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# Virtual Reality in Education: Focus on the Role of Emotions and Physiological Reactivity

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## Abstract

Cognitive and emotional dimensions are often linked to each other in learning experiences. Moreover, emotions and engagement can lead to better outcomes at the cognitive level. Previous research has indicated that virtual reality (VR) provides a feeling of presence and immersion, which can trigger emotionally engaging learning situations. In this study, we explore the opportunities and challenges related to the use of VR in an educational context. The focus of this article is threefold: First, we explore interdisciplinary research literature related to the use of VR for educational purposes. Second, we introduce our VR pilot study in teacher education, applying three different kinds of VR applications. During the pilot study, we utilized physiological measurements, the self-assessed experience of emotional involvement (PANAS; Watson, Clark, & Tellegen, 1988) and students' qualitative reporting on VR experiences. Third, we discuss the potential of brain imaging methods such as EEG measures for capturing learning, performance, and emotions in VR and offer pedagogical guidelines for the future design of VR environments.

## 1. Introduction

Virtual reality (VR) has the potential to revolutionize not only the fields of entertainment and gaming but also education (e.g., Blascovich & Bailenson, 2011; Standen & Brown, 2006). Indeed, VR has become an increasingly popular and affordable educational tool. It offers a platform for people to experience situations with no risk for themselves or others, and it allows users to experience phenomena to which there is a limited or no access in the real world (Freina & Ott, 2015; Shin, 2017). VR is typically referred to as a high-end user interface involving real-time simulation of an environment that people can explore and interact with through multiple senses (Burdea & Coiffet, 1994; Lee & Wong, 2014). However, active learning in VR is not gained automatically and is dependent on many factors, including successful integration VR into broader social and pedagogical scenarios of the classroom (Gouveia, Cook, Snyder, & Payne, 2017). The challenges of VR are often neglected at the cost of the hype and novelty effect (Merchant, Goetz, Cifuentes, Keeney-Kennicutt, & Davis, 2014), and little empirical research has been conducted so far on learning effects in VR (Huang, Rauch, & Liaw, 2010).

In this article, we review existing literature on the prospects of using VR in an educational context. Further, we present the findings of our pilot study on emotional reactions in the context of immersive VR head-mounted displays (HMD). Based on the findings of our study and earlier research literature, we offer a vision for future research and development enabled by emerging methodological advancements (neurophysiological and psychophysiological measurements) to capture learning, performance, and emotions in VR. Finally, we discuss the pedagogical guidelines for future use of VR in authentic classroom settings.

## 2. Earlier Research Literature

The potential of VR in education is often associated with its power to provide users with the feelings of presence and immersion (Ermi & Mäyrä, 2007; Sherman & Craig, 2003). In particular, HMDs are supposed to ‘immerse’ students in real content. This immersion in VR can, at its best, capture learners’ attention in a way that causes them to ‘dive’ inside the simulated world and allows for user involvement. Indeed, VR has been reported to capture attention in a way that improves intervention outcomes in a clinical context as well (Narraro-Haro et al., 2016). It can be assumed that immersive VR also has the potential to trigger emotionally significant learning situations and aid in learning emotion regulation skills (Bosse, Gerritsen, de Man, Treur, 2014). The immersive power of VR can induce learners’ engagement in learning activities (Hanson & Shelton, 2008), thereby causing the learners to engage in deeper cognitive processing of the learning material (Huang et al., 2010). However, VR can also have side effects, such as so-called cybersickness, which is caused by the conflict between what is felt in the body and what is expected in the real world (e.g., Martirosov & Kopecek, 2017).

Earlier research on VR in education has shown contradictory results. Several studies on VR in training contexts (e.g., engineering and robotics) have indicated positive effects on learning outcomes (Alhalabi, 2016; Bric, Lumbard, Frelich, & Gould, 2016; Merchant et al., 2014; Webster, 2016). However, some studies have shown that VR leads to a high sense of presence but have a lesser effect on learning and performance (Makransky, Terkildsen, & Mayer, in press; Moreno & Mayer, 2002; Stepan et al., 2017). Although cognitive outcomes are often used to evaluate the impact of educational methods and tools, particularly in the case of VR, non-cognitive influences such as emotions can also have positive (or negative) effects on or be linked to learning outcomes in the long term (Plass & Kaplan, 2016; Pekrun, 2006). Indeed, in a clinical context, it is the emotional component that is thought to bring about the greater intervention effect compared to traditional training (Faria et al., 2016). Emotions have been shown to strongly modulate learning outcomes and learning experiences (Tyng, Amin, Saad, & Malik, 2017). Emotional experiences also have a crucial impact on other cognitive processes, such as attention, memory, reasoning, and problem-solving (e.g., Tyng et al., 2017; Jung, Wranke, & Knauff, 2014; Um, Plass, Hayward, & Homer, 2012; Vuilleumier, 2005). However, the effects of emotion on learning are moderated by several factors, and emotions can either enhance or impair learning. It is not clear whether positive emotions always facilitate learning while negative emotions hinder it (Tyng et al., 2017).

In therapy context, the potential of VR to improve intervention effects for psychiatric (e.g., Narraro-Haro et al., 2016) or neurological (e.g., Brunner et al., 2017) conditions has been actively explored. For example, specific phobias in autism have been successfully treated with combined cognitive behavioral therapy and exposure to VR (Maskey, Lowry, Rodgers, McConachie, & Parr, 2014). Moreover, VR-based interventions for stroke patients showed greater improvement in global cognitive functions, attention and executive functions compared to conventional rehabilitation therapies (Faria et al., 2016). Although the research on the impact of VR is only starting and often conducted in pilot settings, increasing evidence suggests that VR provides an enhanced ability to tap into elements that are critical in an interventional context.

Learning in an educational context builds on similar principles as intervention effects in the therapy context, and it is thus feasible that similarly enhanced (emotional) engagement would also have benefits for education. As an example, Zlomuzica, Preusser, Totzeck, Dere, and Margraf (2016) studied the impact of emotional states on memory in VR and demonstrated the beneficial effects of positive mood on spatial learning in a negative, anxiety-evoking context. Yet, a large-scale study on spatial learning across different ages showed that although age is associated with the deterioration of spatial memory, memory functions are better preserved in persons with increased anxiety, less indication of depressive symptoms and introvert personality traits (Schoenfeld, Foreman, & Leplow, 2014). Taken together, anxiety seems to have a double-edged influence on learning, perhaps improving simple, immediate recall but reducing the capacity for more complex working memory tasks. This is especially relevant for VR, as it has been shown to be able to create authentic emotional reactions. Besides the positive experience of immersion, these also include fear or anxiety (Allcoat, Greville, Newton, & Dymond, 2015).

Moreover, it is likely that individuals will show significant differences in the intensity of their emotional experiences in VR. McCall, Hildebrandt, Bornemann, Singer (2015) recorded physiological reactions (skin conductance and heart rate) during VR experiences involving threating content. They demonstrated that the user's memorized reports of the arousal levels reliably followed the physiological changes recorded during the VR experience. Importantly, the correlation between memory reports and physiological reactions was the strongest in individuals who showed a generally stronger sensitivity to the autonomic nervous system (ANS) signals. These findings imply that it is especially relevant to consider the effect of emotions in VR—it provides the ability to achieve enhanced intervention/learning effects but also create challenges for individuals who may feel that VR is scary or unpleasant. However, empirical evidence on emotional experiences and their individual variation in immersive VR experiences is still rare. Furthermore, there is even less research in which an objective measure of physiological reactivity (heart rate variability) has been combined with self-assessed subjective feelings and experiences (however, see McCall et al., 2015).

## 3. Pilot Study

In the empirical pilot study, we explored the opportunities and challenges related to the use of VR in educational contexts. Primarily, we explored the feasibility of collecting objective and subjective information on the emotional valence and level of engagement in VR. In this limited sample of students, we also studied the strength of the individual variance in physiological and emotional reactivity during VR experiences. In our pilot study, we used the HTC Vive headset (see Figure 1) and selected three different VR applications that had not been designed specifically for an educational purpose but were thought to vary in their levels of emotional engagement and to induce individual differences.

**Figure 1: Students participating in the VR pilot study**

## 3.1. Research Methods for the Pilot Study

### 3.1.1. Participants

A total of six teacher education students participated in the study on a voluntary basis in March 2017. The ages of the students varied from 21 to 34 years. Four of the students were women and two were men.

### 3.1.2. VR environments

In the pilot experiment, we employed three different kinds of VR applications: Google Earth (exploration), Bow Fight (action/fear) and Guided Meditation (relaxation). These tasks were selected to create maximally different contexts in terms of emotional arousal. All three applications were available for download from Steam, a digital video game distribution platform, and were applied individually for the participants in VR using the HTC Vive headset and controllers.

In **Google Earth**, the students were instructed to undertake a virtual tour comprising three different locations (about five minutes per location). First, we asked the students to select New York as their destination and explore the city freely. Second, the students were instructed to navigate from New York to their desired destination in India and become acquainted with it. The students had free choice of the third location.

Before the **Bow Fight** period, the students were briefed about the rules of the game, that is, how to use the bow and fight against the enemies. The students were instructed to start a new game after the previous game was over and play as many games as they could in 15 minutes.

In **Guided Meditation**, the students were instructed to achieve a high level of relaxation. Each student was able to choose the most relaxing environment from 16 alternatives. After choosing an environment, the students were instructed to start the 'Relaxation series' and a five-minute guided 'Care meditation' session that included piano music. For the remaining 10 minutes, each student was allowed to stay in one spot or move around the environment.

In addition, the students were given similar instructions on how to use the applications (i.e., how to move and use the controllers in each environment).

### 3.1.3. Physiological measures

As a **physiological measurement instrument,** we applied the wearable Firstbeat Bodyguard device to measure heart rate variability (HRV) during the VR experiences. The six teacher education students wore a Firstbeat Bodyguard 2 HRV device that was used to monitor their heartbeat for three full days (including the VR experience) and filled an online diary. The data were analyzed using the Firstbeat well-being analysis protocol (Firstbeat, 2014). The analysis has been optimised for highlighting periods of time that indicate emphasized involvement of the sympathetic nervous system (typical during increased use of cognitive-emotional resources, and if continued without recovery periods, for stress) and the parasympathetic nervous system (typical of periods of recovery and relaxation, when resources are collected for future use). In this pilot, we were especially interested in a) whether the *different VR applications* cause notable differences in the balance between activating vs. recovery statuses of physiological response and b) whether *different individuals* would show variances in the level of activating vs. recovery periods during the VR experience.

The three days that the students wore the Firstbeat devices provided reference data, and the two-hour experiment was analyzed more elaborately using a detailed training effect mode. The focus of the analysis was on examining the changes between the students' stress levels, recovery time and physical activity (see Firstbeat 2012a, 2012b, 2014; Makkonen, Silvennoinen, Nousiainen, Pesola, & Vesisenaho, 2017). Furthermore, we wanted to associate the HRV-based analysis of physiological reactions with the experiential measures, that is, the emotional questionnaire (PANAS, Watson, et al., 1988) and qualitative open questions. Indeed, changes in HRV, reflecting sympathetic/parasympathetic balance, are also associated with different emotional experiences and levels of emotional engagement, but the subjective attributions have a crucial role in determining the valence of the experienced emotion.

In terms of physical activity and movement, the applications had differential demands, and the Bow Fight application was assumed to higher levels of physical activity due to the requirements for body movements.

### 3.1.4. Emotional involvement questionnaire (PANAS)

For studying the **experienced emotional involvement**, the students completed the Positive and Negative Affect Schedule (PANAS) immediately after using each application. The PANAS scale is a reliable and valid self-report questionnaire for evaluating positive and negative effects. It includes ten positive and ten negative affect questions that are answered using an ordinal scale between 1 and 5, where 1 indicates 'very slightly / not at all' and 5 indicates 'extremely' (e.g., interested, strong, scared, nervous) (Watson et al., 1988). PANAS can be divided into Positive Affect Score and Negative Affect Score, each of which includes 10 items (scale 1–5). A higher score indicates a higher level of positive effect or negative effect, respectively. In a non-clinical undergraduate sample, the norms for positive and negative affect scores were reported to be (mean ± SD) 35±6.4 and 18.1±5.9, respectively (28.6–41.4, positive; 12.2–24, negative).

Students also reported their VR experience qualitatively by responding to open-ended questions.

### 3.1.5. Measurement protocol

One at a time, each student used each of the three applications for 15 minutes per application. After using the application, we reserved about five minutes for removing the headset and controllers, relaxing, 15 minutes for completing the PANAS questionnaire and the open-ended questions about the VR experience and five minutes for getting prepared for the next application (Figure 2).

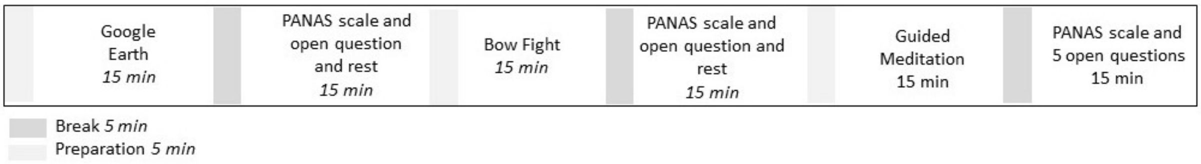

**Figure 2: Structure of the experiment**

## 3.2. Results

### 3.2.1. Heart rate variability

Figure 3 summarises the individual-level results of the HRV measures, as computed using the First Beat analysis protocol (Firstbeat, 2014). The preliminary inspection indicates some interindividual variation in physiological reactions within each VR task/application.

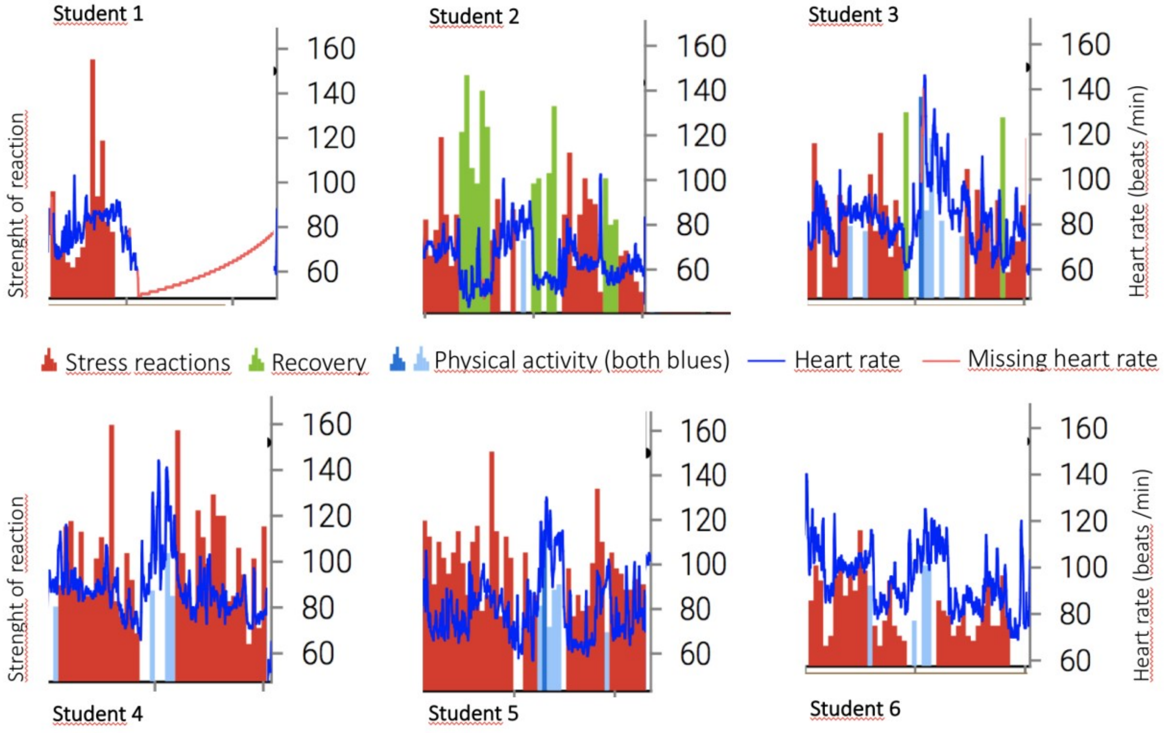

**Figure 3: Summaries of the stress and recovery reactions as well as physical activity calculated based on HRV during the VR experiment**

Based on the summarized **HRV measures**, the preliminary results indicate that the physiological reactions (HRV) showed clear variation across different VR applications as well as across individuals (Figure 3). The red bars in Figure 3 indicate HRV characteristics typical of increased body activation levels, when the sympathetic activity of the autonomic nervous system is dominant (sometimes used interchangeably with ‘stress’). The green bars indicate HRV characteristics that are typical of relaxation and recovery (i.e., the reduced activation level of the body, when parasympathetic activation dominates). The blue curve represents physical activity, calculated based on accelerometer data and estimated oxygen consumption levels. The measurements of all the students indicated an increased activation level (or ‘stress’) during the VR experience. It is important to note that the concept ‘stress’ is used here to refer to the general activity of the autonomic nervous system, and based on HRV measures one cannot interpret whether the experienced stress was negative or positive. A certain activity level is necessary, for example, for optimal performance and learning. As expected, physical activity levels increased, especially in Bow Fight. Some students also showed recovering states during the breaks.

### 3.2.2. Emotional experience

The positive affect PANAS values varied between 13 and 46 during all the applications, whereas the negative affect values varied between 10 and 34 (Figure 4), indicating strong affective involvement. The students reported the lowest negative effect during the Google Earth and Guided Meditation VR applications and the highest negative effect during the Bow Fight application. Bow Fight also demonstrated the strongest variance among the applications, both in terms of positive and negative affect. For instance, the following items ‘Upset, Enthusiastic, Jittery, Nervous and Afraid’ were scored between 1 and 5 (scale 1 = not at all; 5 = extremely). The emotional variability was also high between the students.

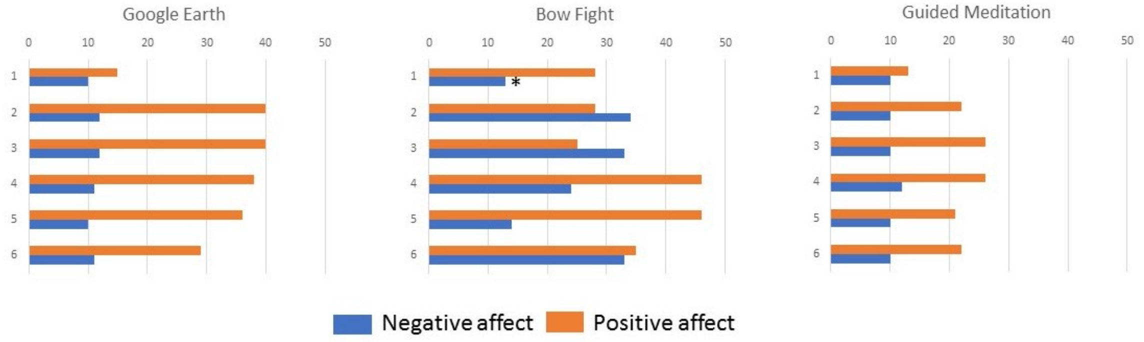

**Figure 4: The Positive and Negative Affect PANAS Values in each individual for the three VR applications (note: * a missing answer of student number 1, the total negative affect value between 14-18 in Bow Fight).**

### 3.2.3. Qualitative reporting of VR experience

In the students’ answers to the open-ended questions, the emphasis was on intense and immersive experiences as well as the experience of reality and the feeling of presence. Some examples are as follows:

> It seemed like I was in a nightmare.
> I felt I could jump into the water.
> It felt a bit like sleeping with my eyes open.
>
> The experience was very real, though nothing seemed exactly the same as in actual reality. I really lost my sense of time and place.
>
> The environment felt so real. For example, I tried to sit on the stone fence and tried to crouch and hide myself behind the low wall.

Some of the students reported having physical reactions in the VR:

> Suddenly, when I diverged from the ground, I felt giddiness.
>
> I was so scared and thrilled that my hands were shaking.

Only a few students reported the possibility of doing things that are not possible in the actual world:

> At first, I dodged everything, like trees, walls and buildings. Then I realised I could go through them.
>
> I get to different places where I would not otherwise get.

The coexistence of sounds/voices and visual experience in VR was highlighted in several of the answers:

> There is a high impact of the synergy of music and the view.
>
> The sounds were affected: the same background music everywhere. For example, Manhattan has its typical sounds and Philippines has its own ones with the sounds of seashore.
>
> The sounds told me that someone approached.
>
> I was a bit restless, but music and breathing exercises helped me relax.

There were also some disruptive things in the VR experiences. One student reported feeling stressed with the devices in the beginning:

> The use of the devices was stressful: can I press the right buttons at the right time?

Clumsy devices and ways of moving in VR were reported to disrupt the authentic experience:

> The experience was a little bit disturbed by the fact that the headphones were pretty big and did not fit right when I rest on the floor.
>
> The play area seems small. I would have preferred to walk rather than press the “fly” button.

Most students were very excited with VR, but there were also clear differences in how the students experienced the VR environment:

> The experience was surprising at first, and I was frightened. Quickly I got used to the game and the gamer in me woke up. Then I tried to get a lot of points.
>
> It would have been great to play more and I noticed I advanced all the time.
>
> I did not experience any new things. This wasn’t my first time in Google Earth, so the experience felt rather flat.
>
> It seemed interesting in the beginning, but towards the end it was boring.

### 3.2.4. Conclusions

Our results demonstrate that it is feasible to record simultaneous physiological (objective) and experiential (subjective) data reflecting emotional and cognitive engagement during VR experiences. This combination is likely to result in advanced opportunities to understand the added value of VR for education. Indeed, the affordances and, especially, pitfalls of the utilization of VR in educational settings need to be investigated carefully. Special attention should be paid to pedagogical use of VR in classrooms settings as well as its impact on students’ learning and well-being (including their emotions and feelings).

## 4. Potential of Emerging Research Methods

VR has tremendous potential to address various educational needs. However, due to their capability of evoking realistic physiological and experiential components of emotional involvement, they can also cause distress and actually weaken learning outcomes. It is thus crucially important to scrutinize the process of learning in VR, with a focus on the motivational, emotional and social modulatory factors. At best, VR can capitalize on the neurophysiological process of learning in a much more influential way than traditional teaching settings. At the neurocognitive level, learning is based on effective and systematic repetitions, which are intensified by an emotionally meaningful and motivating context. Thus, VR has versatile possibilities to create optimal contexts for learning.

Based on the findings and the feasibility pilots for clinical settings, it is likely that VR could also lead to significant improvement in specific educational outcomes, both for learners with special needs and those in mainstream education. The contexts in which VR has been utilized in intervention studies are highly relevant for pedagogical purposes as well (e.g., for reducing anxiety, such as math anxiety) (Maskey et al., 2014). Interestingly, a ‘virtual bystander’ was shown to modulate students’ beliefs, self-efficacy, and anxiety (Qu et al., 2015), suggesting that VR environments can be designed to offer a socially supporting influence.

**Body physiology reflects the emotional involvement, anxiety, and excitement felt during tasks/learning.** In order to achieve more systematic information on the preconditions, modulating factors and mechanisms by which VR could enhance learning, more systematic studies and carefully controlled experimental settings need to be developed. Our present pilot study tested the feasibility of and potential methods for assessing emotional engagement during VR experiences in university students, using HRV measurements for autonomic nervous system (ANS) activity as well as structured and open-ended questionnaires to examine the experienced affective states. In future studies, to holistically capture VR experiences, a broader variety of data should be collected in a synchronized manner in real-time to better understand the different elements that contribute to the VR experience.

First, advanced recordings could be used to obtain behavioral measures: What does the user see, hear and utter, and how does he or she react to and interact with the VR? (e.g., accelerometer for motion, eye-tracking for gaze, microphone for audio output). The VR that was employed in the current study merely involved hand controllers, whereas controllers or sensors worn on other parts of the body, such as the legs or waist, would provide richer data on VR users’ physical motions. Second, accurate information regarding the autonomic nervous system signals during VR experience could greatly increase our understanding of the body functions that support an optimal nervous system state for learning.

**User experiences can be collected during or after VR sessions to understand the individual differences in VR-enhanced learning better.** As stated earlier, the physiological data cannot be interpreted without reference to the psychological meaning given to the ANS reactions: similarly emphasized sympathetic activity can reflect a period of increased anxiety or emotional excitement. Detailed interviews, questionnaires/tests, and online queries would provide more time-sensitive information on the unfolding of the users’ experiences. The feasibility of this approach is supported by the fact that retrospective reports of VR experiences were shown to accurately follow HRV-based changes in autonomic nervous system signaling (McCall et al., 2015). Importantly, individuals with higher sensitivity to ANS signals demonstrated higher synchronization between recorded ANS and memorized affective states. In our recent study (Lyyra & Parviainen, 2018), sensitivity to ANS signals was shown to be associated with specific temperament traits related to behavioral inhibition. Combining ANS and behavioral recordings in VR can reveal how different individuals (e.g., differing temperament styles, age groups) adapt to and can exploit modern learning environments outside of laboratories. Indeed, there is likely to be strong individual variability in the achieved benefits of VR-enhanced learning experiences.

**Electroencephalograms can be used to study perceptual accuracy or level of cognitive engagement.** We have already extended our research methods to test the feasibility of recording electroencephalograms (EEGs) during VR sessions. Technically, it seems that simultaneous EEG can be used to measure the on-going brain signaling while participants are completing specific tasks using VR. This would enable, for example, the comparison of traditional and VR environments in terms of how they engage the critical processes in the brain that support an optimal learning state. In accordance with previous research, EEG data collected in VR could contribute to the investigation of students' cognitive load and engagement during learning (Dan & Reiner, 2018; Makransky et al., in press; Alwedaie, Khabbaz, Hadi, & Al-Hakim, 2018) as well as to the study of specific cognitive functions such as language processing (Tromp, Peeters, Meyer, & Hagoort, 2018).

However, this type of research would need to evolve together with detailed laboratory studies that identify features in neurophysiological signals that are reliably associated with successful conditions for learning. Current research in the field of educational neuroscience provides valuable data in this regard, but further research and methodological development are needed, especially to achieve measures that enable interpretations at the individual level. To ensure the reliability of studies in VR, novel experimental conditions need to be designed to enable appropriate control conditions for VR-enhanced learning. To determine the role of individual differences (as discussed above), a substantial number of participants need to be recruited in future studies.

**Closed-loop systems could be useful in developing technology-enhanced interventions**. The ability to identify brain states in real time allows EEGs (and ANS) to be used as information sources regarding desired (neuro)physiological states for optimal learning. Indeed, EEG-based neurofeedback has been suggested to improve the treatment of attention deficit hyperactivity disorder (ADHD) (van Doren et al., 2018) by enhancing the brain states that are linked with the ability to control and sustain attention. However, the beneficial effects of such feedback compared to traditional treatments is a subject of debate, especially in adults (Schönenberg et al., 2018).

The combination of EEGs and VR offers interesting opportunities for advancing the utilization of VR as an educational tool in the classroom to improve the learning, engagement, and well-being of students. However, there are some challenges, and cross-disciplinary efforts in research and application development are needed to test the potential of this combination in practice.

First, it is necessary to increase the cross-disciplinary interaction between neuroscience and advanced signal analysis (e.g., by machine learning and applied education research) to search for robust features that can be utilized in neurofeedback systems (c.f. Zhigalov, Heinilä, Parviainen, Parkkonen, & Hyvärinen, in press). In general, closed-loop systems can be used to individually adapt VR in real-time based on continuing performance or collected (neuro)physiological data. Accumulated EEG or ANS signals in neurofeedback systems are generally used to calculate features that reliably reflect important attentional, emotional or cognitive determinants of learning. As these features are essential for the advantageous adaptation of neurofeedback systems, the first crucial step in developing such systems for education is to define robust and reliable features from neurophysiological signals with demonstrated significance for learning. The combination of EEG and ANS measurements could shed light not only on students' feelings, emotions and cognitive processes in VR but also indicate, through received neurofeedback, specific parts or aspects of VR environments that need to be developed to provide more efficient learning and ensure the well-being of users.

Second, in addition to the importance of identifying correct features to focus on, the complexity of obtaining EEG recordings in VR can cause challenges (Tromp et al., 2018; Hubbard, Sipolins, & Zhou, 2017). Tromp et al., (2018) indicated some of the technological difficulties (e.g., setting up the EEG cap and VR headset) and pointed out that due to the utilization of EEGs, VR could not be used to its full potential (limiting head movement and interaction with the environment). This may further influence students' VR experience. Moreover, to achieve reliable measures for the desired EEG features, which are defined through careful laboratory experiments, the available portable EEG systems may not offer necessary signal acquisition parameters or adequate sampling rates. Therefore, a further challenge for VR-neurofeedback systems is to develop an EEG–VR environment that is both maximally ecologically valid for educationally relevant paradigms and technically appropriate for ensuring the necessary level of detail in the EEG signals.

Third, applications and games also need to be specifically developed for the purpose of neurofeedback-based enhancement of learning outcomes. This development work could be based on existing learning games that are adaptively modified based on individual performance.

## 5. Conclusions: Practical Implications and Future Research

The inconclusive results of earlier research suggest that many factors influence the way in which immersive VR supports learning (Merchant et al., 2014). Hence, from the perspective of designing VR learning environments, it is important to consider both cognitive and emotional processes as well as interindividual variance when learners interact with VR. In order to utilize VR for learning, it is important that educators also understand the challenges related to VR usage rather than only relying on its novelty effect (Huang et al., 2010).

Based on our experience and prior literature, embedding VR into classroom settings requires knowledge on the part of educators regarding the applied VR in addition to pedagogical consideration of the learning tasks that the students will perform in the environment. For instance, to support the construction of meaningful knowledge, students should have appropriate prior skills and knowledge on which new knowledge can be constructed (Piaget, 2013; von Glasersfeld, 1996). To promote active learning in VR, students should have the ability to interact with relevant content (e.g., seek information, ask questions). Being aware of self-regulated learning strategies, such as attention focusing, can also lead to better learning outcomes. Reflection on the learning process and outcomes would likely result in meaningful and long-lasting learning outcomes (see Zimmerman, 1989, 2002).

Even though the potential of VR to facilitate collaboration has long been recognized, to date, few applications exist (Greenwald, Corning, & Maes, 2017). Collaboration in virtual environments can be highly relevant, for example, when students are confronted with complex tasks but have only limited information (e.g., Kulik, Kunert, Beck, & Fröhlich, 2017). As Kulik et al., (2017) noted, direct and immediate interaction provides access to multiple perspectives as well as to the most feasible interpretations at hand, promoting on-going discourse on the topic. Promising examples of collaborative learning environments in VR are the open-world sandbox game Minecraft and its VR version Vivecraft. We have already tested and piloted these environments and identified their preliminary potential for use in collaborative learning projects and for practicing multidisciplinary problem-based learning skills and creativity.

Moreover, if we wish to truly integrate VR solutions into the regular curricula in schools, as stated by Gouveia et al., (2017), the teacher must have a central role in constructing successful learning experiences (see e.g., Yoon, Koehler-Yom, Anderson, Lin & Klopfer, 2015). Depending on the learning task, the teacher's role may vary between monitoring, support, and guidance. In addition, it is important for teachers to be aware of and consider potential physiological side effects in VR, such as cyber-sickness (e.g., Martirosov & Kopecek, 2017), and psychological distress, that can both be harmful to learning processes. However, little research has been focused on identifying the support that teachers require in terms of utilizing and integrating complex systems, like VR, into classroom pedagogies. In this regard, more empirical understanding is needed; also, in terms of educating future teachers.

## References

Alhalabi, W. (2016). Virtual reality systems enhance students' achievements in engineering education. *Behaviour & Information Technology*, *35*(11), 919–925.

Allcoat, D., Greville, W. J., Newton, P. M., & Dymond, S. (2015). Frozen with fear: Conditioned suppression in a virtual reality model of human anxiety. *Behavioral Processes, 118*, 98-101.

Alwedaie S. A., Khabbaz, H. A., Hadi S. R., & Al-Hakim, R. (2018). EEG-based analysis for learning through virtual reality environment. *Journal of Biosensors and Bioelectronics*, *9*(1):249. doi: 10.4172/2155-6210.1000249

Blascovich, J., & Bailenson, J. (2011). Infinite reality: Avatars, eternal life, new worlds, and the dawn of the virtual revolution. New York, NY: HarperCollins Publishers.

Bosse, T., Gerritsen, C., de Man, J., Treur, J. (2014). Towards virtual training of emotion regulation. *Brain Informatics 1*(1-4), 27-37.

Bric, J. D., Lumbard D. C., Frelich M. J., & Gould J. C. (2016). Current state of virtual reality simulation in robotic surgery training: A review. *Surgical Endoscopy*, *30*(6), 2169–2178.

Burdea, G., & Coiffet, P. (1994). *Virtual reality technology*. New York, NY: John Wiley & Sons.

Dan, A., & Reiner, M. (2018). Reduced mental load in learning a motor visual task with virtual 3D method. *Journal of Computer Assisted Learning*, *34*(1), 84–93. doi:10.1111/jcal.12216

Ermi, L., & Mäyrä, F. (2007). Fundamental components of the gameplay experience: Analysing immersion. In T. S. de Castell & J. Jenson (Eds.), *Worlds in play - International perspectives on digital games research* (pp. 37–53). New York, NY: Peter Lang.

Firstbeat. (2012a). *An energy expenditure estimation method based on heart rate measurement* [PDF file]. Retrieved from https://www.firstbeat.com/wp-content/uploads/2015/10/white_paper_energy_expenditure_estimation.pdf

Firstbeat. (2012b). *VO2 estimation method based on heart rate measurement* [PDF file]. Retrieved from https://www.firstbeat.com/wp-content/uploads/2015/10/white_paper_vo2_estimation.pdf

Firstbeat. (2014). *Stress and recovery analysis method based on 24-hour heart rate variability* [PDF file]. Retrieved from https://assets.firstbeat.com/firstbeat/uploads/2015/11/Stress-and-recovery_white-paper_20145.pdf

Freina, L., & Ott, M. (2015, April). *A literature review on immersive virtual reality in education: State of the art and perspectives*. Paper presented at The International Scientific Conference eLearning and Software for Education, Bucharest (Romania). Retrieved from https://www.researchgate.net/publication/280566372_A_Literature_Review_on_Immersive_Virtual_Reality_in_Education_State_Of_The_Art_and_Perspectives

Gouveia, C., Cook, C., Snyder, A., & Payne, S. (2017). "Nice to have" to "Can't do without": Aligning simulations and VR with current needs in the K-12 classroom. In B. K. Smith, M. Borge, E. Mercier, & K. Y. Lim (Eds.), *Making a difference: Prioritizing equity and access in CSCL, 12th International Conference on Computer Supported Collaborative Learning (CSCL) 2017, Volume 2* (pp. 723-724). Philadelphia, PA: International Society of the Learning Sciences.

Greenwald, S.W., Corning, W., & Maes, P. (2017). Multi-user framework for collaboration and co-creation in virtual reality. In B. K. Smith, M. Borge, E. Mercier, & K. Y. Lim (Eds.), *Making a difference: Prioritizing equity and access in CSCL, 12th International Conference on*

*Computer Supported Collaborative Learning (CSCL) 2017, Volume 2* (pp. 879-880). Philadelphia, PA: International Society of the Learning Sciences.

Hanson, K., & Shelton, B. E. (2008). Design and development of virtual reality: Analysis of challenges faced by educators. *Educational Technology & Society*, *11*(1), 118–131.

Huang, H.-M., Rauch, U., & Liaw, S.-S. (2010). Investigating learners' attitudes toward virtual reality learning environments: Based on a constructivist approach. *Computers & Education*, *55*, 1171–1182.

Hubbard, R., Sipolins, A., & Zhou, L. (2017). Enhancing learning through virtual reality and neurofeedback: A first step. In *Proceedings of the Seventh International Learning Analytics & Knowledge Conference* (pp. 398-403). doi:10.1145/3027385.3027390

Jung, N., Wranke, H. K., & Knauff, M. (2014). How emotions affect logical reasoning: evidence from experiments with mood-manipulated participants, spider phobics, and people with exam anxiety. *Frontiers in Psychology*, *5*, 570.

Kulik, A., Kunert, A., Beck, S., & Fröhlich, B. (2017). Collaborative virtual reality for joint learning experiences. In B. K. Smith, M. Borge, E. Mercier, & K. Y. (Eds.), *Making a Difference: Prioritizing Equity and Access in CSCL, 12th International Conference on Computer Supported Collaborative Learning (CSCL) 2017, Volume 2* (pp. 721-722). Philadelphia, PA: International Society of the Learning Sciences.

Lee, E. A.-L., & Wong, K. W. (2014). Learning with desktop virtual reality: Low spatial ability learners are more positively affected. *Computers & Education*, *79*, 49–58.

Lyyra, P., Parviainen, T. (2018). Behavioral inhibition underlies the link between interoceptive sensitivity and anxiety-related temperamental traints. *Frontiers in Psychology, 9*, 1026. doi: 10.3389/fpsyg.2018.01026.

Makkonen, M., Silvennoinen, M., Nousiainen, T., Pesola, A., & Vesisenaho, M. (2017). To sit or to stand, that is the question: Examining the effects of work posture change on the well-being at work of software professionals. *International Journal of Networking and Virtual Organisations*, *17*(4), 371–391. doi:10.1504/IJNVO.2017.10009382

Makransky, G., Terkildsen, T. S., & Mayer, R. E. (in press). Adding immersive virtual reality to a science lab simulation causes more presence but less learning. *Learning and Instruction*. https://doi.org/10.1016/j.learninstruc.2017.12.007

Martirosov, S., & Kopecek, P. (2017, November). Cyber sickness in virtual reality - Literature review. In B. Katalinic (Ed.), *Proceedings of the 28th DAAAM International Symposium 2017, 28,* 718-726. doi: 10.2507/28th.daam.proceedings.101

Maskey, M., Lowry, J., Rodgers, J., McConachie, H., Parr, J. R. (2014). Reducing specific phobia/fear in young people with autism spectrum disorders (ASDs) through a virtual reality environment intervention. *Plos One, 9*(7). doi:10.1371/journal.pone.0100374

McCall, C., Hildebrandt, L. K., Bornemann, B., Singer, T. (2015). Physiophenomenology in retrospect: Memory reliably reflects physiological arousal during a prior threatening experience. *Consciousness and Cognition 38,* 60-70.

Merchant, Z., Goetz, E. T., Cifuentes, L., Keeney-Kennicutt, W., & Davis, T. J. (2014). Effectiveness of virtual reality-based instruction on students' learning outcomes in K-12 and higher education: A meta-analysis. *Computers & Education*, *70*, 29–40.

Moreno, R., & Mayer, R. E. (2002). Learning science in virtual reality multimedia environments: Role of methods and media. *Journal of Educational Psychology*, *94*(3), 598–610.

Plass, J. L., & Kaplan, U. (2016). Emotional design in digital media for learning. In S. Tettegah, & M. Gartmeier (Eds.), *Emotions, technology, design, and learning* (pp. 131-162), London: Elsevier.

Pekrun, R. (2006). The control-value theory of achievement emotions: Assumptions, corollaries, and implications for educational research and practice. *Educational Psychology Review*, *18*, 315–341.

Piaget, J. (2013). *The construction of reality in the child* (Vol. 82). Oxon: Routledge.

Schoenfeld, R., Foreman, N., Leplow, B. (2014). Ageing and spatial reversal learning in humans: findings from a virtual water maze. *Behavioral Brain Research*, 270, 47-55.

Sherman, W. R., & Craig, A. B. (2003). *Understanding virtual reality*. New York, NY: Morgan Kaufmann Publishers.

Shin, D-H. (2017). The role of affordance in the experience of virtual reality learning: Technological and affective affordances in virtual reality. *Telematics and Informatics*, *34*, 1826–1836.

Standen, P. J., & Brown, D. J. (2006). Virtual Reality and its role in removing the barriers that turn cognitive impairments into intellectual disability. *Journal of Virtual Reality*, *10*(34), 241–252.

Stepan, K., Zeiger, J., Hanchuk, S., Del Signore, A., Shrivastava, R., Govindaraj, S., & Iloreta, A. (2017). Immersive virtual reality as a teaching tool for neuroanatomy. *International Forum of Allergy & Rhinology*, *7*(10), 1006–1013.

Tromp, J., Peeters, D., Meyer, A. S., & Hagoort, P. (2018). The combined use of virtual reality and EEG to study language processing in naturalistic environments. *Behavior Research Methods*, *50*(2), 862–869.

Tyng, C. M., Amin, H. U., Saad, M. N. M., & Malik, A. S. (2017). The influences of emotion on learning and memory. *Frontiers in Psychology*, *8*, 1454.

Um E., Plass J. L., Hayward E. O., & Homer B. D. (2012). Emotional design in multimedia learning. *Journal of Educational Psychology*, *104*, 485–498.

van Doren, J., Heinrich, H., Bezold, M., Reuter, N., Kratz, O., Horndasch, S., Berking, M., Ros, T., Gevensleben, H., Moll, G.H., & Studer, P. (2017). Theta/beta neurofeedback in children with ADHD: Feasibility of a short-term setting and plasticity effects. *International Journal of Psychophysiology 112*, 80-88.

von Glasersfeld, E. (1996). Introduction: Aspects of constructivism. In C.T. Fosnot (Ed.), *Constructivism: Theory, perspectives, and practice* (pp. 3-7). New York-London: Teachers College Press.

Vuilleumier, P. (2005). How brains beware: Neural mechanisms of emotional attention. *Trends in Cognitive Sciences*, *9*(12), 585–594.

Watson, D., Clark, L. A., & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: The PANAS Scales. *Journal of Personality and Social Psychology*, *54*, 1063–1070.

Zhigalov, A., Heinilä, E., Parviainen, T., Parkkonen, L., & Hyvärinen, A. (in press). Decoding attentional states for neurofeedback: mindfulness vs. wandering thoughts. *Neuroimage.* doi:10.1016/j.neuroimage.2018.10.014.

Zimmerman, B. J. (1989). A social cognitive view of self-regulated academic learning. *Journal of Educational Psychology, 81*(3), 329–339.

Zimmerman, B. J. (2002). Becoming a self-regulated learner: An overview. *Theory Into Practice*, *41*(2), 64–70.

Zlomuzica, A., Preusser, F., Totzeck, C., Dere, E., Margraf, J. (2016). The impact of different emotional states on the memory for what, where and when features of specific events. *Behavioral Brain Research, 298*(B), 181-187.

Yoon, S. A., Koehler-Yom, J., Anderson, E., Lin, J., & Klopfer, E. (2015). Using an adaptive expertise lens to understand the quality of teachers’ classroom implementation of computer-supported complex systems curricula in high school science. *Science & Technological Education*, *33*(2), 237–251.