/Images	3.39 (.22)	3.63 (.19)	4.16 (.44)
F-statistic	1.24	1.09	2.08

Cell entries are estimated marginal means from a one-way MANCOVA model. Covariates include virtual reality use, climate change knowledge, and climate change attitudes. None of the means within columns are significantly different from one another. N = 134, $df1$ = 2, $df2$ = 127. *M*: mean, *SE*: standard error.

[3]Of the subjects who "failed" this manipulation check, 89% were in the 360° condition, but indicated that they were in the VR condition. These responses are probably an artifact of question-choice labeling rather than a product of inaccurate recall, as 360° video is a form of virtual reality. We conducted the analyses excluding the subjects who failed *both* manipulation checks (3 subjects, or 2%), and the results were substantively similar to those reported here.

Table 2. Mean differences in presence, flow, and cognitive absorption by experimental condition.

Experimental Condition	Presence *M* (*SE*)	Flow *M* (*SE*)	Cognitive Absorption *M* (*SE*)
Virtual Reality	3.75 (.13)[a]	3.81 (.11)[a]	3.82 (.10)[a]
360° Video	3.11 (.12)[b]	3.45 (.10)[a]	3.52 (.09)[a]
Text w/Images	2.59 (.13)[c]	3.73 (.11)[a]	3.07 (.10)[b]
F-statistic	18.45***	3.15*	12.75***

Cell entries are estimated marginal means from a one-way MANCOVA model. Covariates include virtual reality use, climate change knowledge, and climate change attitudes. Cell entries with different superscripts within each column are significantly different from one another according to Bonferroni post-hoc comparisons with alpha adjusted to .983 for multiple comparisons. $N = 133$, $df1 = 2$, $df2 = 127$. *M*: mean, *SE*: standard error. *$p < .05$. ***$p < .001$.

cognitive absorption in the same model to account for correlated outcomes. Main effects were observed for presence (F (2, 127) = 18.45, $p < .001$) and cognitive absorption (F (2, 127) = 12.75, $p < .001$). Subjects in the VR condition scored the highest on presence (M = 3.75), followed by subjects in the 360° condition (M = 3.11), and then subjects in the TWI condition (M = 2.59). All of these means are statistically different from one another according to Bonferroni post-hoc tests with alpha adjusted to .983 for multiple comparisons. Likewise, subjects in the VR condition scored the highest on cognitive absorption (M = 3.82), followed by subjects in the 360° condition (M = 3.52), and finally by subjects in the TWI condition (M = 3.07). Bonferroni post-hoc tests (alpha = .983) show that VR is significantly different from TWI, but not 360°. For the third mediator, flow, the omnibus test is statistically significant (F

Table 3. Indirect effects of experimental factor on learning outcomes through presence, flow, and cognitive absorption.

Mediator	Free Recall *b* (*SE*)	Cued Recall *b* (*SE*)	Cognitive Elaboration *b* (*SE*)
Presence			
VR:360°	−.01 (.13)	.03 (.11)	−.02 (.23)
VR:TWI	−.02 (.24)	.05 (.19)	−.04 (.41)
Omnibus	.00 (.04)	−.01 (.04)	.01 (.08)
Flow			
VR:360°	−.29 (.16)*	−.14 (.10)*	−.20 (.20)
VR:TWI	−.07 (.15)	−.03 (.08)	−.05 (.13)
Omnibus	.03 (.04)	.01 (.02)	.02 (.04)
Cognitive Absorption			
VR:360°	.08 (.11)	−.02 (.07)	−.26 (.17)*
VR:TWI	.20 (.23)	−.03 (.17)	−.64 (.38)*
Omnibus	−.04 (.05)	.01 (.04)	.12 (.09)*

Cell entries are indirect effects (*b*) and bootstrapped standard errors (*SE*) from a mediation model estimated in PROCESS (Hayes, 2013; Model 4). VR: virtual reality, 360°: 360° video, TWI: text w/ images. $N = 133$. Bootstraps = 5,000. Models include the following covariates: virtual reality use, climate change knowledge, and climate change attitudes. *$p < .05$.

(2, 127) = 3.15, *p* = .046). However, post-hoc tests revealed that none of the means are statistically different from one another (VR = 3.81, 360° = 3.52, TWI = 3.07). In all, these results show a positive effect of VR on presence relative to 360° and TWI, a positive effect on cognitive absorption relative to TWI, and no effect on flow. Thus, the results support H2 (presence) and partially support H6 (cognitive absorption), but they do not support H4 (flow).

Mediation tests (Table 3) were performed using the PROCESS macro for SPSS (Hayes, 2013). Three models were fit for each of the three learning outcomes, and each included the three mediators as parallel outcomes (Model 4; 5,000 bootstrapped iterations). In other words, each model simultaneously estimates three indirect effects for one learning outcome. The inclusion of a multi-categorical independent variable produces contrasts with a reference condition, and in this case, VR is treated as the reference condition and contrasts with 360° and TWI are estimated. Thus, the models produce two contrasts (VR:360° and VR:TWI) for each mediator.

Of the three models, only the third shows an omnibus indirect effect. In this model, the experimental factor is indirectly related to cognitive elaboration through cognitive absorption (*b* = .12, *SE* = .09, 95% CI [0.003, 0.39]). Contrasts reveal that the indirect effect in the VR condition is significantly higher than in the 360° condition (*b* = −.26, *SE* = .17, 95% CI [−0.71, −0.02]), as well as the TWI condition (*b* = −.64, *SE* = .38, 95% CI [−1.53, −0.002]). For the other two models, estimating indirect effects on the recall outcomes, no omnibus indirect effects are observed. However, significant contrasts between VR and 360° are observed for both outcomes through flow (free recall: *b* = −.29, *SE* = .16, 95% CI [−0.71, −0.05]; cued recall: b = −.14, *SE* = .10, 95% CI [−0.43, −0.01]). In summary, VR has a positive indirect effect, relative to 360° and TWI, on cognitive elaboration through cognitive absorption, and it has positive indirect effects, relative to 360°, on

Table 4. Conditional indirect effects of immersion on cognitive elaboration via cognitive absorption at three levels of climate change knowledge.

Indirect Effect via Cognitive Absorption where:	Cognitive Elaboration *b* (*SE*)
Climate Change Knowledge = −1 *SD*	.10 (.13)
Climate Change Knowledge = *M*	.24 (.14)*
Climate Change Knowledge = +1 *SD*	.39 (.18)*
Index of Moderated Mediation	.16 (.09)*

Cell entries are conditional indirect effects (*b*) and bootstrapped standard errors (*SE*) from a moderated mediation model estimated in PROCESS (Hayes, 2013; Model 14). Because this model cannot accommodate multi-categorical independent variables, the experimental factor was converted to an ordinal "immersion" scale where text w/images = 1, 360° video = 2, and virtual reality = 3. *M*: mean, *SD* = standard deviation. *N* = 133. Bootstraps = 5,000. Models include the following covariates: virtual reality use, climate change attitudes, presence, and flow. *$p < .05$.

recall through flow. Thus, the results support H7 (cognitive absorption), and they partially support H6 (flow). However, they do not support H3 (presence).

Tests of moderated mediation (Table 4) were also performed in PROCESS (Model 14; 5,000 bootstrapped iterations) to determine whether the indirect effects of VR are conditional on preexisting knowledge about climate change. Because these models cannot accommodate multi-categorical independent variables, the experimental factor was recoded into an ordinal "immersion" scale where VR = 3, 360° = 2, and TWI = 1. Then, the model estimated the conditional indirect effects of this immersion scale on cognitive elaboration through the moderators at three levels of climate change knowledge. Results show no significant results for either recall outcome, leading to a rejection of H8a-H8c and H9a-H9c.

On the other hand, results do show positive moderated mediation for cognitive absorption (index = .16, *SE* = .09, 95% CI [0.02, 0.39]), but not for presence or flow. For cognitive absorption, the indirect effect of immersion is lowest (and non-significant) among subjects with low climate change knowledge (b = .10, *SE* = .13, 95% CI [−0.15, 0.37]) The effect of immersion is stronger at the mean of climate change knowledge (b = .24, *SE* = .14, 95% CI [0.02, 0.57]), and strongest where climate change knowledge is high (b = .39, *SE* = .18, 95% CI [0.11, 0.84]). Thus, the indirect effect of immersion on cognitive elaboration via cognitive absorption is conditional on climate change knowledge, such that the effect is stronger where knowledge is higher. These results support H10c (cognitive absorption), but not H10a (presence) or H10b (flow).

Discussion

We began with the premise that immersive journalism delivered on virtual reality devices has the potential to enhance learning about scientific issues (Jones, 2017; De la Peña et al., 2010; Shin & Biocca, 2018; Sundar et al., 2017), including climate change. But, consistent with prior research on the effects of immersive VR on science learning in educational contexts (Makransky et al., 2019b; Parong & Mayer, 2018), our results show no direct effects of VR news on learning about climate change. Additionally, while VR news does enhance presence, this feeling does not lead to learning, which runs counter to prior studies (Sundar et al., 2017).

On the other hand, the study did find an indirect effect of VR news on cognitive elaboration via cognitive absorption, suggesting that immersive VR technology may work best as a learning tool when it influences cognitive, rather than affective, pathways (e.g., Makransky & Petersen, 2019). Moreover, this cognitive effect appears to influence how new knowledge is incorporated into existing schemas, but it does not improve recall (e.g., Lee et al., 2010; Makransky & Lilleholt, 2018). Finally, we find that this indirect effect is conditional on preexisting knowledge about climate change. Although this mechanism was not tested directly, theory suggests that preexisting knowledge reduces the cognitive load on VR users, and these users recognize factual information in the story and relate it to what they already know (Makransky et al., 2019a). Therefore, VR news is more effective as a tool for learning about climate change among those who possess high baseline knowledge about the subject.

This study advances theory about learning in immersive environments by testing learning effects under conditions in which intrinsic cognitive load is presumably low (i.e., in a news story designed for a general audience). Research on the Cognitive Theory of Multimedia Learning has studied science educational modules (e.g., Parong & Mayer, 2018), which are detailed lessons tailored to specific audiences tasked with deep retention of knowledge about complex scientific processes and effects. These kinds of modules contain high amounts of complex core information, and it could be difficult for users to process such information in the context of an immersive technology that also presents extraneous, experiential information.

News stories, on the other hand, are created with a more general audience in mind, and information is therefore presented at a more basic level that is easier for people to comprehend (Chaffee & Frank, 1996). Prior research has shown that the average person learns more easily from news than from other informational formats (Lo & Chang, 2006), and the relative ease with which people learn from the news could reduce the cognitive load required to learn in immersive virtual reality environments. While news does not reduce demands on the processing of extraneous information, it should reduce demands on processing of intrinsic information—that is, the core content of the story should be easier to comprehend. Based on these ideas, and with the caveat that the study does not observe cognitive load directly, we predicted that while VR may not directly affect learning from a science module, it may affect learning from a news story. But our results show that it does not directly affect learning, even from a news story. This finding suggests that simplifying content may not enhance learning outcomes, particularly when the information is novel to the learner. But whereas reducing the complexity of information may not be sufficient for improving learning in immersive environments, reducing extraneous information may be, and therefore the focus should be on the latter. This conclusion represents an important advancement for the Cognitive Theory of Multimedia Learning, as it adds to our understanding about avenues for leveraging VR technologies for learning.

The study also advances CTML in several other ways. First, we find an indirect effect of VR news on learning through the cognitive, rather than affective, pathway. Prior research has proposed both indirect pathways as avenues for learning (Makransky & Lilleholt, 2018; Makransky & Petersen, 2019), with the affective pathway emphasizing effects through presence, emotions, and motivations, and the cognitive pathway emphasizing effects through cognitive benefits, and reflection. Our findings provide clear evidence against the affective pathway and for the cognitive pathway. While VR news may increase presence, we did not find any consistent link between presence and indicators of learning. Second, we find learning effects on cognitive elaboration, but not on recall, and this finding also fits with prior literature on the CTML (Makransky et al., 2019a), which found that VR improved problem solving and affected behavioral transfer even though it did not enhance recall. This study similarly finds that VR can affect *depth* of learning when the VR content is appropriately designed to do so, such as in the extended feature news story we showed to our study participants. Finally, we find that this cognitive pathway is conditional on prior knowledge about climate change, which fits with prior research on "pre-training" participants (Meyer et al., 2019). When subjects already know the names and characteristics of main concepts, they presumably spend less effort processing essential information. This finding adds an important corollary to our previous conclusion about improving learning by reducing the essential processing: While reducing essential processing through the simplification of information may not be sufficient for improving learning outcomes, reducing essential processing through pre-training may be. Thus, VR news is most effective as a learning tool when people already know something about the topic.

Before discussing the big picture implications of these findings, it is important to acknowledge that the study is limited in terms of design, participants, and measures. The study does not make direct observations of cognitive load, a key theoretical mechanism. While the logic driving our hypotheses is based on prior literature, future research should test this mechanism directly in the context of VR news. The same limitation also applies to other theoretical mechanisms discussed for presence, flow, and cognitive absorption, including motivation, self-efficacy, attention, interest, and inquisitiveness. Future research could design studies that test these mechanisms directly. Additionally, the design does not account for variation within VR format, nor does it account for repeated exposure to the same story. It is possible that these differences in format or repetition would produce different results, and future research could design studies to test these aspects of the research problem. Additionally, the study is a single-issue study, and the results may not be generalizable to news content about other scientific issues. Future research is needed to investigate learning effects as a response to news about other issues. Relatedly, the study relies on a single stimulus, whereas multiple stimuli would be ideal given the low rates of replicability in the experimental social sciences. Future research should replicate this study using multiple stimuli. In terms of the study's participants, the experiment relies on a student sample. While the study has psychological processes that should not differ across population demographics, it is possible that college students are faster learners than others in the adult population because they live in an active learning environment. A final set of limitations is related to measurement. While the learning measures are based on prior research, other aspects of learning could also be measured, including perceived knowledge. Additionally, future research could validate measures of the three mediators.

Turning now to the big-picture extensions of our work for journalism and public understanding of science, the findings suggest that simply taking news stories and putting them into an immersive VR format will not enhance learning about important public issues, such as climate change, unless the content is linked to the affordances of VR. In that sense, VR may make sense for some stories in which "being there" is an important part of the learning process (Shin & Biocca, 2018; Sundar et al., 2017). However, for stories that feature a good amount of detailed scientific information, presence may detract from the learning process. Where stories are rich in detailed information, they are most effective if tailored toward people with preexisting knowledge of the issue, and aimed at cognitively engaging those individuals in the story. These are important take-home messages for news organizations: Immersive VR stories are most effective at facilitating learning about important public issues when the story's format and core information are aligned, enabling the story to take full advantage of the medium's affordances.

Another set of extensions relates to the well documented struggle for science communicators to reach audiences with less issue-specific interest. As Scheufele (2018) notes in an influential article, a key goal for science communicators should be to overcome traditional barriers in climate change communication to reach audiences who are not already familiar with the core messages from scientists, universities, and climate-change activists. Unfortunately, our findings suggest that VR news is not an ideal way to reach these segments of the public. While the climate change story placed participants in the middle of the Artic and gave them a sense of what it is like to "be there," presence was not a key driver of the observed learning effects. Rather, the individuals who learned the most from the story already knew something about climate change going into the immersive experience, and they did so through cognitive absorption rather than through presence. This finding implies, of course, a limit on the potential for immersive media technologies to close knowledge gaps by reaching "beyond the choir" (Scheufele, 2018). If these previously untapped individuals have no existing base of knowledge about the topic of climate change, they may be less able to integrate new information into cognitive schemata that will help them remember and understand it. The good news for science communicators, if there is any, is that VR news could reinforce support for climate change policy and the political candidates and institutions who promote them.

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Data availability statement

Data supporting the analyses are available on Mendeley at DOI: https://data.mendeley.com/datasets/sk9hmp4mxx/1.

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