Computers & Education: X Reality 1 (2022) 100003

Contents lists available at ScienceDirect

Computers & Education: X Reality

journal homepage: www.journals.elsevier.com/computers-and-education-x-reality

The moderating role of creativity and the effect of virtual reality on stress and cognitive demand during preservice teacher learning

Richard Lamb[a,*], Jonah Firestone[b]

[a] East Carolina University, Neurocognition Science Laboratory, 128 Rivers Building, Greenville, NC, 27858, United States
[b] Washington State University Tri-Cities, Department of Teaching and Learning, TFLO 207C, 2710 Crimson Way, Richland, WA, 99354, United States

ARTICLE INFO

Keywords:
Preservice teacher preparation
Teacher education
Virtual reality
Stress
Protective factors
Sensors
fNIRS

ABSTRACT

Virtual reality (VR) has received considerable attention related to its use in teacher development over the last decade. Despite this attention, there is insufficient understanding of how specific underlying cognitive system responses and autonomic nervous system responses moderate the use of VR and the associated learning outcomes in the development of preservice teachers. This work intends to explore and evaluate preservice service teachers' (PSTs) experiences using VR and the effects of creativity, mental flexibility (MF), acute stress, and cognitive demand (CD). Forty-eight undergraduate college students in year two of their teacher preparation program were recruited for the study. Each of the preservice teachers was assigned randomly to one of two conditions, microteaching ($n = 24$) or VR ($n = 24$). The use of these two conditions allowed the researchers to compare the effects of creativity and MF [measured using the Torrance Test of Creative Thinking] on cognitive demand and stress responses [measured using heart rate variability and electrodermal activity]. Results from analysis of the hemodynamic data and stress response data illustrate that the protective factors of creativity and MF may moderate success in VR and the reduction of cognitive demand and stress when VR is used to develop skills related to teaching.

1. Introduction

Application of artificially intelligent (AI) technologies such as virtual reality based adaptive digital learning environments have been identified as critical tools for educators and learners across the P-20 continuum (Chen, Zou, Cheng, & Xie, 2020; Lamb, Hoston, & Firestone, 2022). AI driven environments provide opportunities for the realization of more fully adaptive and responsive environments which can differentiate learning for all students helping to meet their instructional needs (Wang et al., 2020; Annetta, Lamb, & Stone, 2011). When the unique cognitive, affective and behavior needs of students in the classroom are combined with large numbers of students, differentiation can be time and resource intensive for a teacher or instructor. Making meeting all students needs very difficult. One means to address this difficulty [differentiation], is through the application of AI based interactions in virtual reality environments (Luckin & Cukurova, 2019). Thus, learners are thought to experience greater positive affective, cognitive, and behavioral outcomes during the learning process, when using VR despite be engaged in a cognitively demanding, high-risk, high stress, environments such as teaching in a classroom (Stephan, Markus, & Gläser-Zikuda, 2019).

Virtual reality's application in education, research examination of the underlying cognitive mechanisms associated with VR, as well as VRs possible positive and negative effects on learning, has been identified as a robust and important research direction over the last two decades (Chen, Zou, et al., 2020; Homer, Plass, Raffaele, Ober, & Ali, 2018). Work such as Homer et al. (2018) which examines questions of cognition related to digital environments, focuses on the improvement of global aspects of cognition such as executive functions during the use of digital games and environments. While this work is important it has not examined finer grained aspects of cognition or captured data in real-time to measure the moment-to-moment fluctuations in student's cognition and responses. Thus, it is reasonable to predict that capturing real-time moment to moment fluctuations in student cognition and nervous system responses during the use of digital environments may represent a promising research area and provide a contribution to our understanding of a student's learning experience. In addition to increases in research related to cognition in digital environments, reviews of studies conducted in the last two decades also illustrate that the topic of teacher training using digital environments has also showed a continually increasing research trend, suggesting it is a robust area of research as well (Chen, Zou, et al.,

* Corresponding author.
E-mail addresses: lambr19@ecu.edu (R. Lamb), jonah.firestone@wsu.edu (J. Firestone).

https://doi.org/10.1016/j.cexr.2022.100003
Received 19 July 2022; Received in revised form 4 November 2022; Accepted 7 November 2022

2020). Thus, combining examination of teacher development and a more fine-grained examination of cognitive traits when using VR is a current gap in the literature which needs to be addressed.

Current practices in teacher education and development make use of face-to-face, peer interactions known as microteaching to develop teaching skills in preservice teachers (PSTs). These face-to-face, peer interactions are intended to increase opportunities to try novel teaching approaches without consequence. Microteaching events are defined by the authors as short (usually a single class or portion of a class) opportunities for PSTs to practice teaching skill development while peers act as the students. Microteaching provides some value to PSTs in the form of practice, trial and error, and experiences working with students, however there are several potential difficulties with microteaching (Özcan & Gerçek, 2019). These difficulties include unrealistic responses by the peers, behavioral and learning differences between the PST's peers and the actual students they will teach, and audience effects e.g., concerns of what peers will think as they attempt to teach (Arzal, 2014). Of all of the potential difficulties, audience effects have been shown to be the most detrimental in terms of increasing levels of situational stress and excessive cognitive demand, subsequently reducing creativity, and MF; causing these protective factors [creativity and MF] to be less effective (Kassymova et al., 2019).

Situational stress is a short-term acute form of stress that occurs due to temporary situations (Kent et al., 2020). A PST can develop teaching-based situational anxieties or stress which reduce their effectiveness in the classroom, leading to burnout due to increased psychological allostatic load (Lamb, 2014; Lamb, Hoston, & Firestone, 2022). One means to reduce situational stress and excessive cognitive demand (CD) during teaching is to promote skills which act as protective factors such as creativity and mental flexibility (MF). A protective factor is a characteristic or behavior which is associate with a reduction in the possibility of a negative psychological or physiological outcome (Jiménez-Picón et al., 2021). Creativity and mental flexibility have been shown to be protective factors against stress and excessive cognitive demand particularly when a person engages in activities within high stress, high demand environments such as a classroom (Bottiani, Duran, Pas, & Bradshaw, 2019). Research illustrates that PSTs identify teaching their peers and their initial opportunities to teach in an actual K-12 classroom as highly stressful and excessively cognitively demanding (Weis et al, 2020). A potential means to address some of the difficulties of microteaching is through the incorporation of virtual reality (VR) based simulated teaching experiences using artificially intelligent avatars. VR addresses some of the difficulties of microteaching by removing audience effects allowing for greater use of mental flexibility and creativity which may protect against and reduce stress responses and cognitive demand. This is thought to occur because the PST works with computerized avatars as opposed to their peers in the VR environment (Kapoor & Khan, 2019). In this light, VR can provide consistent, high-quality small-scale experiences for PSTs to explore and try to innovative ideas increasing the availability of protective factors such as MF and creativity. Importantly due to the low stakes environment the PST may experience reduced stress and CD, increasing opportunities for reception of learning.

Due to the need to examine finer grain cognitive factors which may influence outcomes in VR and the potential of protective factors to increase learning reception the authors chose to examine the relationship between VR, stress, creativity, cognitive demand, and mental flexibility. The intent of this study is to identify how VR and microteaching experiences differ for PSTs on factors such as creativity, mental flexibility, acute stress, and CD. A secondary purpose is to understand if and how, creativity and MF moderate or mediate stress and CD. The research questions are: **Research Question 1:** do students using VR illustrate statistically significant differences in moment-to-moment fluctuation in physiological and neurological response when compared to students engaging in microteaching? **Research Question 2:** how do levels of creativity and mental flexibility relate to levels of acute stress and CD during teaching in VR and microteaching conditions?

The underlying framework used in this study to examine the moment-to-moment physiological and neurological data is the brain and nervous system microstate. Under this framework, hemodynamic responses across the brain and autonomic nervous system responses act as variable measurements of systemic responses from environmental inputs by time. Inputs can occur from information from long-term memory to external inputs such as face-to-face or virtual interactions as someone teaches. Neuronal tissue and other ANS response states mirror the dynamics of cognitive and affective states in people, making them ideal to understand these states in real-time (Mercier, 2018). Determination of cognitive and affective states is an essential component of the finer grained measurement resulting from the use of non-invasive neuroimaging and non-invasive autonomic nervous system (ANS) measurement tools. A microstate is the time-limited moment which occurs as the brain processes information or as the ANS responds to the environment (Cacioppo & Cacioppo, 2015). Hemodynamic responses are the movements of oxygenated hemoglobin to areas of neuronal demand due to cognition and reflect a consistent time delay within the stimulus-response complex. ANS signals are similarly conceptualized. The interpretation of hemodynamic response and ANS response into neurological and physiological states via a research design such as the one in this study, allows researchers to move from descriptive actions to mechanisms promoting causal understanding. The framework provides an explanation for the sequence of the microstate as a causal model associated with the task (Jerath, Crawford, Barnes, & Harden, 2015).

2. Review of the literature

Virtual reality has been shown to increase learning outcomes in both educational and training environments (Hamilton, McKechnie, Edgerton, & Wilson, 2021). The increased learning outcomes are thought to occur because VR couples representational experiences to existing understandings in safe low-stakes environments (Pellas, Dengel, & Christopoulos, 2020). VR is defined as three-dimensional environments and graphics used with interactive interfaces to provide realistic interaction in digital environments. Interactions within the 360-degree environment include the ability to walk into the environment leading to both psychological and sensory immersion and the realistic physiological and psychological responses (Lamb, Etopio, Firestone, Zeder, & Hand, 2020). It is these realistic responses which may work to promote integration of external experiences and prior knowledge. When VR is applied in education with sufficient pedagogies, users can interpret sensory cues using affective systems to gather information about a simulated environment. At the same time, they may also use cognitive and behavioral systems to navigate and control objects in the environment. While there are a number of studies which explore the relationship between learning and VR, there is not clarity as to how and why these relationships influence learning outcomes within VR (Petersen, Petkakis, & Makransky, 2022; Radianti, Majchrzak, Fromm, & Wohlgenannt, 2020; Tai, Hong, Tsai, Lin, & Hung, 2022). Specifically few studies examine the specific cognitive and autonomic systems impacts of VR use in the classroom related to learning. Recent studies such as Lamb, Antonenko, Etopio, and Seccia (2018) and Albus, Vogt, and Seufert (2021) have generally focused on the global effects of cognitive mechanism such as executive functions and their influence on learning in virtual environments. This is supported by recent analysis by Chen, Zou, et al., 2020 suggesting as well that much of the work related to digital environments are focused on more global topics such as "learning" and learning environments and not finer grained examinations of specific cognitive systems (, p. 11Chen, Zou, et al., 2020). Importantly, the frequency of the use of the term virtual reality as a keyword has not illustrate a significant change in use overtime, suggesting that despite the amount of high-quality research related to VR, there is still significant work to do related to understanding the cognitive mechanisms that are leveraged when using VR.

Using VR environments that contain artificially intelligent student avatars of differing backgrounds provides a solution to better prepare

PSTs and allow exploration of novel skill use. This is because using a soft failure environment and curated experiences in VR may increase reception to learning (Dunn & Kennedy, 2019). The soft failure environment by its nature reduces situational stress by removing the audience effect and the high degree of control reduces CD allowing the system to adapt to individual student needs. These two affordances allow PSTs to practice novel teaching activities, engage in productive problem solving, and apply prior knowledge without additional psychological allostatic load due to stress and excessive cognitive demand (Lamb, 2014; Lamb, Hand, & Kavner, 2021). The interactions in VR allow repeated practice of experiences, pausing of the experiences, and opportunities to explore alternative approaches with little cost or consequence in interactive digital environments. This allows greater use of creativity and mental flexibility. The detail and interactivity of VR environments makes VR nearly indistinguishable from reality creating parity in ANS and cognitive responses. Specifically, these responses mirror responses in the physical world (Lamb, Etopio, et al., 2020). VR interactions allow the construction of learning and development of novel applications of pedagogy through low-risk environments which is critical in the educational processes of PSTs. Thus, VR has substantial capacity for use in teacher preparation (Tondeur, Pareja Roblin, van Braak, Voogt, & Prestridge, 2017; Huang et al., 2022). Previous research has explored VRs use for practice and skill development across multiple fields to include (a) vocational education (Lamb & Annetta, 2012; Mikkonen, Pylväs, Rintala, Nokelainen, & Postareff, 2017), (b) trauma mitigation (Bush et al., 2015; Lamb & Etopio, 2019), (c) medical education (Pottle, 2019) (d) counseling education (Boeldt, McMahon, McFaul, & Greenleaf, 2019; Lamb, Hoston, & Firestone, 2022), and (e) social studies (Patterson & Han, 2019). Many of these studies explore the use of VR as a trainer for skill development and not for the development of cognition, behavior, and affect.

Cognitive science has recognized several distinct circuits associated with higher brain function. These higher brain functions are used for development of new ideas and problem-solving approaches and are tied to working memory and executive function as the specific term of lateral thinking (Sharma & Babu, 2017). Lateral thinking arises from the ability to integrate new information with old information, retrieve prior experiences, and identify how to apply the information. Behaviorally this is interpreted as creativity and MF. The ability to measure creativity and MF in relation to PST development allows instructors to target interventions that assist in the development of these important cognitive systems and promote exploration of innovative ideas by PSTs. Creativity and MF are closely related constructs and are defined as the production of (creativity) and change to (MF) new, original, unique, and divergent ideas (Syahrin, Suwignyo, & Priyatni, 2019). The ability to generate new ideas and engage in problem-solving strategies and bring them to application helps to reduce CD and acute situational stress (Camacho, Vera, Scardamalia, & Phalen, 2018). A growing interest in creativity and other measures such as situational stress and CD has accompanied the understanding that learning is deeply affected not just by simple singular factors interacting in isolation but by a myriad of cognitive, affective, and social factors interacting with one another as a system. This realization in conjunction with the development of less costly and less invasive technologies to measure these factors in the form of portable neuroimaging devices, and small wearable sensors provides a means to measure and examine the constructs as they interact with one another (Annetta, 2010; Lamb et al., 2014, 2018; Lamb & Firestone, 2018). An understanding of the systemic interactions of situational stress and CD while using VR may lead to not just awareness of how these constructs influence PST learning, but how-to mitigate the negative effects of stress and excessive cognitive demand in virtual learning environments. Mitigating the effects of situational stress and CD is important because of negative effects of these factors can result in severe reductions in learning and implementation of new and existing ideas. In addition to the negative outcomes associated with situational stress and CD on academic performance, repeated exposures to situational stress and high levels of CD have been shown to result in reductions in mental acuity, increase blood pressure, anxiety, depression, and can lead to professional "burnout" (Lea, Davis, Mahoney, & Qualter, 2019; Wiederhold, Cipresso, Pizzioli, Wiederhold, & Riva, 2018).

While effects of situational stress and CD on learning are well documented (Lapina, 2018), measurement of these factors is difficult due to their transient nature. Retrospective approaches such as focus groups, interviews, observations, and surveys do not adequately capture the effects of these factors as they are autonomic in nature. Therefore, they are unavailable for introspection and may not be present unless examined in real-time. Lastly, many measures of these factors require responses from the participants which stops the primary cognitive and affective activity the researchers are seeking to measure. One potential means to accomplish the measurement of these factors is using non-invasive passive sensors which capture data during the process of task completion. (Weis, Withoft, & Heuten, 2020). Stress and CD can be measured via autonomic nervous system measures but, the ability to measure behavioral manifestations of cognitive processes such as creativity and MF is more difficult and must be accomplished through specific tasks such as completion of a drawing e.g., the Torrance Test of Creative Thinking. Creativity and MF are shown to be important protective factors in stress reductions and reductions of CD (Martin et al., 2018; Noworol, Žarczyński, Fafrowicz, & Marek, 2017; Abraham, 2018; Wokke, Padding, & Ridderinkhof, 2019). Development of MF and creativity addresses concerns from PSTs that they are not developing the ability to make the intuitive leaps or solve problems while teaching; critical activities to their success (Kaufman, Plucker, & Russell, 2012). Teacher preparation program instructors must coach their PSTs to be skilled in the application of creativity and mental flexibility during the implementation of pedagogies. In addition, due to the increases in anxiety and stress for all student's socioemotional wellbeing must also be a key consideration when implementing activities in all classrooms (McDonald, Kazemi, & Kavanagh, 2013). Many PSTs have identified that they do not believe they are equipped to successfully identify existing approaches and to implement, either existing or new approaches in creative or unique ways (Tican & Deniz, 2019). The feelings of being ill-equipped coupled with other performance requirements generate tremendous amounts of situational stress and may contribute to PST burnout and other indicators of lack of wellbeing. Incidents of anxiety, depression, and other mental health wellbeing concerns are on the rise in college aged students and PSTs are particularly vulnerable due to demographic vulnerabilities (Gunnell, Kidger, & Elvidge, 2018; Millroth & Frey, 2021). Situational stress has been shown to increase levels of CD and reduce learning outcomes (Zhang, Chen, & Li, 2020). While these concerns are global in terms of the student's overall wellbeing, implementing basic changes in how teacher educators approach teaching and learning in the classroom can have a significant impact on overall student wellbeing and the learning environment. In this light the exploration of technologies and pedagogies which reduce situational stress, CD, and allow development of protective factors such as creativity may be warranted. Virtual reality has been shown to provide responses which address each of these areas.

3. Method

The measures used in this study include real-time neurocognitive measures of CD via hemodynamic response, ANS measures of stress in real time (e.g., HRV, GSR, and ST), and psychological/behavioral measures of creativity and MF measured through the Torrance Test of Creative Thinking (TTCT). Neurocognitive measures are quantifications of hemodynamics i.e., the ratio of oxygenated and deoxygenated blood in neurologically active portions of the brain as task completion occurs. Hemodynamic response is tightly tied to the CDs arising within a task or series of tasks (Cohen, 2018). The use of neurocognitive measures and psychophysiological measures allows the research team to capture physiological responses from the participants in real-time as opposed to retrospectively or through self-reports allowing for a fine grain examination of participant physiological and cognitive characteristics

(Persiani, Kobas, Koth, & Auer, 2021). Analysis such as those conducted in this study provides additional insights into the moment-to-moment fluctuations in autonomic nervous system response and cognition as participants engage with each condition [VR and Microteaching]. Fig. 1 summarizes the study procedures.

3.1. Participants

Forty-eight undergraduate college students in year-two of their educator preparation program were enrolled into the study from a university in the Northeastern United States. Thirty-six females and 12 males took part in the study. The participants were invited to a laboratory classroom to teach a lesson as a part of their course work. Participants were as follows; 31 elementary school PSTs and 17 middle school PSTs. Participants were assigned randomly to one of the conditions, face-to-face microteaching or a VR condition. Participants were directed to focus on the use of specific pedagogies within their concentration area e.g., science, social studies, etc. Each of the PSTs were taught to use the VR systems but not shown the VR classroom environment prior to their experiences. While all students engaged in both conditions and data was collected across all teaching opportunities, data was only used from the first teaching experience they completed to minimize practice effects and sensitization. Written lesson plans with objectives and reviews of the actual lessons taught by the PSTs were analyzed via the Student Teacher Assessment Record Rubric (STAR Rubric). Two researchers trained on the use of the STAR Rubric completed an observation for each student. The observation examined four domains: (1) *pedagogical content*; (2) *pedagogical knowledge; (3) content knowledge*; and (4) *professional qualities*. Each area is scored as *proficient, developing, competent,* and *emerging*. Interrater reliability was calculated using Fliess's Kappa for agreement. The Kappa coefficient for the raters was 0.93, substantial agreement (Falotico & Quatto, 2015).

3.2. Conditions

The VR experience and microteaching experience participants received the same instructions related to the preparation of their lessons. The microteaching condition was specifically selected as a counterpoint to VR because microteaching is one of the primary means for PSTs to experience teaching and interactions with students prior to teaching opportunities in actual K-12 classrooms. Comparing these two conditions provides more parity across conditions for the current level (second year) of the students taking part in the study. The 30-min of teaching had to consist of topics and content related to and aligned with the scope and sequence of a local district and the state standards. The average age of the PSTs was 19.84 years. Each of the participants was at the appropriate level for reading and writing, and each participant had a 3.0 or higher GPA within their education classes. The researchers screened PSTs to assess their reading ability and writing ability via the Adult Reading Test (Uttl, 2002), and the CUNY Assessment Test in Writing (CATW). Participants are neurotypical base upon interviews and neurological histories using the Compendium of Neuropsychological Tests (Strauss, Sherman, & Spreen, 2006). Neurological screenings ensured that any increases in CD occurred because of the teaching tasks and not because of cognitive processing differences. Microteaching participants and VR participants were asked to wear noninvasive neuroimaging system on their head and an ANS sensor on their wrists e.g., HRV, ST, and GSR when teaching their lesson. VR condition participants wore the same sensors while wearing the VR goggles. The headset did not interfere with the fNIRS or wrist ANS sensor.

3.2.1. Virtual reality

The VR environments were created using 360-degree camera footage of a classroom with computer designed elements overlaid on the footage. Interactive elements were created using Unity version 2018.3.6 Unity Technologies, 2018. The PSTs used an HTC VIVE headset for their VR classroom experience. Prior to teaching, the students were given time to familiarize themselves with the headset. The VR experience occurred on a Dell G5 Gaming Desktop with a NVIDIA 1060 graphics processor. The classroom consisted of student desks and other things found in an elementary and middle school classroom such as a whiteboard, posters, student's work, and storage areas. While there were 30-desks, not all had a virtual student assigned to them. The PSTs could walk and interact with a few objects in the classroom as a part of their lesson. Ambient sounds from the classroom included low levels of talking, student movement sounds, and students talking with the teacher. PSTs taught a 30-min lesson to a class of 20 virtual 4th grade elementary students. Fig. 2 provides an illustration of the VR environment with an example unity

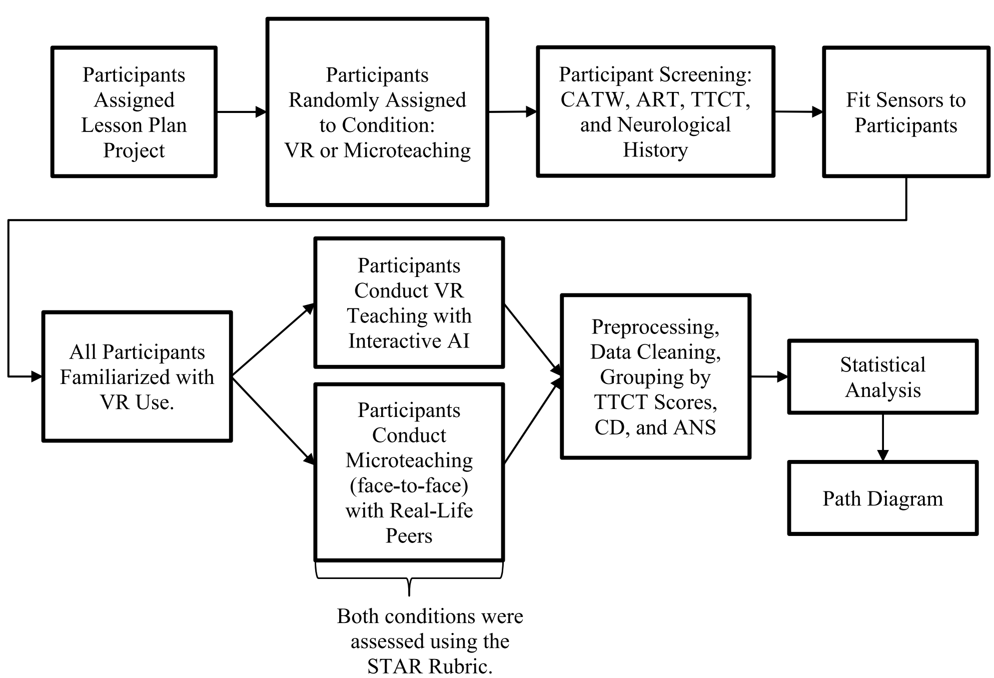

Fig. 1. Flow chart summary of study procedures.

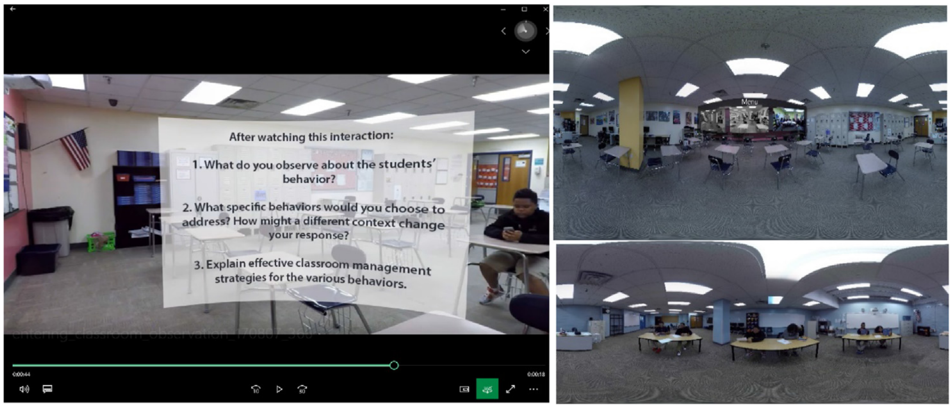

Fig. 2. VR Environment used in the study.

overlay for prompting.

3.2.2. Microteaching

PSTs taking part in microteaching were asked to teach a 30-min lesson to their peers on a content topic of their choice so long as it was consistent with their content area and aligned as discussed above. The PSTs within the classroom condition also submitted lessons which aligned with the state curriculum and were assess using the STAR rubric. Interrater reliability was established using Fleiss's Kappa.

3.3. Cognitive demand and fNIRS

CD data used in this study was collected using a fNIRS. The fNIRS system consists of a small laptop computer and a portable non-invasive neuroimaging sensor (optode) used to measure the optical properties of oxygenated and deoxygenated hemoglobin. As a PST engages in teaching, cognitive systems such as lateral thinking, working memory, and other executive functions within the brain are engaged, oxygenated blood moves to the neural tissues being engaged and is deoxygenated to support cellular metabolism. The movement of blood to neural tissues and the oxygenation and deoxygenation of the hemoglobin in blood is known as hemodynamic response. The levels of oxygenation and deoxygenation reflect the levels of CD as the PST completes the tasks (Foy & Chapman, 2018). CD is defined as a description of the level of cognitive processing, control, and effort a PST needs to complete a task relative to the difficulty of a task and a student's prior knowledge (Lamb, 2013). Changes in hemodynamic response can be measured using optical sensors known as optodes. An optode is an optical sensing device which measures the concentration of a substance through changes in wavelengths associated with the substance. There are 54-optodes which collected the measures of hemodynamic responses during task completion. The prefrontal cortex was the focus of the study as it is the seat of fluid cognitive functioning and learning related to goal directed activities such as teaching (Shallice & Cipolotti, 2018). Examinations of the prefrontal cortex activity illustrate working memory and subsidiary fine-grained systems under executive function such as lateral thinking, can be measured using fNIRS. Measures using fNIRS to obtain neurocognitive data allow researchers to identify when PSTs were engaged in multiple types of tasks, not just in teaching but in the use of cognitive systems in general (Cohen et al., 1994).

3.4. Autonomic nervous system measures

Differentiation and measurement of acute and chronic stress is often difficult using retrospective and self-report data due to the transient and subtle nature of the physiological and psychological effects. In many cases, people are completely unaware of the levels of stress they are under until it is independently quantified. Heart Rate Variability (HRV) and Galvanic Skin Response (GSR) was collected to produce support for acute ANS stress (van der Zwan, de Vente, Huizink, Bögels, & de Bruin, 2015). Due to the link between cognition, affect, behavior, and physical responses, thinking, describing, detailing, and engaging in stressful events creates responses in the ANS which are measurable using HRV and GSR (Lissek & van Meurs, 2015). Measures of HRV and GSR were obtained for each condition e.g., microteaching and VR. Stress data was collected using an Empatica E4 sensor. The sampling rate for the Empatica is 64Hz for HRV and 4Hz for GSR.

3.4.1. Galvanic Skin Response (GSR)

GSR was measured using metal contacts located on the participants wrist via an Empatica E4 sensor. GSR is used to identify levels of anxiety, chronic stress, and acute stress during task completion (Ruiz-Robledillo, Sariñana-González, Pérez-Blasco, González-Bono, & Moya-Albiol, 2015). The sampling rate was 4Hz. Skin conductance responses illustrating the presence of stress are shown to consistently measure acute stress responses such as taking part in an unfamiliar activity. The quick skin conductance signal produced during acutely stressful events is clearly identifiable though analysis of signal peaks and troughs. Using a statistical smoothing algorithms method developed by Benedek and Kaernbach (2010), the authors reduce noise associated with the faster skin conductance response allowing analysis of acute stress responses. Data loss was 18% using these methods.

3.4.2. Heart rate variability (HRV)

The Empatica E4 sensor was also used to collect HRV data. Data collection occurred using the photoelectric pulse wave method sampling at 1Hz. High frequency HRV data is specifically indicative of acute stress responses. Signal cleaning to capture acute stress response as opposed to, interference due to respiration, occurs via signal normalization and subtraction of artifacts related to breathing. Respiration occurs at mid-range frequencies within the HRV signals (Kim, Cheon, Bai, Lee, & Koo, 2018). Data loss was 28% using these methods.

3.5. Torrance Test of Creative Thinking

The Torrance Test of Creative Thinking (TTCT) ($\alpha = 0.76$) was developed in 1966 and measures levels of creativity and MF, the behavioral manifestations of lateral thinking. The figurative test consists of three norm-referenced subtests (1) *compose a drawing,* (2) *finish a drawing,* and (3) *compose a different drawing from parallel lines* (Torrance, 1969). Assessment of the responses occur though identification of the number of relevant responses (fluency), count of the variety of categories (MF), the number of unusual or unfamiliar but relevant responses (originality), and finally the number of details used to extend the response (elaboration). Counts are examined and converted to norm referenced standardized scores representing each category which can then be used for other analyses.

3.6. Data processing

Initial processing of data started with removing interference from respiration, heart beats, and movement artifacts. A low frequency filter (0.14 Hz) was used to remove signal interference from the artifacts allowing attenuation and smoothing of the data (Alghoul, Alharthi, Al Osman, & El Saddik, 2017). Segments were 30-min long and started with the beginning of teaching to the completion of the teaching 30-min later. fNIRS data and other sensor data was analyzed to determine when the PSTs illustrated greater than baseline values for each of the physiological measures as they were teaching. HRV and GSR values were standardized and combined into an overall stress response value. Hemodynamic ratios of oxygenated and deoxygenated blood were also standardized and combined into cognitive demand values. Sensor data taken during teaching which illustrated values above baseline were identified and separated from the full data. This data was then segmented into four groups based upon condition [VR or Microteaching] and the PSTs TTCT score. The resultant groups were, *upper 50% VR*, *upper 50% microteaching*, *lower 50% microteach*ing, and *lower 50% VR*.

3.6.1. Statistical analysis

Analysis for each of the data sources were analyzed using repeated measures ANOVA (rANOVA) and a Tukey-HSD post-hoc test. Analysis was on the mean and attribute maximums for each measurement. rANOVA is specifically indicated for analyses of within group data in which the individual participant's data various over time such as in a baseline 1 (A), stimulus (B), and baseline 2 (A) research design. This analysis, rANOVA, allows researchers to examine within and between subject comparisons collectively. rANOVA also decreases error variance while increasing statistical power for multi-measure data. Power analysis shows a 0.95 probability of identifying a small effect with a sample size of 36. This study's sample size is 48 suggesting this sample size is sufficient to detect small changes and allows for potential attrition of participants. The authors also used a path model analysis to understand how the variables of interest are interconnected through mediation or moderation. Using path analysis allows the researchers to understand the system of variables and their effects on each other using a multiple regression approach (Klem, 1995). The path analysis was conducted using Mplus v.8.6.

4. Results

Statistical analysis was conducted to ascertain differences between each condition and TTCT score groups (*upper 50% VR*, *upper 50% microteaching*, *lower 50% microteach*ing, and *lower 50% VR)*. PSTs were assessed using a STAR rubric for *professional qualities, pedagogical knowledge*, *pedagogical content knowledge*, and *content knowledge*. All PSTs were rated as *developing* ($n = 48$) across all areas of the STAR Rubric. This indicates that no PST groups differ in terms of average skill level in teaching. Table 1 shows mean differences and standard deviations for the VR and microteaching condition on the TTCT. Pretest and posttest results illustrate that regardless of the order of completion, levels of creativity and MF as measured by the TTCT did not illustrate statistically significant differences between the pretest and posttest as compared using a paired sample t-test assuming unequal variance $t(23) = 0.235$, $p = .814$ and $t(23) = 0.463$, $p = .645$. This suggests that creativity as measured by the TTCT was stable and did not significantly change because of the experiences.

Table 1
Comparison between Pretest and Posttest results of the TTCT.

Condition	Pretest (M, SD)	Posttest (M, SD)	Δ Mean	t-Value	p-Value
Virtual Reality	116.05 (14.7)	117.47 (16.6)	1.42	.235	.814
Microteaching	117.14 (15.1)	119.33 (15.4)	2.19	.463	.645

Repeated measures ANOVA provides evidence that the main effect of stress across TTCT groups [*High* or *Low*] by condition [*VR* or *Microteaching*] was statistically different, F (3, 9238) = 8.452, $p < .001$. Post hoc comparisons using a Tukey HSD test shows mean scores for the VR High creativity and MF group illustrated statistically significant differences (less stress) when compared to each of the groups over time. In addition to the VR High creativity and MF group, the VR Low creativity and MF group illustrates statistically significant differences from each of the two microteaching groups. Microteaching groups illustrate statistically significant differences from one another on the factors of creativity and MF group. Results for CD measures also illustrate the same pattern of results F (3, 10,231) = 10.784, p less than .001. Table 2 illustrates the results of the planned comparison. Fig. 3 is a visualization of the between group differences related to the variable of stress during teaching opportunities over 30-min. VR seems to illustrate on average lower stress levels when compared to the microteaching conditions across the creativity and MF group scores. Tukey HSD results also illustrate similar outcomes as well. See Table 3 and Fig. 4.

Path analysis results illustrate that the independent variable of condition [VR or Microteaching] accounts for 47% of the variability in stress response and 38% of the variability in CD. Each of the regression models was significant, Fig. 5 illustrates the resultant *just identified* path models with all non-significant pathways removed. Model fit statistics for each of the path analyses indicate good fit. Given the large number of data points, a significant chi square does not indicate poor model fit, CFI = 1.301, SRMR = 0.162, RMSE = 0.004 and CFI = 1.221, SRMR = 0.1999, and RMSE = 0.001 respectively for each model. Of all the path coefficients, the path from condition to CD is the largest ($B = 0.774$, $t = 9.37$, $p <$ .001), followed by the path coefficient from condition to stress response ($B = 0.681$, $t = 7.33$, $p = .011$). Examination of the TTCT score illustrates that creativity and MF acts indirectly on both stress response and CD, reducing both stress and CD.

5. Discussion

In addressing the research question, do students using VR illustrate statistically significant differences in stress and CD when compared with students engaging in microteaching, the authors examined TTCT scores, ANS data, and neuroimaging data. Results from this study illustrate that the use of VR is significantly less stressful than microteaching and stress response and CD are moderated by the protective factors of creativity and mental flexibility. Creativity, MF, and VR use, moderate stress and CD experiences providing an opportunity for PSTs to fuse theory with practice in safe and low-stake soft-failure environments (Lamb, Cavagnetto, & Akmal, 2016; Lamb et al., 2022a; Lamb, Crowe, et al., 2022; Slavin, 2019). MF and creativity provide a protective effect from acute situational stress and excessive CD. This allows the PSTs to focus on practices and content use during their practice sessions creating opportunities to attempt novel approaches and integrate practices in a more automatic way. Ultimately, having better prepared PSTs using more creative responses, reduces CD, and increased MF leads to greater efficacy and efficiency of instruction (Morrison, Ross, Morrison, & Kalman,

Table 2
Comparison between high and low TTCT group by condition by stress level.

Planned Comparison 1	Planned Comparison 2	Significance
VR H	VR L	.041
	Micro H	.011
	Micro L	less than .001
VR L	Micro H	.031
	Micro L	.044
Micro L	Micro H	.037

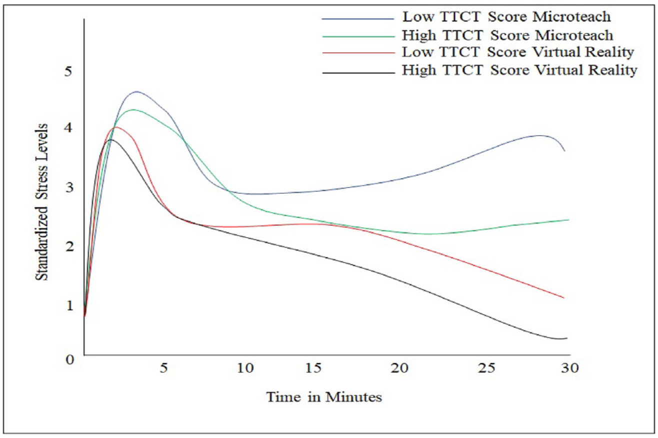

Fig. 3. Visualization of changes in acute stress over time for PSTs by condition and TTCT score.

Table 3
Comparison between high and low TTCT groups by condition by cognitive demand.

Planned Comparison 1	Planned Comparison 2	Significance
VR H	VR L	.021
	Micro H	.032
	Micro L	.004
VR L	Micro H	.048
	Micro L	.032
Micro L	Micro H	.049

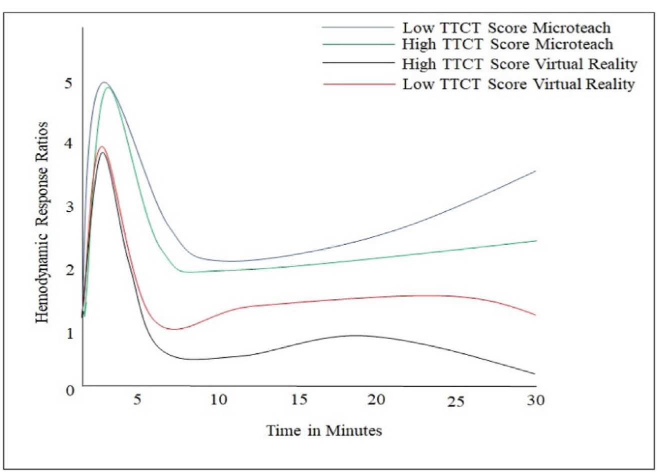

Fig. 4. Visualization of changes in cognitive demand over time for PSTs by condition and TTCT score.

2019). Improved opportunities to practice for PSTs results in the development of stronger pedagogical practices, increased well-being, and better prepares PSTs for complexities that exist in the actual classroom (Darling-Hammond, 2014).

While real experiences over time in classrooms with teachers and students are needed, VR illustrates great potential for PST development with reduce stress and demand. Based upon the results of this study, incorporation of VR as a regular tool for use in-class and practice out-of-class seems warranted. VR simulations enable realistic environments for those engaged in the development of their teaching (Nelson & Annetta, 2016). The realism of the VR environment for the PSTs helps them to learn from modeled and curated situations that promote greater learning

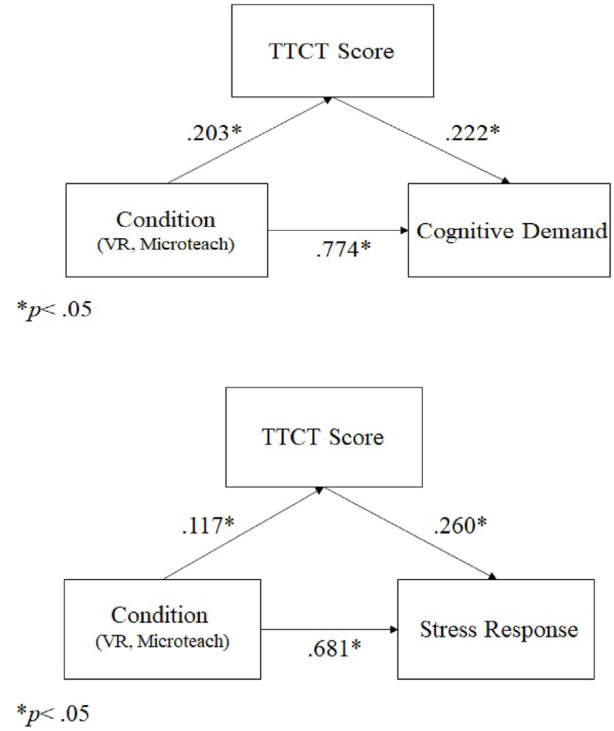

Fig. 5. Path diagram illustrating the relationship between condition, stress response, cognitive demand, as moderated by TTCT scores of creativity and mental flexibility.

than microteaching. VR also provides a more uniform approach for learning purposes than microteaching, allowing for commonality of experience by the PSTs. It is the tension between uniformity/consistency and development of creativity and individual experiences which computerized simulations such as VR address. Using VR, the PSTs, through practice, will improve their skills and understanding with avatars which simulate the populations they will work with as opposed to their peers. Importantly, avatars can be adjusted to reflect populations that the PSTs may not be familiar with, allowing them to experience persons who may have differences from them. As VR scenarios are uniform across participant, PSTs may have a commonality of experience on which to reflect as a class. This can help to promote group discussion and group problem solving of scenario questions and interactions. VR combines vignette base approaches with interactivity and AI based adaptive individual practice allow significant differentiation.

While microteaching does have some of these positive aspects, there are also negative aspects such as promoting higher levels of stress and CD through audience effects and unrealistic peer responses. This may indicate that students during a microteaching session are experiencing an affective priming event which has far less controlled outcomes and is tied to reduced learning (Klauer, 1997; Lamb, Akmal, & Petrie, 2015). The reduced CD associated with VR allows PSTs to dedicate more cognitive resources to the acquisition and practice of skills and development of understanding through a cognitive priming event mechanism (Lamb, Hand, & Yoon, 2017). Using a tiered approach, PST educators may slowly add complexity to the VR scenarios increasing (dis)stress tolerance and CD tolerance over time. The increase in stress tolerance may allow the PSTs to understand the added complexity and develop levels of MF and creativity increasing levels of these protective factors (Lamb, Hoston, & Firestone, 2022).

The mechanism by which creativity acts as a protective factor is supported within this study. Creativity is thought to reduce the use of heuristic thinking processes (Metzl & Morrell, 2008). Heuristic processes are cognitive shortcuts, and these shortcuts are reduced when a task or action induces active consideration/cognition of how to integrate information and make use of the information for novel application (Magnussen & Svendsen, 2018). Overtime, with practice effects, the level of CD reduces novel applications of knowledge and these applications become automatized, converting to heuristic type approaches. Heuristic thinking has been shown to manifest as low levels of hemodynamic response, whereas active engagement in lateral thinking illustrate elevated levels of hemodynamic response.

These results support previous studies which illustrate that simulated and VR experiences may allow novices the opportunity to practice with less anxiety (a stress response) of doing serious harm and allow the more effective integration of new information. Reduced/appropriate levels of CD may facilitate the learning process (Lamb et al., 2021; Yee & Braver, 2018). Levels of CD which are either too high or too low, create frustration and boredom, respectively resulting in affective priming. Modulation of CD may occur through application of slowly increasing complexity of practices and through thorough preparation of activities and planning prior to engagement in the practice of teaching. Based upon the results of this work a tiered approach would start with microteaching, move to VR, and then into an actual classroom allowing for a gradual release of responsibility/control (Eutsler, 2022). The elevated levels of stress associated with microteaching may indicate that the PSTs are experiencing nervousness and lack of surety around their actions creating hesitancy and continuous internal assessment of their action while trying to understand which actions to take. Creating safe conditions and opportunities for more practice prior to work in microteaching environments may assist in effective stress reduction and promote reflection and assessment. One potential area of future research with VR for PST development would be in using neuroimaging data to modify activities in the VR environment to generate levels of CD to suit the PST as they develop as a teacher (Lamb et al., 2021).

5.1. Implications

In many education settings, PSTs and those just graduated from their university program are faced with many challenges which require them to rapidly adjust to novel situations in the classroom. VR has multiple areas of potential in relation to teaching practice. The first is development of classroom management and associated skills for the daily operation of the classroom. Via reductions in stress and CD, VR may allow PSTs to identify and address events within the classroom at an early stage before escalation of the behavior occurs. The second is, the further development of cognitive skills and behavioral actions which promote positive affective outcomes allowing PSTs to address their responses and the responses of their students to novel situations (Snelson & Hsu, 2020). The feeling of presence and emotional involvement that VR produces results in the development of important competencies such as self-evaluation, understanding of content, and automatic practices associated with pedagogy for the PSTs (Pantic & Wubbels, 2010; Billingsley et al., 2019; Cooper et al., 2019). This is particularly true if the VR is sequenced in terms of complexity of tasks, is adaptive to physiological and psychological inputs, and allows varied modes of learning. VR can be used to create active experiences and promote specific learning outcomes for PSTs (Nissim & Weissblueth, 2017). One area of research merging teacher education, user experience research, instructional technology, and artificial intelligence is research into the development of artificially intelligent avatars and adaptive digital learning environments. Research to examine the effects of these simulations (VR) through adaptive and individualized learning opportunities is needed (Dieker, Rodriguez, Lignugaris/Kraft, Hynes, & Hughes, 2014). A second area of current research is how best to integrate the realism of experiences in a practical and low-cost way which is accessible and available to all students. One potential approach is to use 360-degree video technology with Unity overlay (Theelen, Van den Beemt, & den Brok, 2019).

5.2. Limitations

There are a number of limitations associated with this study. One limiting aspect of this study is the gender balance of the participants taking part in this study. Current statistics for elementary school teachers, according to the National Center for Educational Statistics (2022), show that 80.5% of all elementary school teachers are female. This current study has a female gender representativeness of 75%, thus males are overrepresented by 15%. This limits the potential generalizability of the study. A second area of limitation is that there was not an identification of potential underlying stress and anxiety-based disorders within the sample. Preexisting conditions of this nature may make a person more likely to illustrate behaviors, cognition, and affect related to stress when they are placed into a stressful environment, confounding levels of stress they may experience solely from the environment.

5.3. Conclusion

Tracking teacher development beyond the semester was difficult due to time constraints and as a result the research team was unable to gather data showing additional growth because of the experience or maintenance of the protective factors associated with creativity and MF. One additional concern is the absence of baseline data from the PSTs entrance into the preparation program. Lacking this data, it is difficult to assess growth and to determine if levels of stress and CD had changed as the PST developed during the program using VR. The tracking of changes in stress levels and CD over the course of a PST program is an additional area of research which may provide greater resolution related to the results seen in the study. One of the fundamental purposes of clinical experiences in PST programs is to give PSTs the opportunity to experience the complexity and unpredictability of the classroom. Yet, it is the complexity and unpredictably of the classroom which reduces the quality of experiences for PSTs. In many ways, learning is shown to occur most successfully with gradual increases in responsibility, complexity, unpredictability, and by allowing a person to address novel problems in meaningful ways. VR allows this to occur in a controlled and appropriate way.

Ethical statement

All procedures performed in this study involving human participants are in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Consent statement

Written informed consent was obtained from the parents.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Abraham, A. (2018). *The neuroscience of creativity*. Cambridge University Press.
Albus, P., Vogt, A., & Seufert, T. (2021). Signaling in virtual reality influences learning outcome and cognitive load. *Computers & Education, 166*, 1–16.
Alghoul, K., Alharthi, S., Al Osman, H., & El Saddik, A. (2017). Heart rate variability extraction from videos signals: ICA vs. EVM comparison. *IEEE Access, 5*, 4711–4719.
Annetta, L. A. (2010). The "I's" have it: A framework for serious educational game design. *Review of General Psychology, 14*(2), 105–110.
Annetta, L. A., Lamb, R., & Stone, M. (2011). Assessing serious educational games: The development of a scoring rubric. In *Serious educational game assessment* (pp. 75–93). Brill.

Arzal, Z. (2014). Microteaching and pre-service teachers' sense of self-efficacy in teaching. *European Journal of Teacher Education, 37*(4), 453–464.

Benedek, M., & Kaernbach, C. (2010). A continuous measure of phasic electrodermal activity. *Journal of Neuroscience Methods, 190*(1), 80–91.

Boeldt, D., McMahon, E., McFaul, M., & Greenleaf, W. (2019). Using virtual reality exposure therapy to enhance treatment of anxiety disorders: Identifying areas of clinical adoption and potential obstacles. *Frontiers in Psychiatry, 10*, 1–6.

Bottiani, J. H., Duran, C. A., Pas, E. T., & Bradshaw, C. P. (2019). Teacher stress and burnout in urban middle schools: Associations with job demands, resources, and effective classroom practices. *Journal of School Psychology, 77*, 36–51.

Bush, N. E., Dobscha, S. K., Crumpton, R., Denneson, L. M., Hoffman, J. E., Crain, A., … Kinn, J. T. (2015). A virtual hope box smartphone app as an accessory to therapy: Proof-of-concept in a clinical sample of veterans. *Suicide and Life-Threatening Behavior, 45*(1), 1–9.

Cacioppo, S., & Cacioppo, J. T. (2015). Dynamic spatiotemporal brain analyses using high-performance electrical neuroimaging, Part II: A step-by-step tutorial. *Journal of Neuroscience Methods, 256*, 184–197.

Camacho, D. A., Vera, E., Scardamalia, K., & Phalen, P. L. (2018). What are urban teachers thinking and feeling? *Psychology in the Schools, 55*(9), 1133–1150.

Chen, X., Xie, H., Zou, D., & Hwang, G. J. (2020). Application and theory gaps during the rise of artificial intelligence in education. *Computers & Education: Artificial Intelligence, 1*, 1–20.

Chen, X., Zou, D., Cheng, G., & Xie, H. (2020). Detecting latent topics and trends in educational technologies over four decades using structural topic modeling: A retrospective of all volumes of computers & education. *Computers & Education, 151*, 1–21.

Cohen, J. R. (2018). The behavioral and cognitive relevance of time-varying, dynamic changes in functional connectivity. *NeuroImage Part B, 180*, 515–525.

Cohen, J. D., Forman, S. D., Braver, T. S., Casey, B. J., Servan-Schreiber, D., & Noll, D. C. (1994). Activation of the prefrontal cortex in a nonspatial working memory task with functional MRI. *Human Brain Mapping, 1*(4), 293–304.

Darling-Hammond, L. (2014). Strengthening clinical preparation: The holy grail of teacher education. *Peabody Journal of Education, 89*(4), 547–561.

Dieker, L. A., Rodriguez, J. A., Lignugaris/Kraft, B., Hynes, M. C., & Hughes, C. E. (2014). The potential of simulated environments in teacher education: Current and future possibilities. *Teacher Education and Special Education, 37*(1), 21–33.

Dunn, T. J., & Kennedy, M. (2019). Technology enhanced learning in higher education; motivations, engagement and academic achievement. *Computers & Education, 137*, 104–113.

Eutsler, L. (2022). TPACK's pedagogy and the gradual release of responsibility model coalesce: Integrating technology into literacy teacher preparation. *Journal of Research on Technology in Education, 54*(3), 327–344.

Falotico, R., & Quatto, P. (2015). Fleiss' kappa statistic without paradoxes. *Quality and Quantity, 49*(2), 463–470.

Foy, H. J., & Chapman, P. (2018). Mental workload is reflected in driver behavior, physiology, eye movements and prefrontal cortex activation. *Applied Ergonomics, 73*, 90–99.

Gunnell, D., Kidger, J., & Elvidge, H. (2018). Adolescent mental health in crisis. *BMJ, 36*(1), 361–362.

Hamilton, D., McKechnie, J., Edgerton, E., & Wilson, C. (2021). Immersive virtual reality as a pedagogical tool in education: A systematic literature review of quantitative learning outcomes and experimental design. *Journal of Computers in Education, 8*(1), 1–32.

Homer, B. D., Plass, J. L., Raffaele, C., Ober, T. M., & Ali, A. (2018). Improving high school students' executive functions through digital game play. *Computers & Education, 117*, 50–58.

Huang, B., Jong, M. S. Y., Tu, Y. F., Hwang, G. J., Chai, C. S., & Jiang, M. Y. C. (2022). Trends and exemplary practices of stem teacher professional development programs in K-12 contexts: A systematic review of empirical studies. *Computers & Education, 189*, 1–24.

Jerath, R., Crawford, M. W., Barnes, V. A., & Harden, K. (2015). Self-regulation of breathing as a primary treatment for anxiety. *Applied Psychophysiology and Biofeedback, 40*(2), 107–115.

Jiménez-Picón, N., Romero-Martín, M., Ponce-Blandón, J. A., Ramirez-Baena, L., Palomo-Lara, J. C., & Gómez-Salgado, J. (2021). The relationship between mindfulness and emotional intelligence as a protective factor for healthcare professionals: Systematic review. *International Journal of Environmental Research and Public Health, 18*(10), 1–14.

Kapoor, H., & Khan, A. (2019). Creativity in context: Presses and task effects in negative creativity. *Psychology of Aesthetics, Creativity, and the Arts, 13*(3), 1–8.

Kassymova, G.K., Tokar, O. V., Tashcheva, A. I., Slepukhina, G. V., Gridneva, S. V., Bazhenova, N. G., … Arpentieva, M. R. (2019). Impact of stress on creative human resources and psychological counseling in crises. *International Journal of Education and Information Technologies, 13*(1), 26–32.

Kaufman, J. C., Plucker, J. A., & Russell, C. M. (2012). Identifying and assessing creativity as a component of giftedness. *Journal of Psychoeducational Assessment, 30*(1), 60–73.

Kent, J., Thornton, M., Fong, A., Hall, E., Fitzgibbons, S., & Sava, J. (2020). Acute provider stress in high stakes medical care: Implications for trauma surgeons. *Journal of Trauma and Acute Care Surgery, 88*(3), 440–445.

Kim, H. G., Cheon, E. J., Bai, D. S., Lee, Y. H., & Koo, B. H. (2018). Stress and heart rate variability: A meta-analysis and review of the literature. *Psychiatry Investigation, 15*(3), 235–245.

Klauer, K. C. (1997). Affective priming. *European Review of Social Psychology, 8*(1), 67–103.

Klem, L. (1995). Path analysis. In L. G. Grimm, & P. R. Yarnold (Eds.), *Reading and understanding multivariate statistics* (pp. 65–97). American Psychological Association.

Lamb, R. L. (2013). *The application of cognitive diagnostic approaches via neural network analysis of serious educational games (Publication No. 3591980)*. Doctoral dissertation. George Mason University] ProQuest Dissertations and Theses Global.

Lamb, R. (2014). Examination of allostasis and online laboratory simulations in a middle school science classroom. *Computers in Human Behavior, 39*, 224–234.

Lamb, R., Akmal, T., & Petrie, K. (2015). Development of a cognition-priming model describing learning in a STEM classroom. *Journal of Research in Science Teaching, 52*(3), 410–437.

Lamb, R., & Annetta, L. (2012). Influences of gender on computer simulation outcomes. *Meridian, 13*(1).

Lamb, R., Antonenko, P., Etopio, E., & Seccia, A. (2018). Comparison of virtual reality and hands on activities in science education via functional near infrared spectroscopy. *Computers & Education, 124*, 14–26.

Lamb, R. L., Cavagnetto, A., Adesope, O. O., Yin, L., French, B., & Taylor, M. (2014). Artificially intelligent systems in education a tool for the future. *Educational and Learning Games, 79*.

Lamb, R., Cavagnetto, A., & Akmal, T. (2016). Examination of the nonlinear dynamic systems associated with science student cognition while engaging in science information processing. *International Journal of Science and Mathematics Education, 14*(1), 187–205.

Lamb, R., Crowe, A., Stone, J., Annetta, L., Zambone, A., & Owens, T. (2022). Virtual reality enhanced Dialectical behavioural therapy. *British Journal of Guidance and Counselling, 50*(4), 1–22.

Lamb, R., & Etopio, E. (2019). VR has it: A framework for virtual reality integration into therapy. In *Integrating technology into modern therapies* (pp. 80–93). Routledge.

Lamb, R., Etopio, E., Firestone, J. B., Zeder, J., & Hand, B. (2020). Realism, immersion, and interactivity: The effects of virtual reality on students' scientific writing. In K.-A. Croce, & J. B. Firestone (Eds.), *Developing science literacy in the 21st century* (pp. 83–105). Information Age Publishing.

Lamb, R., & Firestone, J. B. (2018). Science teacher education as a way forward for medical schools: A case for medical pedagogical content knowledge. *Journal of Science Teacher Education, 29*(3), 173–178.

Lamb, R., Hand, B., & Kavner, A. (2021). Computational modeling of the effects of the science writing heuristic on student critical thinking in science using machine learning. *Journal of Science Education and Technology, 30*(2), 283–297.

Lamb, R., Hand, B., & Yoon, S. (2017). *Examinations of cognitive processing of science writing tasks. Journal of Psychology and Brain Studies, 1*(1), 1–5.

Lamb, R., Hoston, D., & Firestone, J. (2022). Psychological allostatic load: The cost of persistence in STEM disciplines. *Research in Science Education, 52*(4), 1187–1206.

Lamb, R., Lin, J., & Firestone, J. B. (2020). Virtual reality laboratories: A way forward for schools? *Eurasia Journal of Mathematics, Science and Technology Education, 16*(6), Article em1856.

Lamb, R., Miller, D., Lamb, R., Akmal, T., & Hsiao, Y. J. (2018). Examination of the role of training and fidelity of implementation in the use of assistive communications for children with autism spectrum disorder: A meta-analysis of the picture exchange communication system. *British Journal of Special Education, 45*(4), 454–472.

Lamb, R., Neumann, K., & Linder, K. A. (2022). Real-time prediction of science student learning outcomes using machine learning classification of hemodynamics during virtual reality and online learning sessions. *Computers & Education: Artificial Intelligence, 3*, 1–12.

Lapina, A. (2018). Facilitating coping through reflective learning in adult education: A review of the reciprocal relationship between coping and learning. *Adult Learning, 29*(4), 131–140.

Lea, R. G., Davis, S. K., Mahoney, B., & Qualter, P. (2019). Does emotional intelligence buffer the effects of acute stress? A systematic review. *Frontiers in Psychology, 10*, 8–10.

Lissek, S., & van Meurs, B. (2015). Learning models of PTSD: Theoretical accounts and psychobiological evidence. *International Journal of Psychophysiology, 98*(3), 594–605.

Luckin, R., & Cukurova, M. (2019). Designing educational technologies in the age of AI: A learning sciences-driven approach. *British Journal of Educational Technology, 50*(6), 2824–2838.

Magnussen, J., & Svendsen, I. L. (2018). Getting there: Heuristics and biases as rationing shortcuts in professional childcare judgments and decision-making–an integrative understanding. *Nordic Social Work Research, 8*(1), 6–21.

Martin, L., Oepen, R., Bauer, K., Nottensteiner, A., Mergheim, K., Gruber, H., et al. (2018). Creative arts interventions for stress management and prevention—a systematic review. *Behavioral Sciences, 8*(2), 28–36.

McDonald, M., Kazemi, E., & Kavanagh, S. S. (2013). Core practices and pedagogies of teacher education: A call for a common language and collective activity. *Journal of Teacher Education, 64*(5), 378–386.

Mercier, J. (2018). The feasibility and interest of monitoring the cognitive and affective states of groups of co-learners in real time as they learn. In T. Mikropoulos (Ed.), *Research on e-learning and ICT in education* (pp. 1–24). Springer.

Metzl, E. S., & Morrell, M. A. (2008). The role of creativity in models of resilience: Theoretical exploration and practical applications. *Journal of Creativity in Mental Health, 3*(3), 303–318.

Mikkonen, S., Pylväs, L., Rintala, H., Nokelainen, P., & Postareff, L. (2017). Guiding workplace learning in vocational education and training: A literature review. *Empirical Research in Vocational Education and Training, 9*(1), 1–22.

Millroth, P., & Frey, R. (2021). Fear and anxiety in the face of COVID-19: Negative dispositions towards risk and uncertainty as vulnerability factors. *Journal of Anxiety Disorders, 83*, 1–8.

Morrison, G. R., Ross, S. J., Morrison, J. R., & Kalman, H. K. (2019). *Designing effective instruction* (7^{TH} ed.). John Wiley & Sons.

Nelson, D., & Annetta, L. A. (2016). Creating disruptive innovators: Serious educational game design on the technology and engineering spectrum. In L. Annetta, &

J. Minogue (Eds.), *Connecting science and engineering education practices in meaningful ways* (pp. 3–17). Springer.
Nissim, Y., & Weissblueth, E. (2017). Virtual reality (VR) as a source for self-efficacy in teacher training. *International Education Studies, 10*(8), 52–59.
Noworol, C., Žarczyński, Z., Fafrowicz, M., & Marek, T. (2017). Impact of professional burnout on creativity and innovation. In W. Schaufeli, C. Maslach, & C. Maslach (Eds.), *Professional burnout: Recent development in theory and research* (pp. 163–175). Routledge.
Özcan, Ö., & Gerçek, C. (2019). Multidimensional analyzing of the microteaching applications in teacher education via videograph. *European Journal of Teacher Education, 42*(1), 82–97.
Pantić, N., & Wubbels, T. (2010). Teacher competencies as a basis for teacher education–Views of Serbian teachers and teacher educators. *Teaching and Teacher Education, 26*(3), 694–703.
Patterson, T., & Han, I. (2019). Learning to teach with virtual reality: Lessons from one elementary teacher. *TechTrends, 63*(4), 463–469.
Pellas, N., Dengel, A., & Christopoulos, A. (2020). A scoping review of immersive virtual reality in STEM education. *IEEE Transactions on Learning Technologies, 13*(4), 748–761.
Persiani, S. G., Kobas, B., Koth, S. C., & Auer, T. (2021). Biometric data as real-time measure of physiological reactions to environmental stimuli in the built environment. *Energies, 14*(1), 1–40.
Petersen, G. B., Petkakis, G., & Makransky, G. (2022). A study of how immersion and interactivity drive VR learning. *Computers & Education, 179*, 1–16.
Pottle, J. (2019). Virtual reality and the transformation of medical education. *Future Healthcare Journal, 6*(3), 181–185.
Radianti, J., Majchrzak, T. A., Fromm, J., & Wohlgenannt, I. (2020). A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. *Computers & Education, 147*, 1–29.
Ruiz-Robledillo, N., Sariñana-González, P., Pérez-Blasco, J., González-Bono, E., & Moya-Albiol, L. (2015). A mindfulness-based program improves health in caregivers of people with autism spectrum disorder: A pilot study. *Mindfulness, 6*(4), 767–777.
Shallice, T., & Cipolotti, L. (2018). The prefrontal cortex and neurological impairments of active thought. *Annual Review of Psychology, 69*, 157–180.
Sharma, S., & Babu, N. (2017). Interplay between creativity, executive function and working memory in middle-aged and older adults. *Creativity Research Journal, 29*(1), 71–77.
Slavin, R. E. (2019). *Educational psychology: Theory and practice*. Pearson.
Snelson, C., & Hsu, Y. C. (2020). Educational 360-degree videos in virtual reality: A scoping review of the emerging research. *TechTrends, 64*(3), 404–412.
Stephan, M., Markus, S., & Gläser-Zikuda, M. (2019). Students' achievement emotions and online learning in teacher education. *Frontiers in Education, 4*(109), 1–12.
Strauss, E., Sherman, E., & Spreen, O. (2006). *A compendium of neuropsychological tests*. Oxford University Press.
Syahrin, A., Suwignyo, H., & Priyatni, E. T. (2019). Creative thinking patterns in student's scientific works. *European Journal of Educational Research, 19*(81), 21–36.
Tai, K. H., Hong, J. C., Tsai, C. R., Lin, C. Z., & Hung, Y. H. (2022). Virtual reality for car-detailing skill development: Learning outcomes of procedural accuracy and performance quality predicted by VR self-efficacy, VR using anxiety, VR learning interest and flow experience. *Computers & Education, 182*, 1–14.
Theelen, H., Van den Beemt, A., & den Brok, P. (2019). Classroom simulations in teacher education to support preservice teachers' interpersonal competence: A systematic literature review. *Computers & Education, 129*, 14–26.
Tican, C., & Deniz, S. (2019). Pre-service teachers' opinions about the use of 21st century learner and 21st century teacher skills. *European Journal of Educational Research, 8*(1), 181–197.
Tondeur, J., Pareja Roblin, N., van Braak, J., Voogt, J., & Prestridge, S. (2017). Preparing beginning teachers for technology integration in education: Ready for take-off? *Technology, Pedagogy and Education, 26*(2), 157–177.
Torrance, E. P. (1969). *Creativity. What research Says to the teacher, series, No. 28*. National Education Association.
Uttl, B. (2002). North American adult reading test: Age norms, reliability, and validity. *Journal of Clinical and Experimental Neuropsychology, 24*(8), 1123–1137.
Wang, S., Christensen, C., Cui, W., Tong, R., Yarnall, L., Shear, L., et al. (2020). When adaptive learning is effective learning: Comparison of an adaptive learning system to teacher-led instruction. *Interactive Learning Environments, 28*(6), 1–11.
Weis, S., Withoft, A., & Heuten, W. (2020). aVRaid of heights?-exploring integrated non-invasive sensors for stress testing. In *2020 IEEE international conference on healthcare informatics (ICHI)* (pp. 1–10). *IEEE Computer Soci*ety. November.
Wiederhold, B. K., Cipresso, P., Pizzioli, D., Wiederhold, M., & Riva, G. (2018). Intervention for physician burnout: A systematic review. *Open Medicine, 13*(1), 253–263.
Wokke, M. E., Padding, L., & Ridderinkhof, K. R. (2019). *Creative brains show reduced mid frontal theta*. bioRxiv, Article 370494.
Yee, D. M., & Braver, T. S. (2018). Interactions of motivation and cognitive control. *Current Opinions in Behavioral Sciences, 19*, 83–90.
Zhang, X., Li, P., Chen, J., & Li, H. (2020). Acute stress impairs reward positivity effect in probabilistic learning. *Psychophysiology, 57*(4), Article e13531.
van der Zwan, J. E., de Vente, W., Huizink, A. C., Bögels, S. M., & de Bruin, E. I. (2015). Physical activity, mindfulness meditation, or heart rate variability biofeedback for stress reduction: A randomized controlled trial. *Applied Psychophysiology and Biofeedback, 40*(4), 257–268.