

Virtual Reality: A Study About Olfactory Senses in Immersive Learning

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Brief

This article explores how virtual reality enhances immersive learning experiences by engaging olfactory senses, increasing cognitive absorption, and fostering a sense of telepresence.

Abstract

This study explores the role of olfactory senses in enhancing immersive learning experiences, particularly in virtual reality (VR). With the increased reliance on modern technology due to the pandemic, immersive learning has emerged as a promising tool to teach practical skills. While sight and sound are already integrated into VR, this study examines the impact of smell on cognitive absorption and learning outcomes. Participants were divided into two groups, one experiencing olfactory cues and the other not, while completing a task in a VR kitchen simulation. Results indicate that while olfactory stimuli enhance Telepresence, they negatively affect Task Awareness, likely due to sensory overload. However, Cognitive Absorption remains a key factor in fostering effective learning, with no significant differences observed in mental model changes between the two groups. This research highlights the potential of olfactory integration in VR learning, though further study is required to balance sensory inputs for optimal results.

Keywords: Olfactory senses, immersive learning, virtual reality, cognitive absorption, telepresence

Introduction

Due to the recent pandemic, modern technology has been brought into the spotlight to mitigate some of the most prominent problems. One of the most important and widespread issues is the state of education and the changes to learning. Technological advancements like ZOOM and immersive learning have played a pivotal role in tackling this challenge. Due to the relatively low costs of running a simulation (Cobum et al.

2017), training students or professionals with immersive learning can be an effective way to educate the ever-growing popul^us.

The greatest advantage of immersive learning lies in its ability to replicate interactive learning environments, enabling the teaching of specific skills and techniques. Safe and accessible simulations of real-world scenarios, such as medical procedures, can provide learners with hands-on experience in a controlled setting, which can lead to better preparedness for real world scenarios (Burdea and Coiffet 2003). Virtual reality is also more flexible in terms of time, location and cost than traditional in-person lectures. Yet while the Internet has already been integrated into the curricula of many schools to provide additional ease of access, a key limitation remains its inability to replicate sight, touch, hearing, taste and smell, all of which are essential for pairing stimuli to memory.

The sense of smell, or olfaction, appears to play an especially important role in human experience and perception, and has also been shown to be closely linked to memory (Firestein 2001). This suggests that immersive learning can benefit greatly from the integration of olfactory stimuli, which can enhance the realism of the virtual environment and trigger memories (Sultan et al. 2010). Although sight, sound and touch are currently included in most modern VR headsets, immersive learning in both the academic and corporate world has thus far downplayed the significance of smell. This study aims to address this oversight by exploring the potential benefits of incorporating olfactory stimulation into immersive learning in order to improve its utility as an educational tool.

Literature Review

Training methods such as online courses and video guides have already been used for many years to teach everyday skills. Recent literature involving multisensory and VR training studies (Table 1) indicates that while there is no general consensus on the most effective learning methods, sensory stimulation and the ability to be hands-on both contribute to the overall effectiveness of learning environments. According to theories of sensory memory, the iconic, echoic, haptic, olfactory and gustatory senses all facilitate the linking of stimuli from our surroundings to the prefrontal cortex (Zikopoulos and Barbas 2007), which is why increasing attention has been paid to the incorporation of sensory stimulation into the immersive learning experience (Freitas et al. 2010). Characterized by its unique ability to induce a sense of physical immersion (Wexelblat 2014), VR technology has been found to be particularly effective in promoting learning and skills development in a variety of fields, including medical training (Tang et al. 2022), aviation (Taylor and Clayton 2021), and education (Kovács et al. 2015).

Generally speaking, immersive learning refers to any education or training that takes place within an immersive environment, with its

effectiveness largely dependent on the quality of the immersive experience. And since modern VR is still in the early stages of development, many have begun to explore how the quality of the VR experience can be improved. When it comes to incorporating olfactory stimulation into the immersive learning experience, the potential benefits are twofold. Immersing an individual in a given task promotes a greater sense of Task Awareness (TA), which can result in more effective organization and a greater comprehension of the task or activity (Rae et al. 2014). Higher levels of Telepresence (TP), or the simulation of a sense of presence within another location, have also been shown to build closer and more reliable associations with the task (Rae et al. 2014).

Importantly, research has also shown that both of these factors help create a more potent sense of Cognitive Absorption (CA), or the degree to which an individual’s cognitive resources and attention are fully focused on the task. When individuals are fully engaged in performing a task, their brains are more receptive to new information, which allows them to process and engage with the material better (Alashoor and Baskerville 2015). And since higher levels of Cognitive Absorption have been shown to facilitate successful long-term learning, this study aims to analyze the effect of incorporating olfactory stimulation into the immersive learning experience to enhance Cognitive Absorption by increasing Task Awareness, Telepresence and Mental Model Change (MMC).

Table 1. Multisensory research in immersive learning

	Sight	Sound	Touch	Smell
Civelek et al (2014)			✓	
Francis et al (2014)	✓			
Robert (2014)		✓	✓	✓
Wilson and Soranzo (2015)	✓			
Grajewski et al (2015)	✓		✓	

Kim et al (2017)			✓	
Parong and Mayer (2017)	✓			
Judith et al (2018)				✓
Edwards et al (2018)	✓		✓	
Trujillo et al (2019)		✓		✓
Collaco et al (2020)			✓	
Webb and Tracy (2021)			✓	
Kabor and Zhang (2011)	✓		✓	

Methodology

This section summarizes the research model used by this study (Figure 1) and provides a detailed explanation of each hypothesis.

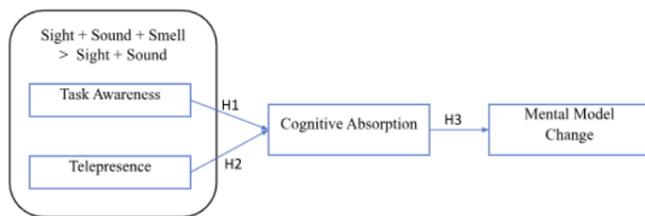


FIGURE 1. Research Model.

(I) Hypothesis

Task Awareness (TA) refers to an individual’s ability to understand and accomplish various components of a task, including any constraints to completing the task. Cues, whether visual, haptic, audio or olfactory, can be used to improve Task Awareness, which has been shown to improve cognitive absorption by allowing individuals to manage the demands of a task more effectively. When individuals exhibit a high level of Task Awareness, they are better able to focus their attentional resources on the most important aspect of the task at hand, which can in turn lead to more efficient performance and a reduced likelihood of errors or distractions that might otherwise disrupt cognitive absorption (Fransen et al. 2011). Task Awareness has also been shown to enhance cognitive absorption by providing individuals with a clear sense of direction, which enhances motivation and engagement (Martin and Dowson 2009). Based on this

correlation, and as set forth in Hypothesis 1 below, our theory posits that olfactory stimulation within the virtual environment can positively impact Task Awareness, thereby enhancing Cognitive Absorption: Hypothesis 1 (H1): The use of olfactory stimulation in VR learning enhances the positive effects of Task Awareness on Cognitive Absorption.

Telepresence (TP) refers to the use of technology to simulate a sense of presence and immersion in an environment, allowing individuals to feel as if they are in another location. According to the social presence theory, individuals interact and react in a variety of ways depending on the level of social presence they experience (Cui et al. 2013). Telepresence can increase social presence by providing individuals with a sense of connection and presence in a remote environment. This fosters immersion by reducing the sense of disconnection that often arises when individuals are separated from a task, while at the same time simulating an engaging and captivating environment that allows individuals to make sense of their surroundings, thereby increasing cognitive absorption. Based on this correlation, and as set forth in Hypothesis 2 below, our theory posits that olfactory stimulation within the virtual environment can positively impact Telepresence, thereby enhancing Cognitive Absorption: Hypothesis 2 (H2): The use of olfactory stimulation in VR learning enhances the positive effects of Telepresence on Cognitive Absorption.

According to Lui and Goel (2021), Cognitive Absorption refers to a state in which an individual is so engaged and focused on a task that he loses track of time, and a Mental Model Change (MMC) refers to a shift in an individual's way of thinking about a concept or situation which can in turn result in a change of behavior. When an individual is cognitively absorbed, he is more likely to experience mental model changes as he actively processes new information and integrates it into his existing knowledge structures. Cognitive Absorption thereby enhances memory retention, which makes it easier for an individual to acquire and learn new information. It also promotes deep level processing of information, which facilitates connections between concepts and the development of complex mental models. As shown in Figure 1 above and Hypothesis 3 below, the purpose of this study is therefore to demonstrate a positive correlation between Cognitive Absorption and Mental Model Changes by increasing Task Awareness and Telepresence through stimulation of the olfactory senses: Hypothesis 3 (H3): Cognitive Absorption positively affects Mental Model Change and the effect stays the same even in the presence of olfactory stimulation.

(II) Data Collection

For the purposes of this study, the role of olfactory stimulation in VR learning was analyzed based on the research model in Figure 1 above by using the IKEA VR Pancake Kitchen experience (Figure 2) to collect the data and partial least squares structural equation modeling (PLS-SEM) to confirm the correlations proposed by the research model. The VR Pancake

Kitchen experience, which teaches users how to make a pancake, was selected in order to reduce the complexity of the experiment and participants from my high school were recruited as subjects, with the data collected between January 15 and February 26, 2023.

After viewing a short training tutorial on the VR controls, participants were randomly divided into two groups: Group 1 (the “no scent group”) and Group 2 (the “scent group”), with the only difference being that the individuals in Group 2 were exposed to the smell of pancakes while the experiment took place and the individuals in Group 1 were not. Group 2 was not informed beforehand about the smell, and both groups were instructed to repeat the following instructions:

1. Gather the necessary ingredients and cooking utensils (milk, eggs, flour, whisk cooking pan);
2. Mix the milk, eggs and flour together;
3. Dispose of the eggshells;
4. Mix the batter;
5. Pour the batter into the cooking pan;
6. Flip the pancake.

The scent of pancakes was administered using a candle positioned at 1.5 meters from the participants, ensuring the scent was dispersed across the virtual environment without overwhelming the senses. The consistency of scent exposure was ensured by using a fan to maintain an even distribution of the fragrance throughout the room. Additionally, the intensity of the scent was measured and standardized using a portable olfactometer, which calibrated the scent strength at regular intervals to ensure a consistent experience for all participants in Group 2.

After engaging in the simulation, the participants were then asked to answer a series of questions based on the research constructs in the research model which were designed to measure Task Awareness (2 questions), Telepresence (4 questions), Cognitive Absorption (7 questions), and Mental Model Changes (4 questions) using a 7-point Likert scale.



FIGURE 2. Screenshot of IKEA VR Pancake Kitchen. Note: The full VR experience can be found here:

<https://www.youtube.com/watch?v=KmxhAcJHjgo>.

Results

A total of 98 useful results were collected from 52 subjects in Group 1 and 46 subjects in Group 2. The descriptive statistics of the Task Awareness (TA), Telepresence (TP), Cognitive Absorption (CA), and Mental Model Change (MMC) variables are shown in Table 2. In order to analyze the relationship between observed variables and latent constructs, the data was then analyzed using the measurement model and structural model of PLS-SEM, as discussed in more detail below.

Table 2. Descriptive Statistics					
Name	Mean	Median	Min	Max	Standard Deviation
TA1	5.602	6	3	7	0.766
TA2	5.663	6	3	7	0.755
TP1	5.010	5	2	7	1.589
TP2	5.051	5	1	7	1.534
TP3	3.602	3	1	7	1.557
TP4	4.796	5	1	7	1.538
CA1	5.735	6	4	7	0.954
CA2	5.520	6	3	7	0.895
CA3	5.510	6	3	7	1.118
CA4	5.156	6	2	7	1.537
CA5	5.000	6	2	7	1.610
CA6	5.327	5	3	7	0.866
CA7	5.327	5	3	7	0.830
MMC1	5.500	6	3	7	1.824
MMC2	4.867	5	2	7	1.056
MMC3	4.612	5	3	7	1.183
MMC4	4.672	5	3	7	1.048

(I) Measurement Model

The measurement model was used to test convergent and discriminant validity, with convergent validity assessed using Composite Reliability (CR) and Average Variance Extracted (AVE). Composite reliability assesses how consistent items in a scale are in measuring the same underlying construct and should be higher than 0.7 (Peterson and Kim 2013). Average Variance Extracted refers to the extent to which variations observed in a group of indicators are associated with the fundamental construct that they are intended to gauge, with an AVE greater than 0.5 indicating a good convergent validity (Alarcón et al. 2015).

To ensure that the variables are distinct from one another, discriminant validity was also tested using the Heterotrait-monotrait ratio

(HTMT), a matrix of values utilized in a structural equation which measures the correlation between items that measure the same construct and compares them with correlations between items that measure different constructs (Henseler et al. 2015). An HTMT of less than 0.85 suggests that the two constructs are sufficiently dissimilar and possess good discriminant validity (Henseler et al. 2015). As shown in Tables 3, 4 and 5 below, the results of the measurement model indicate that convergent and discriminant validity were both satisfactory.

Table 3. Construct reliability and validity

	Composite reliability	Average variance extracted
Cognitive Absorption	0.883	0.521
Mental Model Change	0.866	0.619
Task Awareness	0.799	0.666
Telepresence	0.932	0.775

Table 4. Discriminant validity - Heterotrait-monotrait ratio (HTMT)-Matrix (Continued)

	Composite reliability	Average variance extracted	Task Awareness	Telepresence
Cognitive Absorption				
Mental Model Change	0.588			
Task Awareness	0.278	0.374		
Telepresence	0.806	0.358	0.199	

(II) Structural Model

The path coefficient of the relationship between Task Awareness and Cognitive Absorption was 0.272 in Group 1 (the “no scent group”) and -0.063 in Group 2 (the “scent group”), with a path difference of 0.335 and a p-value of 0.036, indicating a significant difference between the groups. Yet this difference was in the opposite direction than expected, suggesting that Hypothesis 1 (i.e. that olfactory stimulation enhances the positive effect of Task Awareness on Cognitive Absorption) is not supported.

In contrast, the path coefficient of the relationship between Telepresence and Cognitive Absorption for Groups 1 and 2 was 0.445 and

0.616, respectively, with a path difference of -0.171 and a p-value of 0.054, indicating a marginal difference between the groups which was in partial support of Hypothesis 2 (i.e. that olfactory stimulation enhances the positive effect of Telepresence on Cognitive Absorption).

The path coefficient of the relationship between Cognitive Absorption and Mental Model Change for Groups 1 and 2 was 0.376 and 0.616, respectively, with a path difference of -0.162 and a p value of 0.331, indicating no difference between the two groups. This suggests that Cognitive Absorption is almost always associated with a Mental Model Change and is in support of Hypothesis 3. Finally, as shown in Table 6, an R2 between 0.141 to 0.379 represents a reasonable model.

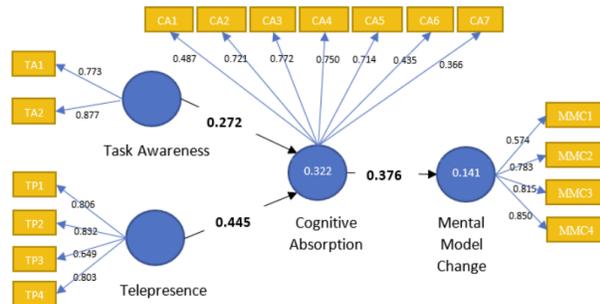


FIGURE 3. Group 1 (“No Scent Group”) Results.

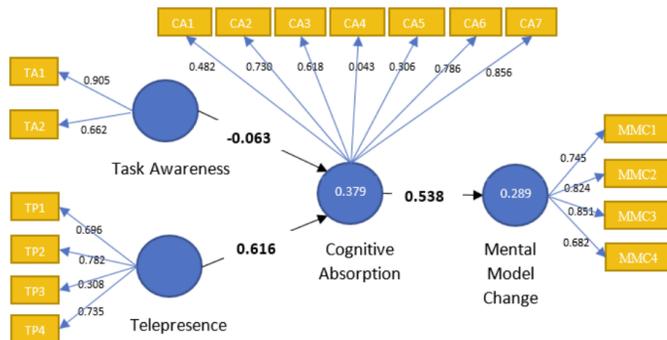


FIGURE 4. Group 2 (“Scent Group”) Results.

Table 5. Multigroup analysis

	Path (No Scent)	Path (Scent)	Path difference	Permutation mean difference	Permutation p value
Task Awareness -> Cognitive Absorption	0.272	-0.063	0.335	-0.006	0.036
Telepresence -> Cognitive Absorption	0.445	0.616	-0.171	-0.004	0.054
Cognitive Absorption -> Mental Model Change	0.376	0.538	-0.162	0.003	0.331

Table 6. R2 Results

	Group 1 (No Scent)	Group 2 (Scent)
Cognitive Absorption	0.322	0.379
Mental Model Change	0.141	0.289

Conclusions and Suggestions

Generally speaking, the results of this study on the role of olfactory stimulation in immersive learning indicate that stimulation of the olfactory senses marginally enhances the impact of Telepresence on Cognitive Absorption, while weakening the impact of Task Awareness. This in turn suggests that Task Awareness is stronger in the absence of olfactory stimulation, which appears to contradict our hypothesis. It may be that stimulation of the olfactory senses contributes to sensory overload, which occurs when an individual’s processing capacity is exceeded by too much sensory input, resulting in a state of cognitive overload where the brain cannot fully process all incoming information as it is preoccupied with processing other stimuli (Lawson 2011). As for the impact of Cognitive Absorption on Mental Model Change, the results indicate that olfactory stimulation does not have an appreciable effect, suggesting that when a user is deeply engaged in the VR experience, his ability to learn will be

the same regardless of whether his olfactory senses are stimulated. This is consistent with our expectations.

It is important to note, however, that these results are by no means definitive and may have been affected by certain limitations in our methodology. First, while our study suggests that olfactory stimulation may improve the effectiveness of culinary training, these benefits do not necessarily extend to other types of training. Moreover, the resource constraints and time limitations of this study, including the size of the sample used, could also be an issue, and our reliance on data largely collected from high school students from the same school means that the findings may not be generalizable to other populations. Finally, participants' lack of familiarity with virtual reality prior to engaging in the simulation may also have skewed the results, and it is therefore recommended that the subjects of future studies undergo training on how to use a VR headset before participating in similar simulations.

Participants were asked about their prior experience with VR before the study. While VR experience was not a controlled variable, future research could compare results between VR experience and non-experienced groups.

An additional factor that may have influenced the results is the novelty of olfactory stimulation. Participants who had not previously experienced olfactory VR might have been more cognitively engaged due to the newness of the stimulus rather than its direct impact on learning. Future studies should control for this by including a pre-exposure phase to olfactory VR.

Notwithstanding these limitations, however, it is our hope that this study will contribute to advancements in the development of immersive learning. In particular, our finding that the inclusion of additional sensory inputs may enhance the positive effects of Telepresence on Cognitive Absorption while having a detrimental effect on Task Awareness suggests that the need to identify the correct balance of sensory inputs to be provided in a VR simulation in order to enrich the learning experience without cognitive overload should be a topic for future research. Second, while our study suggests that olfactory stimulation has the potential to enhance the effectiveness of immersive learning, the costs associated with developing additional sensory inputs are substantial, so it is important that additional studies be performed to prove the benefits of olfactory stimulation before proceeding. Finally, further research into the potential for incorporating inputs involving the other four senses into the VR experience is necessary in order to maximize the potential of immersive learning, which will continue to play an important role in the future of education.

Future research should explore whether varying the intensity and duration of olfactory stimuli impacts cognitive absorption differently. Additionally, comparing different scents (e.g., neutral vs. strong, pleasant vs. unpleasant) could help determine whether specific olfactory

characteristics enhance or detract from immersive learning. Finally, long-term retention studies could assess whether olfactory cues aid memory beyond the immediate VR experience.

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