VR-Based Context Priming to Increase Student Engagement and Academic Performance

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***Abstract*—Research suggests that virtual environments can be designed to increase engagement and performance on many cognitive tasks. This paper compares the effect of specifically designed 3D environments intended to Prime these effects within Virtual Reality (VR). A 27-minute seminar "The Creative Process of Making an Animated Movie" was presented to 51 participants within three VR learning spaces: two Prime and one No Prime. The Prime conditions included two situated learning environments; an animation studio and a theatre with animation artifacts vs. the No Prime: theatre without artifacts. A 20-question multiple-choice content test, User Experience (UX), and affective (anxiety and positive affect) surveys were completed prior to and immediately after the learning session. Increased academic performance was observed in both Prime conditions compared to the control. UX and affective surveys related to the immersive VR experience were positive, but there were no significant differences observed between the Prime and No Prime conditions in either case.**

Index terms*—Context, priming, immersive, supraliminal, positive affect, anxiety, academic performance, situated learning, experiential, virtual reality, applied computing, education, computer-assisted instruction, human-centered computing, human computer interaction, interaction paradigms, virtual reality

I. Introduction

Winston Churchill famously said, "We shape our buildings and afterwards our buildings shape us" [10]. We know instinctively that where we live, work, and learn can affect how we feel and perform. Nature, open spaces, and locations with gorgeous aesthetics are highly coveted and can often improve performance [8][6] yet are inaccessible for most people.

Virtual Reality (VR) affords the opportunity to create and design these highly coveted spaces to Prime (act as stimuli that improves subsequent cognition) engagement and academic performance. While there is research demonstrating that the context of our experiences can affect cognition and behaviour [4][5], there is little research validating the transferability of these effects to leading-edge educational technology like VR or research that informs the design choices to improve cognition within these environments. Given the potential for VR priming to greatly impact the learning process we investigate environment context priming: the impact of VR environments on learning which we achieve by varying the context of the learning spaces.

Following a review of related work and description of our study, we discuss the academic performance, UX, and affective results that will help inform the design of future VR experiences. Our results clearly demonstrate the positive effects of both Prime scenarios to improve academic performance compared to the No Prime condition. We conclude with future research considerations and propose further VR priming studies focused on motivational, reflective, and aggregate priming methods within the experiential learning cycle [22].

II. Related Work

A. The Nature of Context

Marshall McLuhan posited that ***"the medium is the message"*** [26]. He theorized that the medium is any innovation or enhancement that extends human capability. The lightbulb brings light to an environment providing new visual insights and allowing many new activities during periods of darkness. Similarly, VR affords many new possibilities including the design of high-fidelity learning spaces and custom designed scenarios to realistically simulate specifically desired contexts. While these extensions of our visual/spatial capability provide a tangible, observable result, McLuhan's theory suggests that the message is the overall impact of the medium. For example, providing customized VR learning environments may function quite effectively, creating feelings of presence and authenticity [26], [12] but may also induce positive affect and subsequently improve creativity [3].

UX design expert Don Norman, in Emotion and Design [28], describes a study where ATM cash machines were designed functionally identical but with varying aesthetics [28][21]. The research demonstrated that more attractive designs simply worked better. Norman attributes this partly to the induction of positive affect. A 1987 study at University of Maryland demonstrated that inducing positive affect improved creative problem solving [16]. A similar study in 1988 performed with eighth grade students achieved the same results suggesting that positive affect may promote creativity and facilitate problem-solving in young adolescents [14].

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B. The Power of Priming

Priming occurs when a stimulus (the Prime) makes the content and subsequent cognitive processes more accessible, potentially influencing all stages of information processing: attention, comprehension, memory retrieval, inference, and response generation [13]. The most effective priming stimuli are supraliminal (observable but not obvious to the individual) where changing the context of an environment can create effects with little or no perceptual awareness. A picture, for example, can create bias and affect how a person thinks [17] or placing codes (A vs. F) on pre-test forms can affect academic performance [9].

A 1997 retail study [29] provides an excellent example of the subtle, yet effective nature of supraliminal priming. In the study, European retailers tested the effect of varying in-store music related to countries of origin. Four types of French and German wine were displayed equally prominently in a supermarket drink area over a two-week period. The wines were similar in price and dryness. Over that period, French accordion and German Bierkeller music played intermittently. When the French music played 76.9% of the bottles of wine sold in the area were French wine. When German music played, 73.3% of the bottles of wine sold in the area were of German origin. When respondents were asked whether they thought the music influenced their choice of wine, most felt that there was little or no effect.

Priming positive emotions (positive affect) has been shown to improve information organization and creativity. In the previously mentioned University of Maryland study [16], positive affect was induced in study participants by viewing a few minutes of a comedy film or by receiving a small bag of candy. Another group received a neutral stimulus, while two more groups engaged in a physical exercise meant to represent affective arousal. In performing two tasks of creative ingenuity, the positive-affect groups, primed with candy or funny movies saw improved performance while the control and exercise groups saw no performance increases. The researchers concluded that positive affect had improved creativity. In certain situations, positive mood has also been shown to improve divergent thinking [39] and many other cognitive tasks [2].

C. Learning Theories

Priming efficacy directly benefits from repetition [44] and authentic experiences where priming effects can be woven subtly into the environmental context [4], [5]. As such, of particular interest for our research was Kolb's Experiential Learning Theory (ELT) [22]. With ELT, learning begins with having a concrete experience, followed by a reflection of that experience, the conceptualization of abstract concepts that incorporates the new insights from the experience, and finally active experimentation of the lessons learned. The cycle, as presented in Figure 1, continues to repeat as the learner's conceptual worldview is repeatedly refined. Learning is best achieved as a process: a continuing reconstruction of experience.

Hence, the ELT cycle can provide iterative experiences and timed trigger points where various priming interventions may be activated. Trigger points may occur before, after, or during the experience. Such guided priming can lead to increased motivation, better situational context, and ultimately better learning outcomes [15]. Stephen Krashen's Affective Filter hypothesis with second language learning, advocates for creating experiences that reduce anxiety, while increasing motivation and self-confidence [23], [24]. The ELT cycle offers opportunities for priming interventions to improve affective elements and improve academic performance.

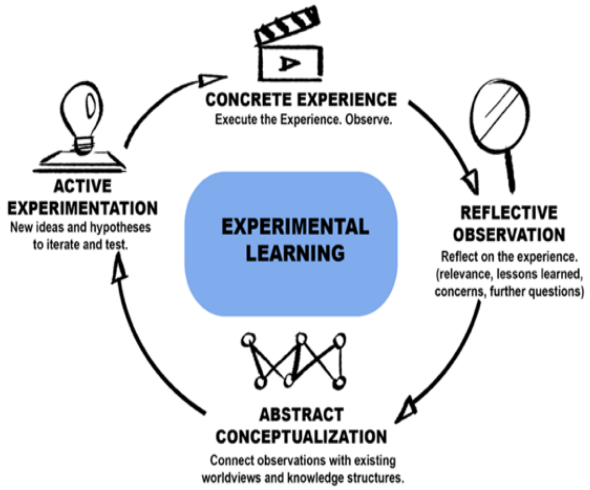

Fig. 1. Experiential Learning Theory (ELT)

Situated Learning Theory (SLT) [7], [25] recognizes the value of social and contextual experiences within a community of practice. Within a specific situation learners can see, hear, do, and feel the experience resulting in higher retention and improved performance. Based on SLT, technology solutions that offer improved situational contexts and modalities should increase engagement and performance. For example, placing someone in an animation studio could amplify the understanding of an animation related idea or concept [7], [25] and given this improved understanding and improved self-confidence, perhaps increase their willingness to participate in the process [23], [24].

D. VR as a "Prime" Enabler

While priming is most effective in the context of authentic, supraliminal, and repetitive experiences [15], ELT and SLT similarly depend upon continuity/repetition and authentic experiences that allow the learner to repetitively reconstruct their knowledge and understanding of the subject matter. [24]

VR offers affordances that address common ELT, SLT, and priming requirements. As a procedural tool, VR provides the ability to simulate, repeat, and reconstruct learning experiences with successive iterations. The 3D visualization and interactive capability of VR provides a powerful capability that could be applied in the conceptualization and experimentation phases of ELT and within the same situated learning environment. While the reflection phase of ELT might seem inherently "low tech", the procedural, repetitive simulation capability of VR lends itself to Artificial Intelligence (AI) and Machine Learning (ML)

where new insights could be applied as reflective priming interventions.

Further, VR provides the facility to design ubiquitous situational contexts: environments, artifacts, and avatars with narrative storytelling capabilities [33], [34] that would not be possible otherwise. As a social and learning tool, myriad VR applications (e.g., Oculus Horizons, Workrooms, AltspaceVR) are already bringing together globally distributed social groups and communities of interest for education, collaboration, and entertainment purposes. These virtual situational environments can legitimately bring expert, learner, and the community together in a common situational context that transcends geography and culture [3], [7], [25].

Most recently, game-based learning experiences and gamification techniques have gained increasing marketplace momentum [41]. These techniques can be combined with VR enabled educational programs to augment and improve experiential learning, reducing anxiety, and priming positive mindsets within the learning experiences [1], [15].

Central to the concept of VR is the quantifiable concept of immersion and the more subjective idea of presence or the feeling of being there. Based on these immersive possibilities and the ability to create a sense of presence, VR is an ideal environment to create scenarios to evoke different forms of conscious awareness [11]. For designers, VR offers the possibility to create learning spaces that are more conducive to learning while "designing out" potential anxiety-inducing barriers. In a 2013 study, 3D virtual environments were used to test the effects of priming on creativity. The results showed that when teams created ideas in the Primed virtual environments, they created more ideas and of higher quality than the control groups [1], [35], [36].

Customizable, inhabitable avatars and computer-controlled Non-Player Characters (NPCs) within specific learning situations offer compelling priming advantages to increase inclusivity and broaden sociocultural contexts by allowing participants to adapt cultural environments and/or inhabit personas of other races, cultures, or genders that challenge existing situated learning norms, an acknowledged concern regarding situated and experiential learning [18]. As such, the combination of VR, ELT, SLT, and context priming show great promise in reducing stereotype threats that have been shown to negatively impact academic performance [3], [31].

III. Methodology

We conducted a user study to perform an evaluation of environment context priming effects within immersive virtual reality environments. In previous research, we investigated the potential value of pre-learning activities like VR video games and meditation as priming methods [15]. This study will deploy a similar remote research process where a VR Head Mounted Device (HMD) is provided and managed by each participant in their own home. Our study was approved by the University's Research Ethics Board and followed all the guidelines, including those for safe experimentation during the COVID-19 Pandemic.

A. Study Overview

The study, a between-subjects test with one independent variable (Priming context), explored the effectiveness of VR-based context priming. A 27-minute seminar "The Creative Process of Making an Animated Movie" was presented to 51 participants within three VR learning spaces: two Prime and one No Prime. The Prime conditions included two situated learning environments: 1) an animation studio and 2) a theatre with animation artifacts. The No Prime condition was the same theatre with no subject matter artifacts. The priming conditions were selected based on SLT [2], [9] that emphasizes the role of authentic and realistic environments in learning.

The study used three dependent variables (academic score, user experience, and affective improvement). Academic score is our main subject and represents the learning effect of the context. It was measured with a 20-question multiple choice test completed immediately after the seminar. While there is little empirical evidence suggesting that context priming in VR can improve the perceived UX or affective response, we remained curious nonetheless to investigate any possible impact on the UX.

The test and the survey are described in Section 3.3. Affective factors: Anxiety and positive affect, were measured using a pre and post course short-form State Trait Anxiety Inventory (STAI) [28], [40] and Positive Negative Affect Schedule (PANAS) [45] surveys respectively. The STAI measured changes in self-reported anxiety levels while the PANAS similarly measured changes in self -reported positive and negative affect. Based on anticipated priming and situational learning effects, we investigated the following hypotheses:

H1: (a) Prime conditions (both) will improve academic performance over the No Prime condition. (b) There will be no significant difference between two priming contexts.

H2: (a) Prime conditions (both) will improve subjective assessments of UX results compared to the No Prime scenarios. (b) There will be no significant difference in UX results between the two priming conditions.

B. Participants

The study was performed with 51 participants over three priming conditions (17 in each condition). Most participants were existing university students in Ontario, Canada with the balance or adult lifelong learning students with an interest in exploring VR educational technology. Due to COVID restrictions, some of the students (foreign students), were living remotely in other countries. The participants, upon acceptance, were randomly placed in one of three groups corresponding to priming or non-priming scenarios. Participants were paid $20 CDN (via e-transfer) upon completion of the course and the post seminar questionnaires.

C. Apparatus

Participants were provided with an Oculus Quest or Quest 2 VR HMD that automatically loaded the necessary testing

software to the registered participants from the Oculus App Lab developer module. Testing and questionnaires were completed on personal computers or mobile tablets within a standard browser.

The 27-minute seminar "The Creative Process of Making an Animated Movie" was presented in an audio-visual format on a large screen with the professor, an experienced animation producer (embodied in a human-like avatar), located behind the podium (see Figure 4 below). The content consisted of charts and videos that described the creative process including sections related to the idea, story structure, characters, aesthetics, prototyping, and key creative roles. Popular movie examples were first analyzed (The Lion King, Monster's Inc), a new movie idea was presented and walked through each stage of the process to demonstrate how to approach the problem from scratch.

Experiential learning theorists might advocate for a more participatory role in the learning process, but this content is not a hands-on process or skill. This subject matter (digital storytelling) within the community of practice (an animation studio or animation theatre) facilitates peripheral participation in the manner presented in this VR seminar. An expert producer, creator, or showrunner would share ideas and examples while the student writers or interns attend the creative sessions, observe, and listen. The process becomes more collaborative over time, but earlier stages of creative projects typically focus on dispensing information to create a common understanding of the process, culture, roles, and key creative challenges.

To properly isolate and measure the specific context priming effect of the VR environments independent of other priming or ad hoc teaching influences, we opted to create a very simple, predictable teaching format; a lecture presented as a pre-recorded, non-interactive experience. The audio and visual course content was identical for all conditions (rendered from the same source files). Within the second Prime condition (theatre with animation artifacts), the artifacts were comprised of popular culture animation movie icons and imagery that iterated every 2-3 minutes above the main content presentation screen (similar to web banner). The artifacts/posters at the sides of the classroom did not change with the specific intent of limiting visual distractions away from the main content screen at the front of the theatre.

The multiple-choice questions (20) related directly to the content presented in the seminar. Certain questions (15) required the student to apply what they had learned from the theory while others (5) challenged the student to choose solutions that applied what they had learned from the new movie idea presented. Presented below are two examples; the first, a theory question based on story structure, the second, an applied question based on a new idea provided.

1) Example Question 1:

Joseph Campbell suggests that the "Hero's Journey" represents myths and rituals that are typically associated with the following in most cultures.

A. Battles between good and evil.

B. A story to explain nature and cosmic events.

C. An initiation process.

D. None of the above.

2) Example Question 2:

Parallel Parker is a universe hopping animated hero with a big job; to save the world. Based on your new insights, what would make a good log line for our new Parallel Parker movie?

A. Parker is young and fearless and with the help of her intergalactic friends, she is destined to save the universe.

B. A stressed-out pre-teen, whose main skills are avoiding school and binge-watching TV suddenly realizes that she, along with her cosmic alter egos, must stop an evil supervillain intent on stealing all that is good from the universe.

C. A super-villainy, interdimensional entity decides to wreak havoc on the universe by sucking up all the positive energy, leaving the rest of the universe to slowly rot.

D. A young, reluctant girl is faced with the decision of her life. Stay home and chillax or get off her butt and save the world. When the chillaxing thing goes wrong, she's forced to save the world instead.

The UX survey consisted of 22 questions related to the various aspects of the experience and a further 6 questions related to feelings of presence. To compare the presence responses, we used the Slater-Usoh-Steed (SUS) version administered immediately after the main UX questions were presented [35][42]. To measure anxiety, we used the short-form State-Trait Anxiety Inventory (STAI) questionnaire [27]. The STAI survey presented six multiple choice questions related to anxiety levels while affect was measured with the Positive Affect Negative Affect Schedule (PANAS) [40]. The PANAS survey presented 20 questions in a multiple-choice grading format to assess positive and negative aspects of mood.

Fig. 4A. No Prime.

Fig. 4B. Prime (animation artifacts).

Fig. 4C. Prime (animation studio) front.

D. Procedure

Given the limitations caused by the COVID-19 social distancing requirements, we designed a study that could be performed independently by participants at their homes. The apparatus was dropped off and picked up at participant sites by the research team. Proper disinfection rules were followed between each device use. Each participant received a unique participant code which was used to link the pre and post seminar questionnaires and results. Participants were also provided a link to a website that provided the following information.

- Short Video Guide
- Consent Form
- Pre-Post Test Surveys (STAI and PANAS)
- Post Seminar VR User Experience Survey
- Post VR Seminar Content Test

Upon completion of the short video guide (a 2-minute explanation of the process), and signed consent, participants were asked to complete a short STAI and PANAS survey, then proceed to the immersive VR seminar within the HMD. The VR experience was available as a VR application that was loaded automatically onto the HMD using the Oculus App Lab utility. Upon completion of the seminar, participants returned to the website to complete the UX, STAI and PANAS surveys and multiple-choice content test.

IV. Results

We had a 1x3 experiment design with one independent variable (Priming condition – Prime vs. No Prime) and three dependant variables (academic performance, UX satisfaction, and affect). After reviewing the outlier data, we opted to eliminate the highest value from each of the three conditions to avoid skewing results based on potentially contaminated data. These high values occurred for academic score and were more than twice the average. They came from participants who were very familiar with the subject. Hence our sample size was reduced to 16 participant inputs per condition. With an equal number of participants (16) we first conducted a single factor ANOVA test for academic score and data samples.

After confirming significance of mean departure within the conditions (p=.0099), we performed a post-hoc t-test with 2 samples, assuming equal variance. We observed significance in both priming conditions compared to the No Prime condition (Prime (artifacts) vs. No Prime (P=.0023) and Prime (animation studio) vs. No Prime (P=.0103)), With t stats of 3.05 and 2.44 respectively (>2.0) we are confident with the results. There was no significant difference observed between the two Prime conditions. See comparisons of academic performance for both Prime conditions vs. No Prime condition in Figure 5 below.

t-Test: Two-Sample Assuming Equal Variances	Artifacts Prime	No Prime	Animation Studio	No Prime
Mean	11.94	9.6875	11.44	9.6875
Variance	4.86	3.83	4.4	3.83
Observations	16	16	16	16
Pooled Variance	4.35		4.11	
Hypothesized Mean Difference	0		0	
df	30		30	
t Stat	3.05		2.44	
P(T<=t) one-tail	0.0024		0.0104	
t Critical one-tail	1.6973		1.6973	
P(T<=t) two-tail	0.0047		0.0208	
t Critical two-tail	2.0422		2.0423	

Fig. 5. Prime (artifacts) and Prime (studio) vs. No Prime.

Both PANAS and STAI observed positive changes, most likely because of the immersive VR experiences that have been shown to elicit positive affective responses [15], but in line with research related to the supraliminal aspects of priming [29], we did not observe a significant difference in either case comparing the Primes to the No Prime condition. The average presence results for all conditions were strong (>5).

The UX and Affect results are presented in Figures 6, 7 and Table 1 below. In Figure 6, we consolidate the positive and negative affect results from Table I, to visualize the net positive effect.

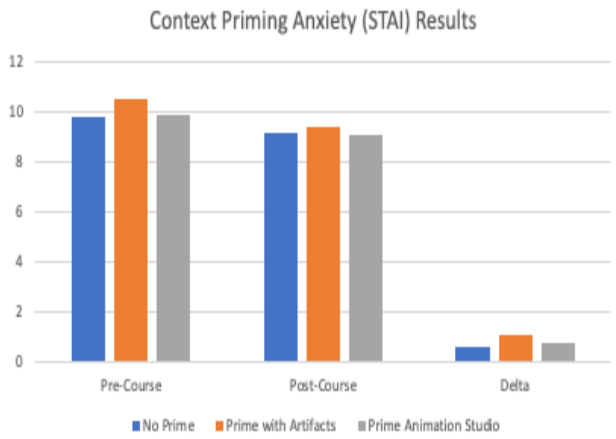

Fig. 6. Comparing pre and post course anxiety levels.

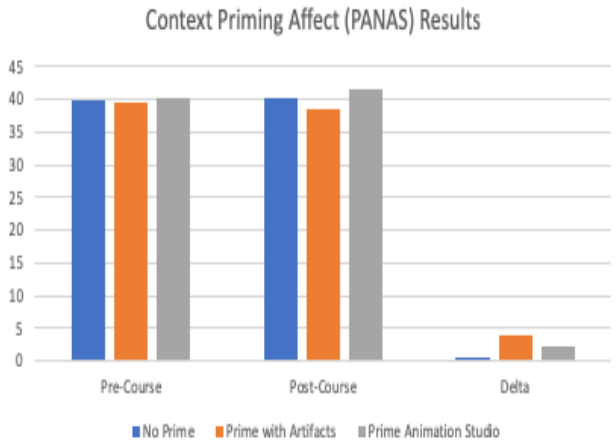

Fig. 7. Comparing pre and post course net positive affect levels.

TABLE I. AFFECTIVE RESULTS FOR ANXIETY AND POSITIVE AFFECT

Affective Results			
Average STAI Scores	**Pre Course**	**Post Course**	**Anxiety Reduction**
Prime Artifacts	9.8	9.2	0.6
Prime Animation Studio	10.5	9.4	1.1
No Prime	9.9	9.1	0.8
Average	10.1	9.2	0.8
Average Positive Affect	**Pre Course**	**Post Course**	**Positive Affect Increase**
Prime Artifacts	28.7	29.1	0.4
Prime Animation Studio	26.2	27.7	1.5
No Prime	27.9	29.9	2.0
Average	27.6	28.9	1.3
Average Negative Affect	**Pre Course**	**Post Course**	**Negative Affect Reduced**
Prime Artifacts	11.3	11.1	0.2
Prime Animation Studio	13.2	10.9	2.3
No Prime	12.3	11.7	0.6
Average	12.3	11.2	1.0

1) UX Commentary Feedback

There were dozens of unique comments that validated designs and/or recommended improvements to the VR experience. A sample of the more salient comments are presented below. We do not differentiate comments between Prime and the No Prime conditions as all VR conditions elicited both positive and negative feedback, which was consistent with the affective data.

2) Example Positive Comments

- Felt real and engaging
- When in VR classroom, you feel totally immersed
- Far better than wearing a mask for 2 hours trying to hear what your prof is saying.
- It reminds me of the university setting but with the elimination of the anxiety.
- When focused on the lecture I enjoyed the information and was surprised at how much it felt like a real classroom.

3) Example Negative or Mixed Comments

- Not quite real enough though better than zoom
- Sometimes images would distort which reminded me that I was in a virtual space rather than a real one.
- Issues of image resolution and inability to take notes.
- I found myself very tired and not able to focus
- During my experience, I'd repeatedly remind myself that as real as it seems it's merely a virtual world.

V. DISCUSSION

In reviewing the first hypothesis (H1), both Prime conditions observed significant improvement over the No Prime condition, while there was no significant difference between two priming contexts. Hence, H1a and H1b are both supported. The priming conditions improved academic performance. In reviewing the second hypothesis (H2) (UX), neither Prime condition demonstrated significance over the No Prime condition. Hence, H2a was not supported. The Prime conditions did not observe significance between themselves with respect to UX results. Hence, H2b is supported. In summary, Prime conditions did not improve the perceived UX compared to the No Prime condition or between Prime conditions.

There was a great deal of relevant feedback provided through the UX study that will inform future design. In general, it was a very positive experience where most participants felt a strong sense of presence and were sufficiently engaged in the content.

That said, image resolution and blurriness appeared to be a distraction for some and as such, most likely reduced immersion, and presence effects. Striving to eliminate issues of blurriness, aliasing, or any image resolution issues should be a major focus in future environment and character designs for VR spaces.

Further, the seminar for this study was a creative process that was conducive to collaborative, community-based learning and was suited well for both the ELT cycle and an SLT learning effect. For future research, determining the effect of context priming for different subjects of study will be necessary. Would science or math related courses gain more from priming activities than the creative arts? Also, it is critical to explore additional priming methods within the ELT cycle, such as preparatory, motivational, and reflective priming, and the combined effect of deploying multiple priming intervention methods concurrently.

Finally, as accessibility is critical and not everyone can use a VR HMD, assessing the effectiveness of priming in non-immersive VR environments could inform the design of new or varying priming strategies.

VI. Limitations

Part of the Information Technology (IT) challenge with VR HMDs is that one size does not fit all participants. Some participants may have benefitted from optical lenses that improve the visual experience without the need for glasses. In a non-COVID study, where participants would have had immediate, in person feedback from researchers, most of the visual distortion issues could have been easily mitigated on the spot. The challenges of testing remotely with new technology were significant. Technology glitches or even minor issues are easily alleviated with "in person" IT support and multi-person sessions that can be scheduled in advance. The deployment of each HMD required at least one and most often 2 to 3 email or phone exchanges to support or help the participant feel comfortable. That said, the remote process was the only possibility solution for university researchers in 2021 and the research team was able to complete the testing and maintain the integrity of the process.

There were limitations to be considered for future research. First, these studies are small numbers and could benefit from a much larger study. Affective surveys (anxiety and positive affect) were subjective user responses. Ideally, to properly assess positive affect and anxiety levels, an fMRI to monitor brain activity and/or a molecular imaging solution to measure dopamine release and other neurotransmitter levels could be used while content is observed, and the tests are administered.

While the UX and affective measurements were secondary to the core study, comparing the UX and Affect data in Primed and Non Primed VR environments did provide insights into future designs and the overall emotional impact of the technology solutions.

VII. Conclusion

Motivated by the disruptive potential of immersive VR, we wanted to understand the priming potential of VR environments to improve student performance. In our study of 51 participants, with three conditions (2 Prime, 1 No Prime) we observed a clear priming effect that we attribute to the impact of situated learning induced by simulated animation studio and the effect of subject matter artifacts situated in the VR learning space.

We discussed future areas of research that included further priming methods, varying subject matter, and exploring the effects of concurrently deploying multiple methods of priming.

We proposed further study related to other potential trigger points within the ELT that could Prime positive motivation and reflective activities to facilitate the student to better reconstruct knowledge and experience. We also proposed further research to better understand the neuropsychological mechanisms at play with various priming methods.

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