VR-based Student Priming to Reduce Anxiety and Increase Cognitive Bandwidth

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ABSTRACT

Recent research indicates that many post-secondary students feel overwhelming anxiety, negatively impacting academic performance and overall well-being. In this paper, based on multidisciplinary literature analysis and innovative ideas in cognitive science, learning models, and emerging technologies, we introduce a theoretical framework that shows how and when priming activities can be introduced into the experiential learning cycle to reduce anxiety and increase cognitive bandwidth. This framework proposes a Virtual Reality based priming approach that uses games and meditative interventions. Our results show this approach's potential compared to no-priming scenarios for reducing anxiety and significance for VR gaming in improving cognitive bandwidth.

Keywords: Anxiety, scarcity, priming, virtual reality, games.

Index Terms: Applied computing – Education – Computer-assisted instruction; Human-centered computing – Human computer interaction – Interaction paradigms – Virtual reality

1 INTRODUCTION

In a 2017 survey by the American College Health Association (ACHA), 40% of college students said they had felt so depressed in the prior year that it was difficult for them to function, with over 60% experiencing overwhelming anxiety in that same period [1]. The 2018 follow-up to the 2017 ACHA study yielded similar results where over 62% of students said they had felt overwhelming anxiety in the previous twelve months. Anxiety disorders are among the most critical challenges facing post-secondary students today, negatively affecting students' academic performance and general well-being [1,7]. Emotional engagement is critical to successful learning, and high levels of anxiety can negatively affect students' ability to engage, diminishing the learning experience, and the overall learning [47].

The American Psychological Association (APA) describes anxiety as the feeling of worry, nervousness, or unease about something with an uncertain outcome, and while anxiety is often perceived as a negative process, it derives from our primal need to prepare and respond to potential dangers [39].

This response is a critical evolutionary process but can become a problem when it is not relevant, proportionate to the threat, or is sustained for a prolonged period of time [33,49]. This chronic state of anxiety is the focus of this paper.

While it has been shown that emergent technologies such as computer games and Virtual Reality (VR) can have positive emotional impacts [12], there is no comprehensive and interdisciplinary research that shows how, and based on what theoretical models, that can be used in an educational context to prepare students for a better learning experience.

To better understand the sources of anxiety, we review specific cognitive biases and mindsets that co-present with anxiety. We specifically argue that anxiety is an aspect of "scarcity mindset"; a self-limiting perspective that appropriates cognitive capacity required for essential processes like learning in favour of meeting more critical needs or perceived insufficiencies. Central to this problem is the concept of cognitive priming. Generally referred to as "priming", it is a framework that uses a prime stimulus or action to affect the information processing availability of a subsequent idea or experience [18,31]. Information processing availability or cognitive bandwidth, in this context, refers to both cognitive capacity and executive control capabilities [18,31]. The priming cases presented in our research indicate that priming for positive affect (improved mood) reduces anxiety, improves creativity, and cognitive performance [2,28] while priming scarcity concepts reduce cognitive bandwidth and academic performance [43,44].

Our literature review suggests technology solutions most relevant to addressing the student anxiety problem. While VR, Artificial Intelligence (AI), video games, and biometrics offer significant potential, VR and video games appear to demonstrate the most promise [21,23,15]. Cognitive priming techniques, VR, and video gaming technology in their own right have been shown to reduce anxiety [10] and improve learning outcomes in other applications but the "who, what, where and when" of combining these technologies and applying these collective insights digitally remain largely unanswered.

Based on the set of interdisciplinary insights derived from our literature review, we propose Cyclical Priming Methodology (CPM), as a comprehensive approach to use cognitive priming throughout the learning cycle. CPM can be used with different technologies and methods, and aims at reducing anxiety and increasing cognitive bandwidth, which together can improve academic performance and well-being. We also propose Virtual Reality Experience Priming (VREP), a VR-based gaming and meditation experience that is built on the CPM concept and demonstrates the abilities of the framework. To evaluate CPM and VREP, and to see if VR games and VR meditations can be used effectively in priming, we performed a user study. We used the Beat Saber VR game [57] and a custom-designed nature meditation application for this VR experience test and measured anxiety and cognitive bandwidth using the State Trait Anxiety Inventory (STAI) questionnaire and the University of California Matrix Reasoning Test (UCMRT) respectively.

Our research confirmed the potential value of VREP, particularly VR games, for reducing student anxiety and increasing cognitive bandwidth. In the following sections, we present our literature review and the analysis and insights, theoretical basis of CPM and VREP, the experiment design,

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results, and discussions. Some directions for future research and concluding remarks are offered at the end.

2 Related Work

2.1 Understanding Anxiety

Anxiety can have an extremely negative impact on learning performance and general health [9,76]. In situations of intense anxiety, social judgment and cognitive performance suffer [20]. Chronic anxiety creates a scarcity mindset that appropriates necessary cognitive resources when individuals feel their resources are insufficient to meet their needs [45].

There is, however, growing evidence that daily routines such as mindfulness programs [14,26,42], gaming [9], and daily nature walks [11] can have mitigating effects on anxiety. Whether through increased working memory capacity or increased positive affect, research shows that reducing anxiety can improve cognitive bandwidth and academic performance [15].

2.2 Cognitive Biases and Scarcity

While we may assume that we are in complete control of our decisions, there are myriad influences and biases that shape our perceptions and affect how we think, feel, and act. These cognitive biases or mindsets are lenses through which we experience our world. Often evolutionary in nature, these biases may have helped us survive in the past but can make us vulnerable to external influences in our changing world [25,30,39,41,52].

These biases effectively create a Scarcity Mindset that preconditions us to focus our mental and physical energies on meeting the most pressing needs at the expense of other important goals [43,44,53]. This mindset can make us more effective in provisioning for basic survival requirements but may create barriers to learning and other critical, yet less-urgent activities. And while this may create powerful short-term capabilities, the longer-term consequences are negative and degenerative [47,49]. In a classic scarcity study at a suburban New Jersey shopping mall [43,44], participants were given Raven's Progressive Matrices (RPM) fluid intelligence tests before and after being exposed to different financial problems. The researchers observed that participants with lower income scored 13 IQ points lower on the second, post-experiment test, which was preceded by a more financially dire priming scenario. The researchers concluded that this group had been induced into a scarcity mindset that diminished cognitive capacity in the more consequential scenario. The scarcity mindset, as evidenced in the study above, exhibits critical effects such as reduced cognitive bandwidth, disproportionate thinking, vulnerability to distractions, and scarcity deficits [43].

2.3 Cognitive Priming

The studies presented above [43] illustrated that the most subtle priming techniques could have profound effects on our mental mindsets and cognitive capabilities. Priming occurs because the prime stimulus makes the content and subsequent cognitive processes more accessible, potentially influencing all stages of information processing: attention, comprehension, memory retrieval, inference, and response generation [22,59]. Generally, priming stimuli are subliminal (brief and not detectable to the individual who is exposed) or supraliminal (detectable yet not obvious to the individual).

While there are many different ways to administer a positive priming stimulus, our research showed the most common methods included positive affect priming (creating positive emotions or feelings of joy) [29], mental mindset conditioning (e.g., meditation or mindfulness) [14], motivational messaging or imagery [9], repeated content exposure [62,63] and attentional controls [27]. In this study, we focus on positive affect priming and mental mindset interventions.

2.4 Positive Affect Priming

Conscious supraliminal activities like positive affect priming demonstrate a positive impact on information organization and creativity. In a 1987 study [29], 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 [55].

Video games can also have a positive effect on mental mindsets enabling participants to achieve flow states (powerful experiences reflecting intense focus and oneness of mind and body) [16,21]. Conversely, negative affect priming causing negative feelings can cause mental strain, reducing cognitive flow and creativity [29,32]. We might consider positive affect priming to be a lubricant for the associative network of ideas. Daniel Kahneman uses the analogy of water flow and argues that any process that induces ease can have a similar effect. Calm waters allow more flow than stormy waters [32,42].

2.5 Learning Theories and Motivational Mindsets

Various learning theories can help us understand and contextualize the concept of cognitive priming. Behaviourism and associative learning evolved from the work of early thinkers like Pavlov and Skinner who introduced classical conditioning (a process that pairs stimuli to achieve similar learning responses) and operant conditioning (uses rewards/punishment to effect learning) [13,51]. This research is used extensively in game design today. Strictly controlled narratives and the scheduling of rewards derive directly from Skinner's operant conditioning, so much so that computer games are sometimes referred to as Skinner boxes [61].

Non-associative learning (processes that use repetitive exposures to affect stimuli salience) like habituation and sensitization, are also useful tools to effect permanent changes to stimuli [56]. Habituation is used in cognitive based therapy (CBT) [12] to diminish fears and phobias in patients. Alternatively, sensitization techniques can be used to heighten sensitivity to stimuli that may predict high risk scenarios. Furthering the concept of repetitive exposure, Robert Zajonc demonstrated that "mere exposure" repetition paired with non-negative consequences can heighten the affective response and perceived authenticity of the information or stimuli [62,63].

The emotional/affective domain of learning is also a critical element to consider. Bloom's taxonomy and Social and Emotional Learning (SEL) theories are constructed upon the notion that learners are social and emotional beings, and as such pedagogical methods should take their affective concerns into account [8,14,31].

Carol Dweck's Mindset research suggested that if students believed that their intelligence and academic success was within their control, malleable, organic, and capable of growing, they experienced greater academic success than students who believed that intelligence was "predetermined," and that they were not in control of those factors [19]. Albert Bandura's Self Efficacy theory similarly draws causal connections between self-efficacy mindsets (the confidence and willingness to try and fail) and academic performance, suggesting that finding methods to prime growth mindsets and self-efficacy could have lasting academic effects [3,4,5,6].

Due to the subtle nature of cognitive priming and how it can be woven into our life experiences, of particular interest for our research was Kolb's Experiential Learning Theory (ELT) [34,35]. According to ELT, learning begins with having a concrete experience, followed by a reflection of that experience, then the conceptualization of abstract concepts that incorporates the new insights from the experience with existing conceptual models and finally active experimentation of the lessons learned. The cycle continues to repeat as the learner's conceptual worldview is repeatedly refined. The cycle is presented in Figure 1. Learning is best achieved as a process: a continuing reconstruction of experience. While experiential learning presents a simple and elegant thought paradigm, it can also be affected by negative influences in the real world. In his 1998 analysis of the experiential learning cycle, Russ Vince argues that anxiety can have a very negative effect on the learning cycle, effectively breaking the cycle, creating defensiveness, and an inability to learn [54].

ELT and its cycle can provide insight into what types of priming activities should be considered to provide more hands-on engagement and when, during the learning cycle, they can be applied. Such guided priming can then lead to reduced anxiety, increased motivation, improved mental health and ultimately better learning outcomes. See Figure 2.

Combining the insights from the above priming and learning literature, we propose the following features to be among the essential needs of any educational priming system:

- Attentional controls to provide focus and reduce cognitive strain [27,32,53].
- Customization to provision for different scenarios based on the user's characteristics and needs [48].
- Identity development (personal characteristics, representation, embodiment, etc.) to increase engagement and help with self-perception [35].
- Interactivity for more hands-on learning and engagement [15,34,35].
- Presence and suspended disbelief to achieve the state of flow and total engagement [15].

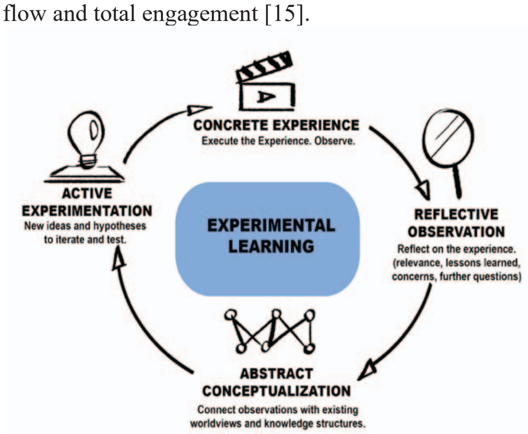

Figure 1: Experiential Learning Theory (ELT)

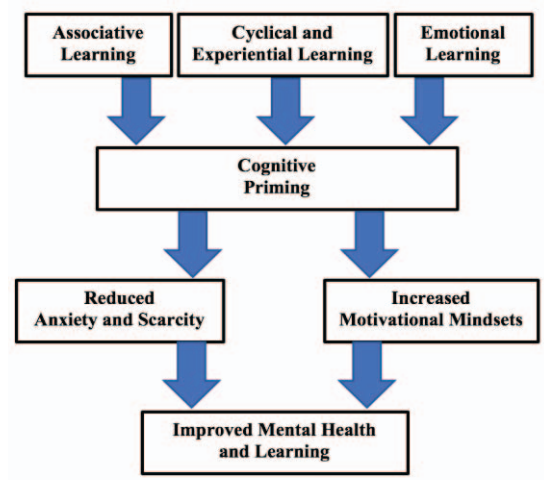

Figure 2: A model of learning, priming, and anxiety

2.6 Technology Solutions

In a recent post-secondary study from Kent State, technology and social media consumption were positively correlated to anxiety and negatively correlated to GPA performance [36,37]. Further studies suggested that cell phone usage also contributed to less cardiovascular exercise and more sedentary behaviour [38]. This seems to support a common perception that technology and social media may be the negative influence that ails our students. While there is evidence to suggest that technology usage may be a contributing factor to anxiety, the opposite may also be true; that technology solutions can offer mitigating effects to this chronic anxiety. In our literature search on the technologies used in relation to student anxiety, we identified the leading candidate technologies that have demonstrated the potential for mitigating and reducing anxiety effects. VR technology is proving valuable in cognitive-based therapy applications and in priming creativity and increasing cognitive bandwidth through positive affect inducement. Gaming technology, specifically casual video games (CVG), allows the anxious student to escape into a state of flow as a partial alternative to anti-depressants [15,21].

There is growing empirical evidence suggesting that virtual reality exposure therapy (VRET) [12] can become a viable, mainstream treatment alternative for phobias and various anxiety-related disorders. Efficacy rates for VRET are comparable to other forms of in vivo (real-world exposure) cognitive based therapy (CBT) [12]. CBT is a structured, goal-oriented form of psychotherapy that helps people learn how their thoughts, attitudes, and beliefs relate to the emotional and behavioural reactions that cause them difficulty. While CBT uses in vivo exposure techniques to diminish fears or negative thought patterns, VRET offers the possibility of creating an environment to face those fears that might otherwise be too costly or inaccessible. One VRET study followed the use of automated psychological coaching therapy using immersion therapy to treat fear of heights. The VRET solution showed considerable improvement over the control group, which was sustained in subsequent follow-ups [10]. With regular CBT, exposing a patient to tall buildings or even spiders can be costly and unsafe. With VRET, this exposure therapy is now safe and affordable.

Games have demonstrated therapeutic effects that can aid in reducing dependence on Selective Serotonin Re-uptake Inhibitors (SSRI) anti-depressants. One of the most compelling examples of this was demonstrated in a 2018 study called

Zombie's verses Anxiety: An Augmentation Study of Prescribed Video Game Play Compared to Medication in Reducing Anxiety Symptoms [21]. Results demonstrated that the CVG/one medication combination under a prescribed condition, reduced state anxiety (transitory emotional state) more effectively than the medication-only scenario. The study applied flow as a theoretical framework, and participants claimed to have achieved flow state after 30 minutes of gameplay, which occurs only in the absence of anxiety [16,21]. These findings are significant and suggest that gaming interventions may offer non-invasive and cost-effective companions or alternatives to medications. A further study on the effect of anxiety levels on learning performance found that digital game-based learning was beneficial to high anxiety learners. At the same time, there was a negligible effect for learners with low anxiety [60].

AI-based Intelligent Virtual Agents (IVA) and other forms of social and learning avatars also show great promise within the learning environment [50]. Studies have demonstrated that the animated avatar virtual coaches yield better results than the other chosen methods of treatment by the control group [23]. In addition to AI, biometrics combined with machine learning algorithms are becoming valuable tools of data acquisition and analysis, providing high degrees of personalization and situational customization. In a 2015 study [48] researchers analysed 30 days of data collected from wearable sensors and surveys in an effort to predict mood, happy or sad, from daily behaviours and previous sleep history. Neutral interactions and total academic hours were shown as differentiators between happy and sad groups, while the machine learning analysis resulted in a 70-82% prediction accuracy when using one to five nights of previous sleep analysis. These results were not accurate enough to suggest the use of this technology in behavioural prompting but could provide a data for improved understanding of a student's propensities and vulnerabilities.

Each of these technological approaches offer unique affordances that can be useful educational tools to augment cognitive priming initiatives. For example, games can capture attention and engagement in custom worlds that induce flow and reduce anxiety. Through its immersion, VR offers powerful engagement, interaction, and attentional control mechanisms by affording new custom worlds where distractions can be minimized, and specific priming nuances can be built into the design of environments and avatars. In doing so, participants can be exposed to various challenges in programmed scenarios. While many studies have demonstrated the value of VR, Gaming, AI, and biometrics solutions working independently, it is logical to assume that the effect of combining these technologies would amplify the value of any one technology solution. In this paper, we focus primarily on the use of VR environments and VR Games.

3 Proposed Solution: A Theoretical Framework

3.1 Cyclical Priming Methodology (CPM)

Building on cognition, learning theories, and technology insights, we propose a Cyclical Priming Methodology (CPM) that exploits these learned insights: where high anxiety and scarcity mindsets are transformed into abundance thinking. This theoretical framework could provide the basis for a technology platform to reduce student anxiety and increase cognitive bandwidth. See Figure 3.

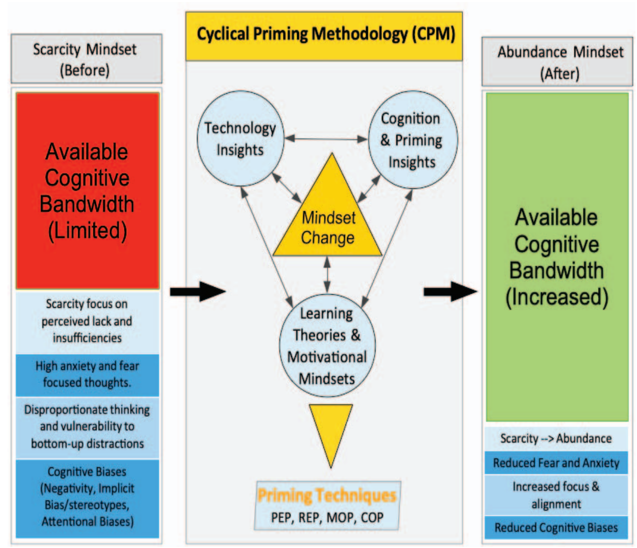

Figure 3: Cyclical Priming Methodology (CPM)

CPM offers a transformational process used to change negative mental mindsets to more optimal learning mindsets with reduced anxiety and increased cognitive bandwidth. The priming strategies create positive associative learning effects to facilitate improved emotional learning. Strategies may include positive affect inducement, relaxation, mental conditioning (meditation), motivational messaging, repeated content exposure, and attentional controls. To accommodate these priming strategies and techniques, and based on the insights developed earlier, CPM best practice guidelines are defined as follows:

- Focus on priming activities that generate calm, improve motivational mindsets, or induce positive affect.
- Deploy priming interventions within controllable environments to enhance presence and believability.
- Create scenarios where participants are able to think from "others" lens to increase empathy and reduce stereotypes.
- Use repetitive exposure techniques to create ease and familiarity with foreign ideas, concepts, or cultures.
- Use the ELT cycle to iterate and simulate within the learning process.

As shown in Figure 3, CPM proposes the following four unique priming intervention techniques:

- PEP - Pre-Learning or Preparatory Experience Prime
- REP - Post-Learning or Reflective Experience Prime
- MOP - Motivation Oriented Prime
- COP- Context Oriented Prime

These interventions allow priming at the start of educational activity but also throughout the learning experience. While priming is typically defined as a stimulus that affects the information processing of subsequent concepts or actions [31], we propose and use a more general definition that applies priming to other phases as well within the ELT. An example of a pre-learning or preparatory experience prime (PEP) might be a short game, nature walk, or funny story before a class. A post-learning or reflective experience prime (REP) might be a prompt that asks the student to consider the relevance to a real-world situation that they may have experienced. Motivation Oriented Primes (MOP) are delivered within the context of the learning experience and could be as simple a "fun fact" delivered between learning modules as a way of inducing positive affect or a growth mindset reminder like, "Did you know that 90% of students have rated this module as critical to their development"? Finally, a Context Oriented Prime (COP) could be the process of designing an anxiety-reducing environment that the student can exist within. Even subtle effect like an inspiring mountain scene or the sound of a stream in the background can provide a calming effect.

If we were to apply these CPM priming techniques (PEP, REP, MOP, and COP) into the ELT cycle, it would be applied as illustrated in Figure 4 below. While most of the priming interventions are front-loaded to coincide with the actual experience, a REP could occur at any time within the cycle: after abstract conceptualization or active experimentation.

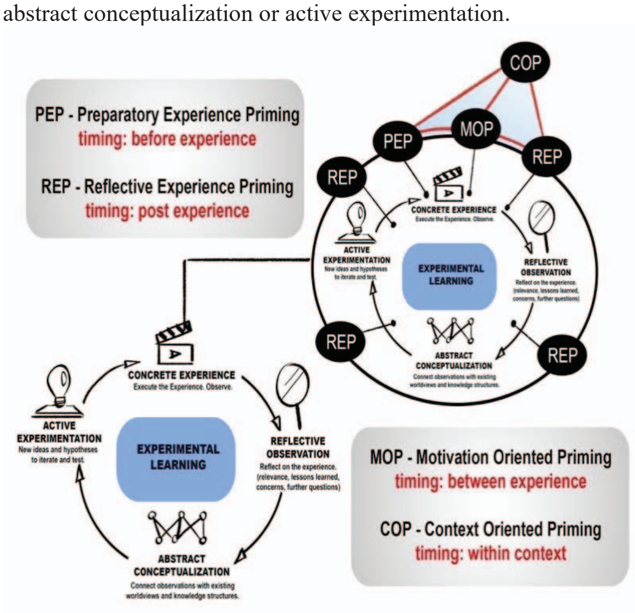

Figure 4: Applying CPM priming methods to the ELT cycle

3.2 Virtual Reality Experience Priming (VREP)

Building on the proposed CPM best practice guidelines, we propose a specialized educational model called Virtual Reality Experience Priming (VREP). VREP is a specific implementation of CPM that exploits the unique affordances of VR [21,23,27]; notably, attentional control, presence, and the ability to create worlds and simulative scenarios that would otherwise not be possible. We compare VREP to VRET, a proven model that successfully deploys CBT (as discussed in Section 2.6). Similarly, VREP will deploy the processes of CPM. VREP is to CPM as VRET is to CBT. The VRET process is presented in Figure 5.

VRET, like in vivo CBT, utilizes habituation techniques; an iterative process of exposure to fear stimulus [12,56,65]. Once that level of fear stimulus is diminished, the stimulus will be elevated to a higher level and re-iterated until the fear or phobia is fully extinct. VREP similarly uses iteration and repeated exposure techniques but for differing objectives: educational vs. therapeutic. Where VRET typically focuses on repeatedly exposing and overcoming negative stimuli in a therapeutic context, VREP focuses on priming positive affect, calm, or motivation in the context of an educational experience intending to reduce anxiety and increase cognitive bandwidth. While VRET uses repetitive exposure in the absence of negative consequences to reduce fear, VREP uses positive emotional exposures to achieve optimal mental states for learning [62,63].

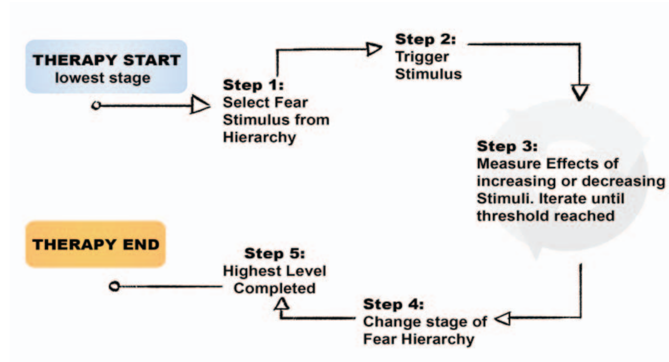

Figure 5: VRET process: a proven model [12]

As viewed in Figure 5, VRET may require many iterations to improve mental states while the VREP process is more ephemeral and can have an immediate impact on cognition. A conceptual model of VREP in the context of an educational experience is presented in Figure 6. The priming strategies are activated within the ELT cycle; before, after, within the content, and within the context of the educational experience.

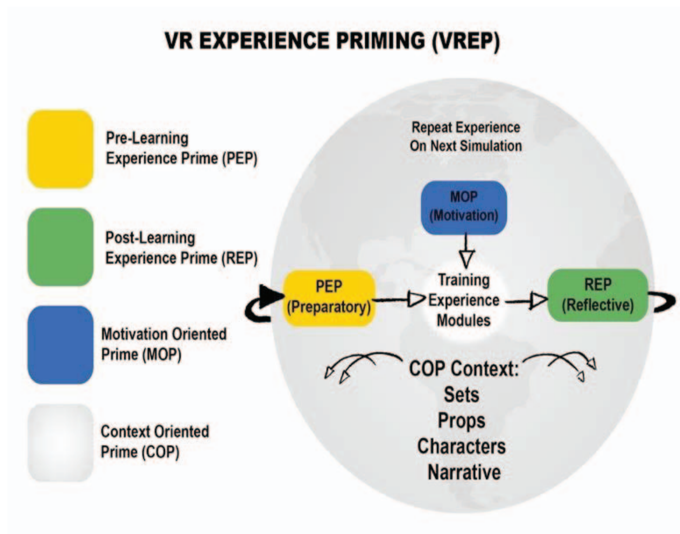

Figure 6: VREP: an emerging model

4 Methodology

We conducted a user study to perform an initial evaluation of CPM and VREP. Investigating the full CPM framework with all four priming intervention techniques, and within the context of VREP requires complex design and implementation, especially for interventions that match the educational content. While that is our long-term goal, as a starting task, we aimed at investigating the potential value of CPM/VREP through evaluating a relatively simple case of VR-based intervention most suitable for Pre-learning Experience Prime (PEP). We included VR-based games and meditation as the priming method. 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.

4.1 Design

Our research intent is twofold. Given that Meditation and Games have been shown to work in other "real world" contexts to reduce anxiety and increase cognitive bandwidth, we hope to determine first, whether they do work within fully immersive VR environments and second, their relative efficacy. While we are interested in the general effectiveness of VR Priming, Meditation and Games represent different unique approaches (mental conditioning vs. positive affect inducement). Hence, our hypotheses are presented in Table 1.

Table 1: Research hypotheses

H1a. VR Meditation can reduce anxiety levels.
H1b. VR Meditation can increase cognitive bandwidth.
H2a. VR Gaming can reduce anxiety levels.
H2b. VR Gaming can increase cognitive bandwidth.
H3a. VR Gaming will be more effective than VR meditation for reducing anxiety.
H3b. VR Gaming will be more effective than VR meditation for increasing cognitive bandwidth.

Based on this goal, we designed an experiment with two independent variables: (A) priming method (game vs. meditation) and (B) priming condition (primed vs. no primed). Participants would be divided into two groups based on variable A and would do both options of variable B (primed and no-primed game, and primed and no-primed meditation, in random order). This 2x2 design resulted in a mixed-method (between and within-subjects). The dependent variables (measurements) for each of the four cases were anxiety and cognitive bandwidth.

4.2 Participants

The user study was performed with 56 participants between the ages of 17 and 48. 46 of the participants were university students, 30 participants identified as female, 26 as male. (N=56, F=30, M=26, S=46, NS=10). They were randomly divided into two groups corresponding to games and meditation priming, with 30 and 26 members, respectively. The group sizes were not equal due to some assigned participants who did not finish the experiment and could not be replaced later, due to logistic limitations. Participants were paid $30 CDN or given with a Tim Horton's Gift Card of equivalent value.

4.3 Apparatus

All participants were provided with an Oculus Quest VR headset for the gaming and meditation activity and a 7th Generation IPAD for the cognitive testing. All headsets and tablets had the exact same system specifications. We considered the guidelines presented at the end of Section 3.2 for selecting and designing our VR-based interventions as much as possible. We particularly focused on the first guideline, creating virtual worlds and experiences that motivate, induce positive affect, and calm the mind.

The software used for the game priming was the Beat Saber Demo game on the Oculus Quest. The app is one of the more popular applications on the Oculus Quest, mostly due to the "fun factor" and its ability to generate a positive affect. The process is very simple and lasts 2 minutes and 35 seconds. Users must user their sabers to slice oncoming blocks and circles in an optimal manner while energetic music plays in the background. We requested users play the demo round twice for a total of 5 minutes and 10 seconds.

The Meditation app was a custom-designed guided meditation application inspired and informed by the CALM app and recent research on mindfulness app evaluations [17,24,28,58]. It was created by the research team, using Unreal Engine, and sideloaded onto the Oculus Quest HMDs using the Sidequestvr program. As the participant enters the meditation space on a lofty mountaintop above a large body of water, they are met with beautiful nature sounds (waves, wind, and birds chirping), and after 15 seconds, a voice-guided meditation commences. The guided meditation is very simple, focusing primarily on noticing the beautiful scenery and bringing attention to the breathing process. The meditation process lasts for 5 minutes, at which point participants are asked to take off the headset to begin the next step. Images of the custom Meditation app and the Beat Saber game are presented in Figure 7.

Figure 7: Screenshots of apps used in the study

Our study required us to measure changes in two factors: anxiety levels before/after priming activities and cognitive bandwidth before/after priming activities. The anxiety was measured subjectively and using a questionnaire based on an approved shortened version of the STAI [40]. We chose the approved shortened version (6 questions) to maintain the flow of the experiment. We used UCMRT to objectiely measure the cognitive bandwidth. Similar to STAI, the UCMRT cognitive test was a shorter version of the industry-standard Raven's Progressive Matrices (RPM) test but designed for academic research [46]. The UCMRT presented 23 multiple-choice visual puzzles that were answered in a multiple-choice format within a 10-minute time limit. The front-end UCMRT application was presented on a 7th generation IPAD, and the data was collected on the University of California Riverside's backend cloud-based server. The app, downloadable from App Store or Google Play Store, is called "Recollect the Study" and is made available to the academic research community only [46].

4.4 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. To enable the process, our 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 was provided with the hardware, software, and a user guide explaining the process, and were given up to 48 hours to complete the study. Because our within-subjects study required two separate tests, one after the priming condition, the second after the no prime condition, we wanted to mitigate the possibility of any learning effect, whether through the specific test or the process itself. As such, we interlaced the priming process to alternate between the first test event and the second test event. Once our participants were confirmed, we randomized the list and slotted them sequentially into one of four conditions below: each method requiring two scenarios; one before and one after the cognitive test. A random code was given to each participant and entered in all steps to allow tracking and connecting the participant data anonymously.

- Meditation – Prime First Test, No Prime Second Test
- Meditation – No Prime First Test, Prime Second Test
- Game – Prime First Test, No Prime Second Test
- Game – No Prime First Test, Prime Second Test

5 Results

We had a 2x2 experiment design, two independent variables each with 2 two values. Our first variable (A) determined the game vs. meditation participant groups and was between subjects. The second variable (B) determined primed vs. no-primed measurements for the same participants within each group. This experiment design resulted in four sets of measurements and required a mixed model, so we ran a 2-factor ANOVA with one repeated measure for both anxiety and cognitive score data to see if there was any significant difference in between-subjects and within subjects-data. We then ran T-Test for prime and no-prime data for game and meditation separately, and also a T-Test between game and meditation with the change from no-prime to prime. These measurements were done for both cognitive bandwidth (objective) and anxiety (subjective). They were all continuous data and had a fairly normal distribution. This allowed us to use parametric methods such as T-Test and ANOVA. The ANOVA results are shown in Figure 8. We can see that for both anxiety and cognitive bandwidth, ANOVA shows significant difference along the variable B (prime vs. no-prime), while variable A (game vs. meditation) only has a significant difference for anxiety. Table 2 presents the Mean and Standard Deviation (SD) results for both conditions and both methods.

ANOVA Summary	2rows x 2columns				
A = groups: the between-subjects variable delineated by the rows B = the repeated-measures variable delineated by the columns					
Source	SS	df	MS	F	P
Between Subjects	945.86	55			
A	90.26	1	90.26	5.7	0.020495
Subjects within A	855.6	54	15.84		
Within Subjects	285	56			
B	116.04	1	116.04	37.07	<.0001
A x B	0.15	1	0.15	0.05	0.823907
B x Subjects within A	168.81	54	3.13		
TOTAL	1230.86	111			

(a) Self-Assessed Anxiety Scores from Short STAI

ANOVA Summary	2rows x 2columns				
A = groups: the between-subjects variable delineated by the rows B = the repeated-measures variable delineated by the columns					
Source	SS	df	MS	F	P
Between Subjects	2015.42	55			
A	52.91	1	52.91	1.46	0.232195
Subjects within A	1962.51	54	36.34		
Within Subjects	520.5	56			
B	58.58	1	58.58	7.31	0.009150
A x B	29.38	1	29.38	3.67	0.060701
B x Subjects within A	432.54	54	8.01		
TOTAL	2535.92	111			

(b) UCMRT Cognitive Test Scores

Figure 8: Anxiety and cog. priming w 2-factor ANOVA

Table 2: Mean/SD of anxiety and cognitive test scores

Statistical Results	Meditation Priming		Game Priming	
UCMRT Scores	Prime	No Prime	Prime	No Prime
Mean	12.3846	12.0385	12.0333	9.6333
Standard Deviation	4.6740	4.7030	0.5843	4.1893
STAI Anxiety Scores	Post Prime	Pre Prime	Post Prime	Pre Prime
Mean	8.6923	10.8077	10.5667	12.5333
Standard Deviation	1.4301	2.7389	3.3185	2.9564

Separate post-hoc paired t-test comparisons for meditation and gaming cognitive test scores clearly demonstrated significance for VR Game priming (P=.0007) with no significance shown by VR Meditation priming (P=.34). A similar test for anxiety showed significance for both games and meditation, with P values of .0003 and .000007, respectively. A further T-test comparing deltas of prime vs. no-prime between VR Meditation and Gaming for anxiety reduction yielded no significant difference (P=.41), while their difference in cognitive test results did demonstrate significance (P=.03), as shown in Table 3. This makes sense because for anxiety, both methods were successful, so had no significant difference, but for cognitive bandwidth, only game was successful. Based on the test results, we review our research hypotheses in Table 4.

Table 3: T-test results for cognitive bandwidth

t-Test: Paired Two Sample for Means		
Meditation Priming	**Prime**	**No Prime**
Mean	12.3846	12.0385
Variance	21.8462	22.1185
Observations	26	26
Pearson Correlation	0.5852	
df	25	
t Stat	0.4133	
P(T<=t) one-tail	0.3414	
t Critical one-tail	1.7081	
P(T<=t) two-tail	0.6828	
t Critical two-tail	2.0595	
P(T<=t) two-tail	0.1699	
t Critical two-tail	2.0595	
Game Priming	**Prime**	**No Prime**
Mean	12.0333	9.6333
Variance	27.1367	17.5506
Observations	30	30
Pearson Correlation	0.7006	
df	29	
t Stat	3.4995	
P(T<=t) one-tail	0.0008	
t Critical one-tail	1.6991	
P(T<=t) two-tail	0.0015	
t Critical two-tail	2.0452	

Table 4: Hypotheses results

H1a. VR Meditation can reduce anxiety levels.
Supported. VR Meditation demonstrated statistically significant anxiety reduction as a result of the priming activity.
H1b. VR Meditation can increase cognitive bandwidth.
Not Supported. VR Meditation did not demonstrate an increase in cognitive bandwidth in the subsequent test.
H2a. VR Gaming can reduce anxiety levels.
Supported. VR Gaming demonstrated statistically significant anxiety reduction as a result of the priming activity.
H2b. VR Gaming can increase cognitive bandwidth.
Supported. VR Gaming demonstrated a statistically significant increase in cognitive bandwidth in the subsequent test.
H3a. VR Gaming will be more effective than VR meditation for reducing anxiety.
Not Supported. There is no significant difference in anxiety reduction between the two methods.
H3b. VR Gaming will be more effective than VR meditation for increasing cognitive bandwidth.
Supported. VR Gaming was demonstrated to be a more effective process for increasing cognitive bandwidth.

We also conducted a UX survey questionnaire, with questions such as previous experience with VR and games. The participants also provided final feedback related to their VR, gaming, and meditation experience, along with their thoughts on their assessment of the experience. While 50 of 56 participants were newbies or very inexperienced VR players, almost 50% claimed to be frequent gamers. 48 of the 56 participants did not meditate regularly or did so occasionally if stressed. Participants were randomly distributed among groups, and we did not observe any correlation between these and anxiety and cognitive bandwidth results. 34 of 56 participants felt that the VR priming activities did reduce anxiety in a small or large way while the remainder felt that there was an effect but nothing significant. Only one participant claimed to have no anxiety reduction at all. 8 of the 56 participants fell some level of discomfort with VR but nothing significant. One person did experience cyber nausea and stopped the experiment.

Some of the comments provided by participants were:

- I felt more focused for the second test
- Was fun and made you forget the stress of the test
- Also had more energy.
- Slight motion sickness but nothing terrible.
- Gave me a headache but a great overall experience.
- Found VR very relaxing

6 Discussion

Reviewing our hypotheses, it appears that there was little question about whether VR priming did reduce anxiety levels. With both meditation and gaming, while the assessment was subjective, all participants felt better after the priming exercises than before. This was to be expected. After reflection, we were also less surprised about the limited effect on cognitive bandwidth with VR meditation activities. Like sports or crafting skills, meditation is a long-term skill, and that yields more benefits over time as participants improve their skills and gain a better understanding of how to best apply the process. Since most of the participants were newbies or inexperienced meditators, it was unlikely that they would have sufficient skills and practice to benefit considerably in such a short trial.

We compared these two VR priming methods because they represented different approaches to optimizing learning mindsets. Meditation is a controlled mental conditioning exercise that takes focus, concentration, and calmness. VR gaming is far more ephemeral and intended to generate immediate feelings of positive affect. These positive feelings not only served to reduce anxiety but also to increase the cognitive bandwidth in the subsequent testing process by creating a more effective escape from the culprits of anxiety (fear, scarcity, distraction). Gaming generates more of a dopamine effect, which has been shown to improve learning, particularly with creative tasks [29] whereas meditation has been shown to improve serotonin flow [12,42] and reduce cortisol, which will yield long term benefits. So, both methods may offer benefits but in differing temporal contexts.

The game and meditation interventions were chosen based on existing literature that suggest the potential of active games and calming experiences in clearing the mind. We hypothesized that they would help the transition from a scarcity mindset to an abundance one, although in different ways. Activities like dance, yoga or other physical activities or even less kinetic games like bird watching or similar search and concentration games would be worth exploring for efficacy. Determining the effect of priming for different subjects of study is another area of future research. It would be interesting to know if anthropology, or other humanities gain more from priming activities than science or math-related courses.

Our study was limited to simple interventions suitable for Pre-learning Experience Priming (PEP). A full investigation of CPM/VREP requires evaluating all four intervention techniques in various educational contexts. For example, changing the context of the environments, referred to as Context Oriented Primes (COP) in our proposed CPM framework, can change mindsets. Taking a class in a VR nature environment, for example, might not only reduce anxiety and induce calm but could also spark more creativity. Also, the effect of these interventions on academic performance and the level of learning needs to be investigated. Further research could also be done to understand how to best apply priming interventions within the ELT cycle.

Exploring techniques that are sensitive to current emotional states would add a dimensional insight that could improve the effectiveness of VR priming. Further, the act of embodiment of VR avatars has been shown to have major effects on self-perception and could also affect performance. Similarly, using methods of priming motivation through positive messaging and visual effects in VR is also a worthwhile avenue of research exploration. Finally, in this study, we focused on Immersive VR HMDs. Desktop and Mobile VR (3D Virtual environments, in general) may have similar benefits which need to be investigated in the future.

7 Conclusion

Motivated to find ways to deal with the epidemic state of student anxiety, we embarked on a course of research to explore different ways of reducing that anxiety and re-appropriating critical cognitive bandwidth to become more available for learning activities.

The multidisciplinary literature analysis explored innovative ideas in cognitive science, learning models, and emerging technologies that offered prospect solutions to address the anxiety issue. Based on this research we introduced Cyclical Priming Methodology (CPM), a theoretical framework that shows how and when priming activities can be introduced into the learning cycles to help with anxiety and the related cognitive bandwidth issues. Building on this, we proposed a VR specific process called Virtual Reality Experience Priming (VREP) that exploits the affordances of VR to create positive priming interventions. Based on CPM/VREP, we evaluated a Virtual Reality-based priming approach that uses games and meditative interventions.

Our results showed a strong potential for the priming approach compared to the no-priming scenario. In a study of 56 Participants, our research demonstrated that priming interventions administered prior to a cognitive test clearly reduced anxiety. While our meditation priming failed to demonstrate significant cognitive bandwidth lift, the game priming experiences clearly improved cognitive bandwidth. Acknowledging the limited scope of priming activities tested with the current study, we suggested a series of potential directions for future research.

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