Technology Solutions to Reduce Anxiety and Increase Cognitive Availability in Students

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***Abstract* — Recent research indicates that the majority of post-secondary students in North America "feel overwhelming anxiety," an issue that has also been observed in many other regions and is negatively impacting students' academic performance and overall well-being. This paper reports the results of our interdisciplinary analysis of innovative ideas in cognitive science, learning models and mindsets, and current technological approaches that are aimed at understanding and addressing these anxiety and academic engagement issues. We identify the knowledge gaps and propose critical insights and research directions, such as the use of virtual reality and computer games, to fill those gaps and deal with the anxiety problem.**

***Index Terms*—Cognitive Priming, Anxiety, Experiential Learning, Situated Learning, Mindset, Virtual Reality, Artificial Intelligence, Gaming, Biometrics.**

I. INTRODUCTION

ANXIETY disorders are among the most critical challenges facing post-secondary students today, negatively affecting students' academic performance and general well-being. In a 2017 survey by the American College Health Association (ACHA) [1], 40% of college students said they had felt so depressed in the prior year that it was difficult for them to function. Over 60% experienced overwhelming anxiety in that same period. The 2018 follow-up study [1] yielded similar results, where over 62% of students had felt overwhelming anxiety in the previous twelve months. While ACHA did not measure specifically for anxiety levels after 2018, psychological distress increased during the COVID pandemic, with 2019 (67.6%), 2020 (72.7%), 2021 (72.8%), and culminating with the 2022 ACHA study revealing that 75% of all students experienced moderate or serious psychological distress in the previous year [1].

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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 outcomes [2]. 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 for and respond to potential dangers [3]. This response is a critical evolutionary process but does become a problem when it is not relevant, proportionate to the threat, or sustained for a prolonged period of time [4]. This chronic state of anxiety or anxiety disorder is the focus of this paper. The APA recognizes several forms of anxiety disorder, such as general or social anxiety, phobias, agoraphobia, and Post-Traumatic Stress Disorder (PTSD). We will contain our scope to generalized anxiety disorders and social anxiety disorders, which are common among students [2]. Our primary motivation is to investigate such disorders among post-secondary students. But we do include work with other learners from adjacent/overlapping demographics (e.g., late high school and adult learners) as they may be similarly affected by anxiety.

Therapy and medication are commonly used to treat anxiety disorders, but there are other non-clinical approaches that can help more naturally and indirectly. Research suggests that priming for positive affect reduces anxiety and improves creativity and cognitive performance [5]. In this paper, we define priming as using a stimulus or action to affect the information processing availability of a subsequent idea or experience [6]. The research also suggests that negative priming techniques can appropriate cognitive capacity [7], while positive priming techniques like rituals, priming competence, or creativity can increase cognitive function, reduce anxiety, and improve performance [8].

While many consider technology use a source of anxiety [9], it has been shown that emergent technologies such as computer games and Virtual Reality (VR) can have positive emotional impacts [10][11][12][13]. However, there is no comprehensive and interdisciplinary study that brings together the knowledge about the anxiety problem and the affordances (and limitations) of these technologies. Such a study can identify the research gaps and offer insight into potential research directions. This paper aims at providing an interdisciplinary and systematic review of literature related to this subject.

To better understand the sources of anxiety and how it relates to cognition in learning, we review anxiety literature and other biases and mindsets that may create similar barriers to learning and academic performance. We review various priming methods and educational theories to help us understand how to deal with learners' anxiety. We then focus on technology research most relevant to addressing student anxiety problem. We show that Virtual Reality (VR), Artificial Intelligence (AI), Games, and Biometrics all offer significant contributions to the required affordances.

The primary contribution of this work is to offer an interdisciplinary insight into the problem of student anxiety and the possible role of technology in solving it. We do this by bringing together research on anxiety, priming, education, and digital interactive technologies, and offering the foundation of an interdisciplinary theoretical model. The second contribution of our work is to identify research gaps and open questions and suggest various possible directions for future research.

II. Methodology

Our literature survey is an interdisciplinary, systematic, and critical review of research targeted at anxiety reduction and learning engagement for post-secondary students. We were inspired by Scarcity studies [7]. They demonstrated how the most subtle cognitive priming techniques could have profound effects on mental mindsets and cognitive capabilities. We were similarly inspired by Daniel Kahneman's "Thinking Fast and Slow," which offered searing insights into the related cognitive and behavioral science [14]. Starting from here, we identified four key areas directly related to the inciting material: student anxiety, priming, emotional learning, and various technologies.

To gain an initial sense of the available literature, we focused our search on IEEE and ACM digital libraries and Google Scholar as a general database to find research studies related to the concurrence of the keyword "anxiety" combined with the critical keywords indicated above.

We identified 43 papers that we deemed very relevant to the research problem based on keywords present and the year of publication (no hard limit but priority to more recent ones). Employing forward and backward snowballing [15], we searched through the references identifying other adjacent disciplines of relevance. These related disciplines included learning theories and mindsets, cognitive neuroscience, and more specific technology solutions (e.g., Serious or Video Gaming, Virtual Reality (VR), Augmented Reality (AR), Artificial Intelligence (AI), Machine Learning (ML), and Biometrics. Exploring these new domains increased our number of reference papers to 344, which served as our initial set of research documents to review thoroughly.

We further removed some redundant examples and technology papers that did not address the problem. This tightened our scope of technologies to include Virtual Reality (VR), Artificial Intelligence (AI), Games, and Biometrics, as the commonly used and suggested ones. As we gained a more comprehensive understanding of the problem, most key insights fell within four aggregate domains: Anxiety, Cognitive/Affective Priming, Learning Theories and Mindsets, and Technology Solutions.

With our technology focus narrowed, we searched for more commonality within the Cognitive Priming and Learning/Mindset literature. Few studies covered all disciplines together. So, we elected to include studies containing at least two critical domains (learning theories and mindsets, cognitive priming, or technology solutions). For example, using VR to create cognitive priming effects, even if they were performed outside of a learning environment [13], would still serve as a valuable reference. Similarly, the use of priming techniques to effect positive change in a learning context without a specific technology solution [16] would also contribute relevant insights. This approach afforded us a sufficient depth of material to fully understand the gaps and opportunities in the current research canon, with 99 references used directly in the paper.

III. Literature Review

A. *Understanding Anxiety in Learners*

Anxiety can negatively impact learning performance and general health [17][18]. Cue Utilization theory [19] suggests a narrowing of focus that restricts our utilization of environmental cues that may be very relevant to our learning situations. The weapon focus effect [20] is perhaps the most extreme but best example of what stress/anxiety can do to performance. When viewing a situation where a gun is present (e.g., a holdup at a store), to deal with the immediate threat, a process of cognitive tunneling (strong focus) is induced that excludes other relevant information in the environment. While this focus effect is critical to survival in chronic conditions of anxiety, such a narrowed focus becomes a barrier to learning.

In situations of intense anxiety, social judgment and cognitive performance suffer [21]. The human body reacts to stress by secreting neurotransmitters that elevate blood pressure, and while there may be short-term positive effects on performance, it is generally considered degenerative in the long run. Prolonged stress may result in permanent hormonal loss in the hippocampus. If students are continually exposed to stressors, their cognitive functions may be impaired [4]. Social anxiety, another form of chronic anxiety, can also diminish an individual's ability to learn from changing social dynamics and probabilities, assessing threats where they may no longer exist [22].

B. *Priming*

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 [23][6]. The priming stimulus can be subliminal (brief and not easily detectable to the individual who is exposed) or supraliminal (detectable to the individual).

A simple example used to illustrate the concept of priming involves word priming. Given the fragment SO_P, you are more likely to complete the word as SOUP than SOAP if you've been recently exposed to the word EAT. The opposite would happen if you were most recently exposed to the word WASH. This influence is known as a priming effect. With the word EAT in your mind, myriad food-related concepts and words will be activated and made more readily available to your conscious mind [14]. In an experiment by Bargh et al. [24], one group of students was primed to create sentences with words related to the elderly. Words like balding, forgetful, gray, or wrinkle were used to prime the concept of old age. The second part of the experiment involved walking to another room to complete a second task. The study intended to compare the primed group's time to walk to the second room to the groups not exposed to the elderly concepts. As predicted, the elderly primed groups walked much slower, exhibiting a significant behavioral priming effect [24].

Priming is not restricted to just concepts or words. It can also affect physical behavior, motivation, goal attainment, emotion, and mood. Janiszewski and Wyer [6] present a model of content priming that demonstrates how different nodes are linked, in most cases, bi-directionally (Fig. 1). This model includes four different types of content priming (Semantic, Goal, Affective, and Behavioral). Semantic priming initiates an idea, whereas goal priming may stimulate a behavior towards a specific goal. Affective priming is focused on emotion and makes these related states and feelings more accessible. This focus, in turn, can prime related emotional concepts. Behavioral priming may prime actions like mimicry or physical responses to cognition or emotion [6].

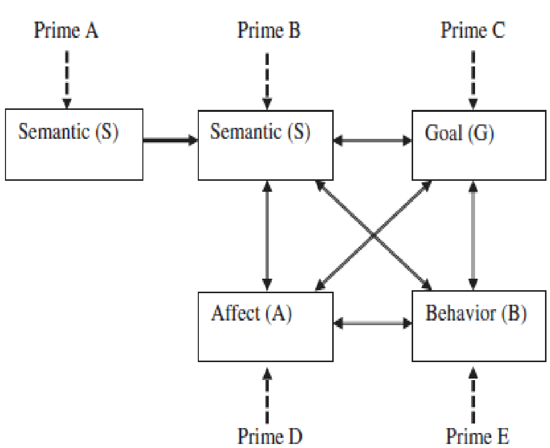

Fig. 1. Associative model of content priming

Based on the literature, the most common types of priming interventions appear to fall within two main classifications (although highly intertwined and overlapped): Affective and Cognitive. Affective priming techniques generally include methods to generate positive or negative affects depending on the priming objective. Affective methods also seek to increase or trigger intrinsic motivation based on social/relatedness goals, personal development of competence-related activities, and methods that afford autonomy and immersive escapism. These intrinsic motivators are in line with both Deci and Ryan's Self Determination Theory (SDT) on human motivation [25] and Yee's theory on what drives motivations in gaming [26]. Cognitive priming methods can be used to create associations, both positive and negative. They can also induce states of calm/mindfulness, reflection, imagination/improvisation, growth mindset triggering a predetermined map or belief system [27], and attentional controls [28] to direct focus away from negative experiences like pain and towards positive stimuli [29]. In the Janiszewski and Wyer [6] model above, we would classify sematic and behavioral priming within the cognitive domain, while affect and goal would fall within the affective classification (Fig. 2).

Most Common Priming Interventions
Affective
Positive Affect/Negative Affect
Intrinsic Motivation (Social/Relatedness)
Intrinsic Motivation (Competence, Self-Perception)
Intrinsic Motivation (Autonomy or Immersive Escapism)
Cognitive
Associations (Positive and stereotypical/situational)
Calm Mindfulness
Reflectivity/Reflexivity
Attentional
Imagination/Improvisation
Growth Mindset

Fig.2. Common Priming Interventions

1) Affective Priming

Conscious supraliminal activities like positive affect priming positively impact information organization and creativity. In a 1987 study [30], positive affect was induced by viewing a few minutes of a comedy film or by receiving a small bag of candy. Another group received neutral stimuli, while two more groups engaged in a physical exercise meant to represent affective arousal. In performing two tasks that required creative ingenuity, the positive-affect group, primed with candy or funny movies, saw improved performance, while the control group or exercise groups saw no performance increase. Motivational priming techniques are most often utilized in game design. Most games are expressly designed to induce feelings of social context, enabling autonomy or escape, and a feeling of competence or achievement facilitating positive self-image [31][26]. Another insightful study by Brooks et al. [8] used rituals to effect positive self-perception and demonstrated the impact of affective priming. This showed that executing rituals before critical experiences can decrease anxiety and increase perceived self-control and overall performance.

Changing the context of people or environments can significantly reduce anxiety and improve cognitive performance. The Proteus Effect posits that as we change our digital self-representations, these self-perceptions can change our behavior [32]. In a 2018 study [33] of participants embodied in a VR character, researchers demonstrated that virtually “Being Einstein” allowed participants to perform better on cognitive tasks compared to the control normal body group. Results from Einstein and the control group were compared with prior cognitive abilities. This research confirms earlier non-VR priming studies from the 1990s. Supported by multiple stereotype studies performed by Bargh, Chen, and Burrows [24], and a further study at the University of Nijmegan [34], it is generally concluded that priming a stereotype or trait leads to overt behavioral changes.

Stereotype threat is a psychological state where apprehension about a negative stereotype may disrupt or diminish cognitive performance within that group. Research suggests that by priming positive stereotypes or eliminating the saliency of potentially negative stereotype cues, threats could be reduced, and cognitive performance improved [35][36][37].

Priming activities can also have a positive impact on negativity bias [38]. A 2014 study on cognitive priming and the positive interpretation of daily events demonstrated the potential to prime positive effects by creating positive visual imagery in advance of daily activities. In a within-subjects experiment, 214 college students practiced goal-oriented mental imagery and to-do list techniques on alternate days. Students were far more likely to report a sense of accomplishment, ease, coping, and positive affect on mental imagery days than on to-do list days. The to-do list management techniques were still valuable, and it would be reasonable to suggest that concurrently performing the more salient positive visualization practice and to-do list methods would likely result in further improvements [16].

2) Cognitive Priming

Central to the concept of priming is the idea that Kahneman refers to as cognitive ease and cognitive strain [14]. Kahneman proposes that we have two cognitive processes operating simultaneously and interchanging conscious control, depending on the situation. The FAST or autonomous processes, “System 1 thinking”, are the daily heuristics that we use to navigate everyday life. These processes “get us through the day” but are subject to appropriation and influenced by outside forces and cognitive bias. The SLOW processes, or “System 2 thinking”, are the analytical or contemplative processes that are triggered by the challenges that require us to think more deeply, associated with higher cognitive load and higher active memory usage. Priming interventions that induce strain or negative affect can also be useful in triggering the slower system 2 thinking that is more likely to improve cognitive performance. The use of poorly visible fonts, for example, reduces perceptual fluidity, inducing increased focus and deeper thought [41][40].

Psychologist Robert Zajonc created several studies that demonstrated that mere repeated exposure to a word, concept, or image would enhance the positive affect of the initial stimuli and even extend to similar or related concepts. He argues that this is a feature of most living organisms whose survival prospects are better served by avoiding novel stimuli [41]. Simple repeated exposure to an idea causes it to be seen more clearly. That sense of ease, in turn, causes familiarity, a feeling of truth, goodness, and an overall positive feeling. This evolutionary trait may create implicit biases that predispose us to stereotypical thinking that might be perceived as racist, xenophobic, and averse to that which is not familiar [143].

Consistent, repeated exposure to ideas or information induces cognitive ease, regardless of the moral value or veracity of the information. Eventually, the process will condition us to familiarity and enhanced positive affect related to these concepts. Celebrity culture is similarly based on this concept, as illustrated by Jacoby and colleagues [42], with long-term priming effects of name exposure. This human predilection for familiarity enables positive feelings for those concepts most exposed over other alternatives [7]. This repetitive media exposure to people, places, and things similarly creates cognitive ease and good feelings. As such, these repetitive exposures can be used to create ease and comfort between cultures that interact within the learning environment..

3) Insights for Using Technology in Priming

Based on the reviewed work, we identified some of the specific priming techniques that could be considered when using technology. While this list is not comprehensive, it does offer insights into when technology can be more effective:

- An immersive environment that creates feelings of presence to enable supraliminal priming effects [43][33][44]
- Simulated worlds that are believable and immersive enabling autonomy and escapism [26]
- Substrates that allow repetition and procedural programmability [41]
- Engagement that induces sufficient challenge or flow experiences [11]

- Social platform to facilitate relatedness and human connection [31]
- The customizability of People, Places, and things that induces positive affect and positive associations [45][43][33]
- Personalization to create unique content experiences, and address diverse preferences, and rates of progress [46]
- Embodiment and immersion in self and other narratives or avatars [32]
- Attentional controls in order to divert negative feelings and focus attention positively [29]

C. Learning Theories and Mindsets

Student anxiety and its effect on academic performance is a clear example of how learning is not a purely cognitive process. Bloom [47] identifies three domains of learning; Cognitive, Affective, and Psychomotor, further breaking down these roles into several categories. Further learning theories, mainly Behaviorism, Cognitivism, Constructivism, and Experientialism, have expanded on this notion, and understanding them is essential in developing proper mechanisms for dealing with student anxiety and educational priming.

1) Behaviorism

Behaviorist learning evolved from the work of Pavlov and Skinner, who introduced associative learning based on classical and operant conditioning [48]. Classical conditioning is a process where an initially neutral stimulus is paired with an unconditioned stimulus to evoke a similar response [49]. In contrast, operant conditioning focuses on rewards based on the stimulus and response of the operant or individual. Behaviorists offer great insights into the aspects of priming that influence our cognitive and affective processes. The famous Pavlov's dog experiment demonstrated that a dog could be primed to salivate upon demand based on the presentation of a secondary stimulus (a Bell) in the absence of food. Operant conditioning, often used in traditional educational processes, uses stimulus reward methods to improve the frequency and motivation of positive responses. Similarly, computer games often employ strict narratives and similar stimulus reward techniques [26].

2) Cognitivism and Constructivism

Cognitivism is more concerned with the process of learning than behavior. Cognitive Psychology suggests that learning is more than a change in behavior but instead mediated by thinking that results in a change in understanding. The learner acquires knowledge and internal mental structures. Learners take on information, store it, relate it to other ideas and worldviews, and store it to be retrieved later when needed [18].

Constructivism extends the previous theories by proposing a more subjective model of learning. With behavioral and cognitive theories, the world is real and external to the learner. In contrast, constructivism is a function of how individuals create meaning from their own experiences [18]. Piaget, a pioneering thinker in cognitivism and constructivism, suggested that learners construct understanding. They do not simply mirror and reflect what they hear or what they read but instead look for meaning, regularity, and order in the events of the world, even in the absence of full or complete information [50].

Vygotsky, a social constructivist, pushes beyond Piaget's thinking to introduce the social dimension. He proposes that learning is a socially mediated activity with an emphasis on the teacher as an expert or scaffolder. He originated the concept of Sociocultural Learning (SCT), describing learning as a social process and the origination of human intelligence in society and culture. He suggests that learning occurs on two levels, first socially and then integrated into the individual's mental structure [51].

3) Social and Emotional Learning (SEL)

Cognitive performance by students of all ages is affected by many social and emotional factors. Social and Emotional Learning (SEL) programs balance emotion and cognition to improve academic outcomes [52]. Influenced by Bloom [47], they are based on the notion that learners are social and emotional beings, and as such pedagogical methods should take their affective concerns into account. SEL and other learning theories are not mutually exclusive concepts but are built on the foundations of behaviorism [48], cognitivism, and constructivism [18].

4) Experiential Learning Theory (ELT)

Due to the nature of how priming is woven into our life experiences, of particular interest for our research was Kolb's Experiential Learning Theory (ELT) [53][54]. According to ELT, learning begins with having a concrete experience, followed by a reflection on that experience, then the conceptualization of abstract concepts that incorporates the new insights from 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 continually refined. The cycle is presented in Fig. 3.

Experiential learning theory draws on the earlier work of Dewey, Piaget, and Jung to provide a more holistic model of learning [53][54]. The theory presupposes the following statements:

- Learning is best achieved as a process: a continuing reconstruction of experience.
- All learning is relearning.

- Learning requires the resolution of conflicts between different views.
- Learning is a holistic process of adaption to the world.
- Learning is the result of synergetic transactions between learners and the environment.
- Learning is the process of creating knowledge.

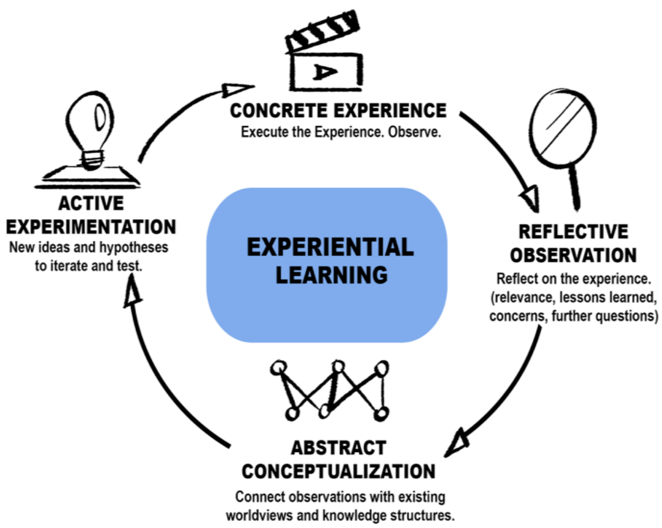

Fig. 3. The Experiential Learning Theory Cycle

Vince [55] argues that anxiety can have a very negative effect on the learning cycle, effectively breaking the cycle, creating defensiveness, and an inability to learn (Fig. 4). While some students with persistence and self-discipline may be able to maintain the anxiety levels and remain engaged, others may disengage. In both cases, however, anxiety will diminish the overall learning experience.

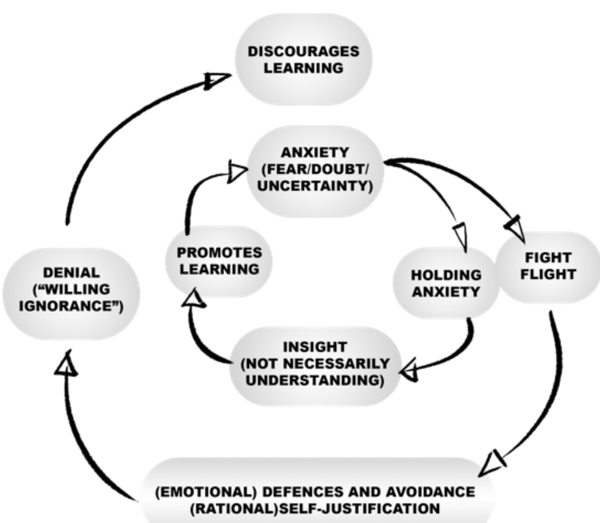

Fig. 4. Learning Cycle with Anxiety [55]

5) Situated Learning Theory (SLT)

Building on the experiential framework, Situated Learning Theory (SLT) advocates for learning within a community of practice and within a specific situation [56][57]. Within a situated environment, learners can see, hear, do, and feel the experience resulting in higher retention. The critical challenge of experiential and situated learning is attaining the proper context and frequency of access to relevant workplace experiences. Since the onset of COVID-19, the availability of situated placement opportunities has diminished further, and students have struggled to gain social context and work-based relationships. Remote learning technologies such as video conferencing may not be suitable for situated learning experiences, while VR offers a potential solution that may simulate a professional environment and enhance social context [45].

6) Motivational Mindsets

Dweck [58] suggests that if students believed that their intelligence and academic success were malleable, organic, and in the process of growing, they would progress and achieve greater success than those students who believed their intelligence was "predetermined" and that they were not in control of those variables. Dweck has furthered this research to indicate that disciplines like math, long considered the domain of the few, can be mastered simply by employing a growth mindset [58][59]. A fixed mindset student views intelligence as static, whereas a growth mindset student believes that intelligence can develop. Those views manifest themselves behaviorally. Students with fixed mindsets tend to avoid challenges, become defensive, or give up easily. Those with a growth mindset, on the other hand, embrace challenges, learn from criticism, and perceive their efforts as a path to mastery.

7) Insight for Educational Priming

The reviewed learning-related theories provide a compelling reason to bring an emotionally aware thought paradigm into the design of learning processes. These studies also suggest an opportunity to consider the use of technology solutions to prime students for better performance. Priming interventions may lead to reduced anxiety, increased positive affect, creativity, focus, and motivation resulting in improved mental health and academic performance in students, as presented in Fig. 5.

Combining the insights from priming and learning literature, we can conclude that the following features are among the essential needs of any educational priming system:

- A cyclical learning process to facilitate repetition, programmability, and critically-timed learning opportunities
- Attentional controls to provide a key focus
- Customized and personalized environments, characters, and artifacts to provide situated learning

scenarios based on the user's characteristics, needs, and social requirements
- Identity development (personal characteristics, representation, embodiment, etc.) to increase engagement and help with self-perception
- Interactivity for more hands-on learning and engagement
- A social platform for a meaningful community of learning engagement
- Sufficient subject matter challenge to attain flow experiences

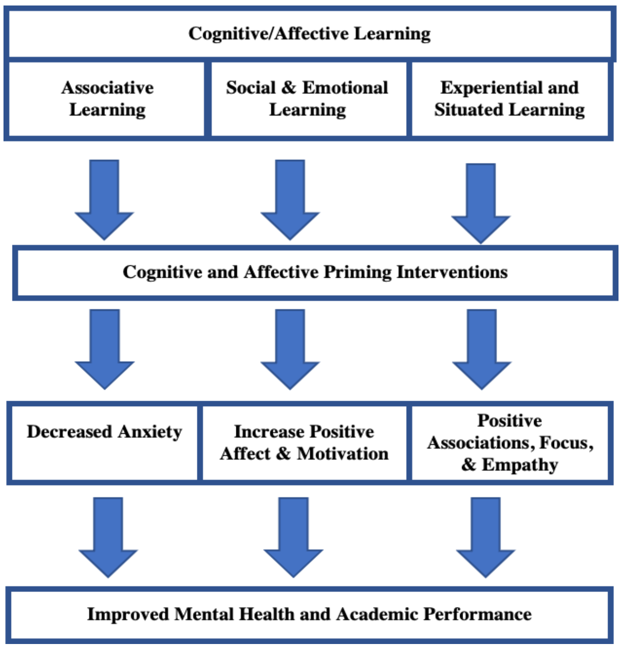

Fig. 5. A Model of Learning, Priming, and Anxiety

D. *Technology Solutions*

In a recent post-secondary study, technology and social media consumption were positively correlated to anxiety and negatively correlated to GPA performance [60]. While there is evidence to suggest that technology usage may be a contributing factor to anxiety, negative mindsets, and reduced academic performance, the corollary may also be true; that innovative technology solutions can offer mitigating effects to student mindset challenges and performance. In our technology research, we identify four key digital technologies that have demonstrated disruptive potential for improving student learning mindsets and academic performance. VR, video games, and artificial intelligence solutions are already showing great promise and proving valuable in myriad application domains [45][12], while biometrics are also beginning to be deployed personally and increasingly in therapeutic and health/wellness contexts [61]. In the following sections, we review the related work on these four major technology solutions.

1) *Virtual Reality*

Virtual Reality (VR) can be experienced through a Head-Mounted Display (HMD) or mobile/desktop devices. It is defined as a 3D Virtual Environment (3DVE) that simulates the physical world and can seem almost real to the users affecting them through different sensors [62]. As a technology, VR offers unique design and psychological affordances such as realistic/stylistic simulations, interactions, presence, and [63][64]. It provides the facility to design situational contexts: environments, artifacts, and avatars [45] and can help create custom physical environments to prime the learners would be very difficult and costly, if not impossible [65].

In a 2013 study, 3DVEs were used to test the effects of supraliminal priming on creativity [44]. The results showed that when teams created ideas in the primed 3DVE, they created more ideas, and the ideas were of higher quality than in the neutral, non-primed environments. Similarly, in a 2022 study [66], 68 participants were presented with a 30-minute animation seminar on the creative process of making an animated movie. Primed participants observed the seminar from within one of two custom, situated, virtual learning environments: 1) an animation studio or 2) a theatre with animation artifacts. They were compared to the non-prime condition: a standard theatre classroom with no animation artifacts. In both cases, participants observed an increase in academic performance compared to the non-primed participants [66][67]. A follow-up study observed similar performance results within a desktop VR environment compared to the Oculus Quest 2 VR head-mounted device [68].

Ellard [69] suggests that the groundswell of interest in incorporating multi-sensory research for interior and urban landscape design is driven, in part, by emerging technologies, such as immersive VR. They allow us to create convincing simulations of built or natural settings, approaches that would have been previously impossible. While this research does not test specific cognitive performance effects, it does suggest that the positive psychological effects are transferrable between virtual and real-world environments and could be a powerful design tool for both real and immersive domains.

A 2021 study [70] compared wayfinding behavior and spatial knowledge acquisition in VR to real-world environments. It found that while wayfinding results were comparable, spatial knowledge was processed differently between real and immersive mediums. While visual information was more efficiently processed in the real world, searching for visual information was more effective within immersive environments [70].

Another study tested game scores within a VR-based archery game following a 10-minute meditation using the *Muse* meditation headset (choosemuse.com) [71]. While there was no direct linkage to cognition, they observed improved game scores for all categories (Beginners + 275%, Intermediate +107%, Experts +17). The game did, however, test hand-eye coordination and reaction times. Furthermore, after completing these activities, all participants reported feeling recharged to continue their daily activities [72]. Most research suggests that mindfulness does offer positive psychological value, even with shorter sessions [72][73] but derives more benefits with prolonged practice [74].

Hawes and Arya [67] studied the efficacy of VR-based meditation and VR gaming as a priming activity for students prior to participating in a test of cognitive reasoning: the University of California Matrix Reasoning Test (UCMRT) [75]. The UCMRT was created as an academic equivalent of Raven's progressive matrices test, and considered a non-biased, non-cultural specific test of fluid intelligence [7][75]. In the study of 56 participants, all prime conditions observed anxiety reduction, while the VR gaming participants also observed an increase in cognitive performance after playing the VR game [67].

The "immersion" and "presence" affordances make VR a strong candidate for not just training simulations but also different emotional experiences. USC Institute for Creative Technologies initiated a VR research program to study emotional issues relevant to military applications [76]. These studies suggest great application possibilities in simulating, evoking, and dealing with PTSD. Based on these immersive possibilities and the ability to create a sense of presence, VR is an ideal technology to create wartime scenarios that evoke intense emotion in the context of rapid learning and performance requirements. VR can be used to create scenarios that induce emotional states similar to what the soldier may experience in battle. This training could better prepare the soldier for pre-war learning and understanding post-war psychological impacts.

The positive emotional effects of awe-inspiring environments were substantiated in a VR application with a 2019 study from Bond University. Comparing VR participants who embarked on a virtual tour of Hawaii to a non-VR control group showed a considerable reduction in anxiety for the VR group over the neutral control group [77].

VR is also proving valuable in many other cognitive domains. Growing empirical evidence suggests that Virtual Reality Exposure Therapy (VRET) is becoming 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) [10]. CBT is a structured, goal-oriented form of psychotherapy that helps people learn how their thoughts, attitudes, and beliefs relate to the emotional and behavioral 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 immersive VR for the treatment of fear of heights. The VRET solution showed considerable improvement over the control group, an improvement that was sustained in subsequent follow-ups [78]. With regular CBT, exposing a patient with fears such as heights or insects to tall buildings, flying, or even spiders, can be costly and/or unsafe. With a VRET process, as presented in Fig. 6, the patient iteratively faces increasing levels of exposure until the fear is extinct.

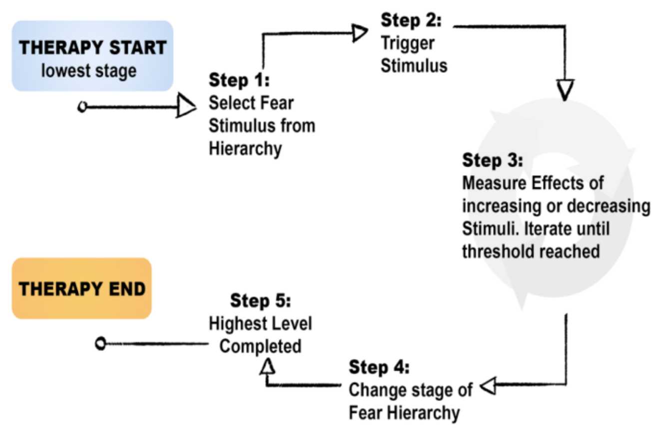

Fig. 6. VRET Fear Extinction Cycle

Attentional affordances are also available in VR environments that can offer therapeutic and pain reduction benefits [29]. In a 2000 study on the use of VR as an adjunctive non-pharmacologic analgesic for acute burn pain during medical procedures, researchers demonstrated that when burn victims were immersed in a distracting VR environment, they reported 35-50% reductions in the pain incurred during the wound care process [79]. The researchers theorized that with less attention available to real-world pain due to the attention required for the VR distraction, there was a direct reduction in perceived pain.

Beyond priming affordances of custom and personalized VR environments [63][80], characters and avatars offer further advantages. Avatar embodiment techniques that allow participants to inhabit custom personas of other races or cultures show great promise in reducing stereotypes, low self-perception, and negative academic performance associated with stereotype threats [81]. Further, existing research indicates VR effects on reducing anxiety [77], and improving academic performance and student [82][83]. There is also growing evidence to suggest that VR may offer perceptual advantages that could not be acquired in the real world. Through priming self-perception, participants embodied in an iconic character (Albert Einstein) performed better on cognitive tasks than the control normal-body group. This result suggests that the design of avatars in the environment also presents opportunities to elicit positive psychological effects that improve cognition [33].

VR may also be used to create custom learning environments and personalized conditions, especially when combined with AI. An example is allowing autism spectrum disorder (ASD) students to experience customized environments with varying conditions while being in the same learning space as the general student population [84].

2) Computer Games

In popular culture, we associate games with being fun and escapist, which can seemingly diminish their potential positive impact. Today's games, particularly serious games, are far more complex and may contain positive pedagogies at various levels of play [85]. Immersive worlds and simulation logic can allow educators to provide more realistic simulations that represent the learning context that they are attempting to convey. Games can be complex learning environments with the potential to mediate emotion and various cognitive processes.

According to Self-Determination Theory (SDT) [31], games lead to motivation for three reasons: competence, autonomy, and relatedness, all of which are primarily intrinsic motivators that can positively affect learning [86][87]. Furthermore, games combined with VR have been shown to induce a sense of overall presence through the feeling of being within the virtual world (physical presence), by experiencing emotions as deeply as in the real-world (emotional presence), and by feeling a part of the narrative (narrative presence) [88]. The SDT pyramid is presented in Fig. 7.

Fig. 7. The Self-Determination Theory (SDT) Pyramid

Behaviorist theories focus on extrinsic motivators and would be relevant to games that focus on scoring, measuring, and providing intermittent rewards that may be useful in the process of inducing positive affect. Game researcher Nick Yee [26] categorized ten motivation subcomponents that fell under one of three categories: Social, Achievement, and Immersion. His findings are presented in Fig. 8.

Both Yee [26] and the Deci/Ryan [25] models provide different lenses, but they do present a consistent theme. The achievement motivators (e.g., Game Mechanics) would relate to competence, the social motivators to relatedness, and the immersive motivators to autonomy.

Achievement	Social	Immersion
Advancement Progress, Power, Accumulation, Status	**Socializing** Casual Chat, Helping Others, Making Friends	**Discovery** Exploration, Lore, Finding Hidden Things
Mechanics Numbers, Optimization, Templating, Analysis	**Relationship** Personal, Self-Disclosure, Find and Give Support	**Role-Playing** Story Line, Character History, Roles, Fantasy
Competition Challenging Others, Provocation, Domination	**Teamwork** Collaboration, Groups, Group Achievements	**Customization** Appearances, Accessories, Style, Color Schemes
		Escapism Relax, Escape from RL, Avoid RL Problems

Fig. 8. Gaming Motivations [26]

Beyond being motivational tools of engagement, games can directly impact participants' mental states and performance. Dennis et al. [89] demonstrated that supraliminal priming, where users are aware of the priming but not the intent, did result in more creativity. Members of brainstorming teams exposed to priming in web-based computer games generated significantly more ideas of better quality than the neutral primed control group.

Games have been demonstrated to have therapeutic effects that can aid in reducing dependence on Selective Serotonin Reuptake Inhibitors (SSRI) anti-depressants. One of the most compelling examples of this was demonstrated in a 2018 study called Zombie's versus Anxiety: An Augmentation Study of Prescribed Video Game Play Compared to Medication in Reducing Anxiety Symptoms [12]. In comparing two groups suffering from symptoms of anxiety, one group was prescribed one medication, plus casual video game (CVG) play, four times per week for 30-45 minutes for one month. The control group was prescribed a traditional two-medication regimen for controlling symptoms of S-Anxiety and T-Anxiety. (State and Trait Anxiety). Trait anxiety generally describes a personality characteristic rather than an ephemeral state of anxiety. State anxiety is anxiety related to an anticipated threat or fear. Results demonstrated that the CVG/one medication combination under a prescribed condition significantly reduced S-Anxiety symptoms and moderately reduced T-Anxiety, compared to the medication-only control scenario.

The study applied flow as a theoretical framework, and participants claimed to have achieved flow immediately after 30 minutes of gameplay, which occurs only in the absence of anxiety [11]. Csikszentmihalyi's flow theory [11], referenced in the study, is illustrated in Fig. 9. These findings are significant and suggest that gaming interventions may offer non-invasive and cost-effective companions or alternatives to medications.

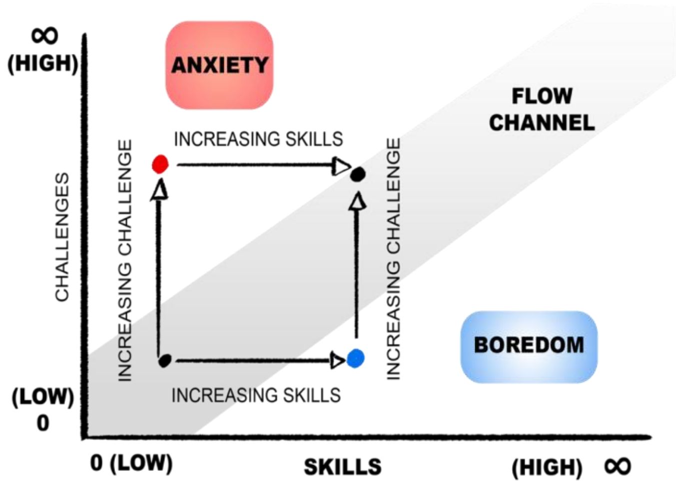

Fig. 9. Finding Flow

Gaming solutions have also been shown to improve working memory and, consequently, cognitive capacity. The results from this 2017 study revealed that the extent of daily gaming activity was related to the enhancement and speed of the most demanding level of working memory task [90]. A further study on the effect of anxiety levels on learning performance found that digital game-based learning was beneficial to high-anxiety learners, while there was a negligible effect for learners with low anxiety [40]. Finally, video games do provide a substrate for supraliminal priming effects, as they are activities of which we are conscious (exposure greater than 500 milliseconds) yet unaware of their effects. This is amplified if an elevated suspension of disbelief or heightened sense of presence is achieved (physical, emotional, narrative) [84][107].

3) Artificial Intelligence (AI)

AI-based Intelligent Virtual Agents (IVA) and other forms of social and learning avatars show great promise within the learning environment and will become powerful personal and educational resources as they become more intelligent and more affect-aware [91]. The VRET fear of heights study referenced above clearly demonstrated that the animated avatar virtual coach yielded better results than the control group's other treatment methods [92]. Considering the expense of qualified psychotherapists, the availability of a VR fear training solution using a virtual coach offers the prospect of higher accessibility and affordability to the public.

Similarly, a 2018 review of social robots for education showed that they could be effectively used in educational settings to increase cognitive and affective outcomes. Much of the positive learning effect was attributed to their physical presence [93]. Interestingly, some of the challenges of physical robots alluded to in the study could be avoided by simply using animated AI characters in VR. Nonetheless, as researchers continue to hone the interplay between personality, motivation, emotion, and mood, Intelligent Virtual Agents (IVA) will become far more engaging and useful in learning environments [91]. As AI agents become mainstream tools for information processing and personal management tasks, it would seem logical that various emotion management modules would become applications built on these AI platforms.

Combining AI with VR offers unique possibilities. Current VR implementations with high-fidelity immersive virtual spaces and customizable computational platforms are nearing ubiquity. They offer the prospect of scalable priming interventions aimed at emotion regulation and academic optimization that can be personalized uniquely to each student and refined using AI and ML algorithms for cognitive optimization [94].

4) Biometrics, Wearables, and Smartphone Apps

There is growing evidence that personal technologies can help manage emotional states and prime learner engagement. In a 2018 study called "There's an app for that: The impact of reminder apps on students' learning and anxiety", a homework suite planner app facilitated student organization and time management leading to more completed assignments, lower anxiety, and greater overall learning satisfaction [95].

Biometrics combined with machine learning algorithms are becoming valuable tools for data acquisition and analysis, providing high degrees of personalization and situational customization. In a 2015 study [61], researchers analyzed 30 days of data collected from wearable sensors and surveys to predict mood, happy or sad, from daily behaviors 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 clearly not accurate enough to suggest the use of this technology in behavioral prompting. Still, the acquisition of this data could provide a valuable input stream for improved analysis and understanding of a student's individual propensities and vulnerabilities. Smartwatches and other biometric wearable devices (e.g., Fitbit, Apple Watch) already provide real-time feedback on ECG, heart rate, and, in some cases, blood pressure allowing the user to monitor data and set alerts and notifications as desired. These tools and the availability of personal health data can be used to improve personal health awareness and anxiety management.

There is growing evidence that certain daily routines can have mitigating effects on anxiety. Mindfulness programs that are often facilitated by Apps like Calm [96], have proven effective for student anxiety management [73]. Further, recent mindfulness studies are actually seeing increased working memory capacity and improved academic performance related to Graduate Record Examination (GRE) scores [74].

One of the more interesting apps was a cognitive priming app that is used to achieve cognitive bias mediation for attentional biases for negative or anxiety-ridden people. Stressed-out individuals, by their very mental state, will notice negative cues, faces, and events far more frequently than positive ones. With attentional bias, what is focal is causal, and for that reason, a negative state of mind will notice more negative imagery. A literature review in 2018 [97] reviewed several commercial apps focused on cognitive bias modification, concluding that there has been very little validated scientific study regarding these applications, but there appears to be some promising content. One such app mentioned combatting negativity bias was SPOT Smile [98]. This app presents several screens, nine squares at a time. On each screen, the users are asked to pick out a smiling face. As in most games, speed and accuracy are rewarded, but the real intent of the game is to prime the individual into a positive affective state by finding smiles. This attempt at cognitive bias modification is a simple daily game that could offer a positive lens for those so challenged. More academic study and validation are required in this area, but the general trend and thinking are promising.

Finally, anxiety management drugs and related consumables are big businesses, and although there is proven value in these techniques, they fall outside of the scope of this paper. It is important to note that quite often, a combination of technology and medical solution can effectively reduce the pharmaceutical portion to lower levels, reduce side effects, and help achieve the anxiety management objective [12].

IV. Discussion

A. Technology Affordances for Priming

Each of the reviewed technologies offers unique affordances that can be useful educational tools to be deployed alongside priming initiatives. Table I shows a high-level summary of technology affordances relevant to cognitive and affective priming opportunities.

VR offers powerful attentional control mechanisms by affording new custom worlds where distractions can be minimized, and specific priming nuances can be built into the design of these virtual worlds. Antecedent intervention strategies could benefit from the custom design capabilities of these environments, avatars, and special effects. In doing so, participants may experience various learning challenges as iterative scenarios in realistic environments in a manner that is more situationally relevant and personal. Computer games can capture attention and engagement in custom worlds that induce flow and reduce anxiety. Data acquired through biometric sampling and other methods can be mined with machine learning algorithms to provide actionable insights delivered through AI guidance. For example, AI can be used as a tool to increase awareness of students' emotional states. This awareness may help facilitate interventions or dynamic customization of environmental factors like lighting to reduce anxiety.

TABLE I
Technology Affordances of VR, Games, AI, and Biometrics

Priming Techniques	VR/MR	Games	AI	Biometrics
Immersive environment that creates feelings of presence to facilitate supraliminal priming effects.	Immersive environments create feelings of presence and believability, affording fluent supraliminal priming	Immersive narratives, artifacts, and engaging game mechanics contribute to higher levels of immersion and presence.	Real-time data analysis can provide relevant feedback and actionable insights on priming efficacy	Real-time data monitoring provides valuable affective data to AI/ML routines to adjust experiences in real time
Simulated World that is believable and offers a form of autonomy and escapism	Simulated worlds for situated cognition for more effective experiential learning	Games designed as experiential simulations enable high engagement, social content, increased autonomy, and enhanced learning	Real-time data analysis can provide relevant feedback and actionable insights to improve subsequent iterations	Real-time data monitoring can provide valuable affective information to AL/ML routines to facilitate real-time change
Repetition and Programmability	Procedural processes to enable cyclical iteration and more effective experiential learning.	Games and characters can be designed with repetition and iteration to increase positive affect and associations	Real-time data analysis can provide relevant feedback and actionable insights to improve subsequent iterations	Real-time data monitoring can provide valuable affective information to AL/ML routines to facilitate real-time change
Facilitate sufficient challenges capable of inducing flow experiences. (Flow and ZPD) to improve self-perception	VR Environments create intuitive and adjustable settings to facilitate ease of use and sufficient complexity of gaming or learning content	Games designs and narratives designed as multilevels afford gamers autonomy in choosing varying levels of engagement and complexity.	Real-time data analysis can provide relevant feedback and actionable insights to improve subsequent iterations	Real-time data monitoring can provide valuable affective information to AL/ML routines to facilitate real-time change

Social Platform to enable feelings of belonging and relatedness. (SDT)	Enables privacy of personal experiences with IVAs or within human social group within custom environments	Shared collaborative activities and data sharing create improved competence, and social connection (relatedness)	IVAs and customizable NPCs can enhance private experiences	Shared affect and experience data provides improved social connection (relatedness)
Customizability of People (Avatars), Places (Virtual Places) and things (Artifacts) to induce positive feelings and associations. (Kahneman, Banakou)	Customizable: able to create personalized environments with antecedent conditions to induce desired cognitive and affective states	Gaming environments can be designed to optimize cognitive and affective states using supraliminal priming to effect specific goals.	Real-time data sampling and machine learning enhance the customization process and cue elicitations	N/A
Personalization of unique experience with unique sensitivities, preferences, and rate or progress.	Personalized environments with antecedent conditions to address unique sensitivities, preferences, and desired cognitive and affective states	Gaming environments can be designed to optimize cognitive and affective states using supraliminal priming to effect specific goals.	Real-time data sampling and machine learning enhance the customization process and cue elicitations and progress monitoring	N/A
Embodiment of avatars to create positive associations and self image (Proteus)	Ability to create anti-stereotypical representations and represent specific desired representations. Enables more immersive role-playing with greater feelings of empathy.	Custom or dynamic avatars can facilitate powerful priming effects and behavioral changes.	Real-time data analysis and emotional responses can facilitate dynamic designs and real-time changing social contexts.	Biometrics can be monitored to detect stress or subconscious challenges with avatar inhabitation
Attentional Controls to improve focus on key learning concepts	Filters out the external world and other distracting elements and facilitate intentional attentional control. Real-time Heads up Displays (HUD)	Attention capturing, engaging with possibilities of achieving flow state and reducing negative factors like pain and/or anxiety.	Real-time data analysis and emotional responses can facilitate dynamic designs and real-time changing social contexts.	Data monitoring and notifications provide information for real-time interventions and attentional controls

B. Research Gaps & Opportunities

The result of our review of priming methods and technology solutions is summarized in Table I. It shows the affordances of four reviewed technologies for priming with regard to basic priming techniques. On the other hand, the review of learning theories suggested cyclical priming, attention control, customization and personalization, interactivity and hands-on work, and engagement as some of the requirements of an emotionally-aware learning process. Together, they suggest the following gaps and opportunities for further research:

- Priming should be applied throughout the ELT cycle. Current priming work is mostly limited to preparing learners prior to a learning activity.
- Priming should include both affective and cognitive aspects. Various forms of intrinsic motivation, personalization, attention control, and repetition are less-developed areas of work in educational priming. Techniques in Table I require further research to utilize VR, games, AI, and other technologies.

The preparatory experience priming (POP) and context-oriented priming methods (COP) have been explored and validated within immersive VR environments in previous research studies [63][64]. But many other potential cognitive and affective priming methods remain that could be transferable to the disruptive technology platform of VR/AI/Gaming and Biometrics.

For example, while positive affect has been shown to induce creativity, stimulating a creative process with randomness or a disruptive suggestion (improvisation) may improve how we process information and the resulting creativity. Additionally, visualization of an experience, particularly from a first-person perspective, can improve the performance of tasks that were not actually performed. The process of visual imagination can be enough to generate real physical effects [99]. Interestingly, imagining exercising can actually increase heart rate. We refer to the related forms of possible priming as creative improvisational priming (CIP) and visual imagination priming (VIP).

The implicit biases predisposing us to negative stereotypes could be addressed with repeated exposure to ideas or information that induce cognitive ease [14] and improved acceptance of the “other” through what we can call prosocial inclusiveness priming (PIP). For example, when designing VR-based learning environments, avatars from varying cultural backgrounds (even as non-inhabited avatars), and diverse cultural artifacts can facilitate the process of representation as a method of mitigating implicit bias. Direct attentional priming (DAP) is another possible intervention process to minimize distraction and draw attention to a specific subject or process to enhance real-time engagement. Table II and Fig. 10 show some of the future possible priming methods throughout the ELT cycle, building on the current research [66][67], such as priming methods for motivation, reflection, creativity, imagination, attention, and prosocial inclusiveness.

TABLE II
PRIMING INTERVENTIONS

Cognitive & Affective Priming Strategies for Improving Student Mindset, and Academic Performance applied within ELT

Priming Categories	Example Priming Activities	Recommend ELT Timing	Prime Type	Key Focus
Preparatory Primes (PEP)	Games, Meditation/Mindfulness, Movement/Exercise, Stories, Mysteries, Humour, Gifts, etc …	Pre-Concrete	Real-time Emotion Regulation	Affective
Context Oriented Priming (COP)	Situated Learning Environments, Characters, Artifacts, Sound/Music, Light, embodiment, etc ...	Concrete	Supraliminal/Subliminal Priming	Cognitive/Affective
Prosocial Inclusiveness Priming (PIP)	Design of Inclusive Environments, Characters, Social/Cultural artifacts, embodiment, etc …	Concrete, Pre-reflective, Reflective	Supraliminal/Subliminal Priming	Affective/Cognitive
Motivation Oriented Priming (MOP)	Associative priming from positive words, imagery, sounds/music, challenges, mystery	Concrete, Pre-reflective	Direct Calls to Action	Affective/Cognitive
Reflective Experience Priming (REP)	Questions related to learnings, theories, real world implications or other considerations	Pre-reflective, Reflective	Direct Calls to Action	Cognitive/Affective
Direct Attentional Priming (DAP)	Distraction or calls to attention to enhance real-time engagement or awareness of critical norms	Concrete	Direct Calls to Action	Cognitive
Visual Imagination Priming (VIP)	Visualizing and Imagining an activity being performed and the intended result	Pre-Abstract, Pre-Experimentation, Pre-Concrete	Direct Calls to Action	Cognitive/Affective
Creative Improvisational Priming (CIP)	Thought experiments, planned or random changes that disrupt the process requiring improvisation	Pre-Abstract, Abstract, Pre-Experimentation, Experimentation, Pre-Concrete	Direct Calls to Action	Cognitive

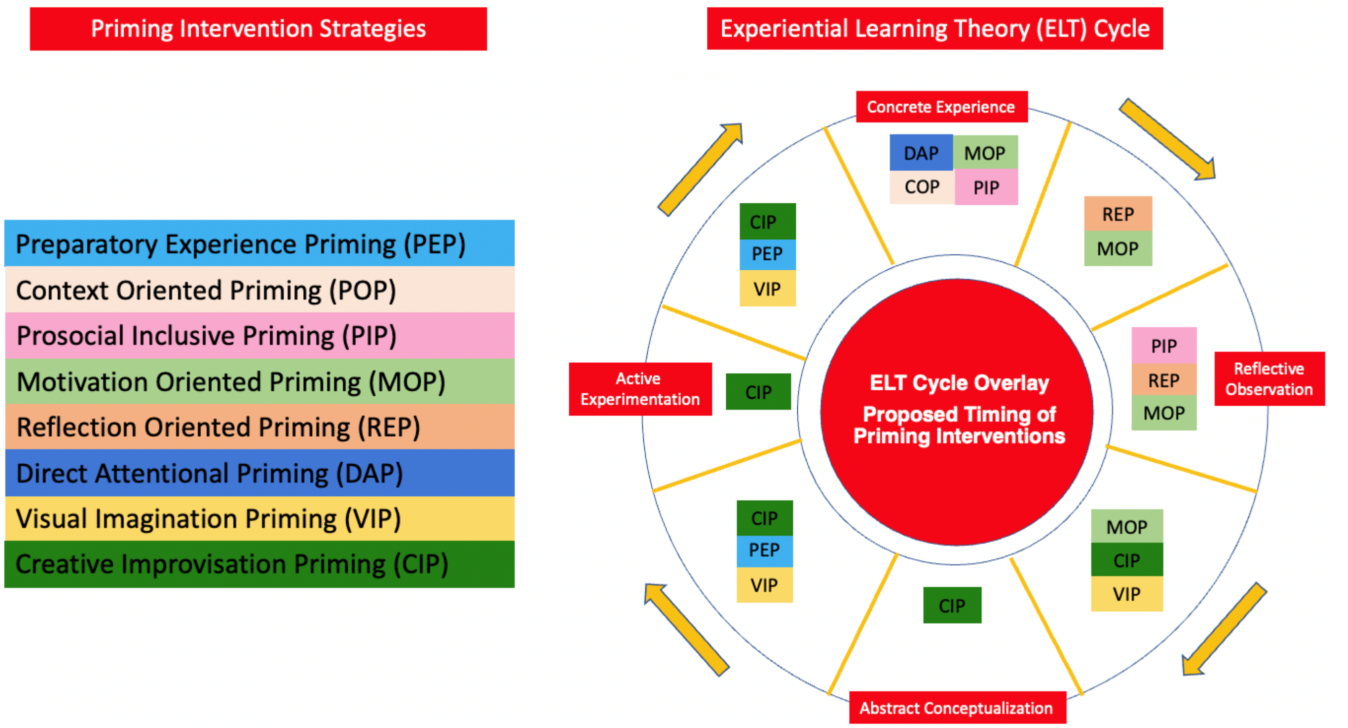

Fig. 10. Proposed Timing Interventions within the ELT Cycle

V. Conclusion

In our literature review, we identified the problem of student anxiety and its adverse effects on post-secondary students' academic performance and general health. We examined the current academic thinking in cognitive science, learning and mindset theories, and the current state of disruptive digital technology solutions available to this problem space. Except for some successful K-12 SEL programs, there appears to be very little empirical evidence of these insights being applied in any technological context within the design of educational curriculums for post-secondary students.

The priming research presented many examples of how these techniques could induce positive mindsets in students. The technology possibilities we explored offered promising platforms for applying our priming insights within VR, gaming, AI, and biometric technology solutions and, likely, using multiple technologies concurrently.

To address these insights, we considered the unique affordances and capabilities offered by the technology and how they might address both cognitive and affective priming opportunities. Building on existing research for preparatory priming and context-based priming, we proposed an expanded research focus on further priming strategies that could be embedded within the ELT process.

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