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PAPER

Beyond Immersion: A Systematic Review of Extended Reality and Biofeedback in Social Emotional Learning

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ABSTRACT

This is a qualitative systematic review examining the effectiveness of the combination of the extended reality (XR) technologies and biofeedback mechanisms with social-emotional learning (SEL) outcomes in school-aged learners with a specific emphasis on adolescent girls. Based on the 2020–2025 peer-reviewed literature, the review will combine the results of different educational and clinical settings and explore the role of immersive digital environments and physiological feedback systems in emotional regulation, empathy building, and metacognitive development. Instead of using a strict method such as PRISMA, they use the thematic synthesis based on the self-regulated learning (SRL) model, which is composed of the forethought, performance, and self-reflection stages to investigate the effects of technology-based interventions on emotional and cognitive learning processes. The analysis demonstrates that XR environments can support the learner presence, motivation, and perspective-taking in early goal-setting and emotional awareness and regulation in performance by real-time biofeedback. The literature however also identifies gaps especially in long term efficacy, gender specific-design, and scalability of these tools in mainstream classrooms. The review suggests that an Immersive Hybrid Feedback model is a conceptual intermediate between affective computing and educational design as an example of the potential and constraints of adopting embodied technologies into social-emotional learning.

KEYWORDS

extended reality (XR), social-emotional learning (SEL), immersive education, biofeedback, self-regulated learning (SRL)

1 INTRODUCTION

The development of immersive technologies has resulted in an increasing attention to the potential of virtual reality (VR) to change the process of learning. VR environments have high immersion, embodiment and presence where learners are able to feel like they are truly in the area [1, 2]. This hyper-realism can frequently

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make VR an effective pedagogical technology: students have an opportunity to digitalize real-life situations, learning more, and retaining more about complicated topics [3, 4]. As an example, systematic reviews of VR in education claim that VR enhances deeper knowledge and memory in difficult subjects and always increases engagement, knowledge, and practical skills [5, 6]. Similarly, higher education research indicates that VR based activities have beneficial effects on communication, problem-solving and teamwork, and also elevate motivation and improved comprehension of complex ideas [7, 8]. Stated briefly, immersiveness and the experience of VR make the learning more active and engaging [9, 10]. They might particularly apply to self-regulated learning (SRL), the process through which learners establish goals, implement strategies, and assess their outcomes.

The SRL theory suggests that learning occurs in three stages: forethought (goal-setting and planning), performance (strategy use and self-monitoring) and reflection (self-evaluation and adaptation) [4]. VR worlds would have a major influence on every stage. As an example, the novelty and existence of VR can increase the motivation and self-efficacy of learners in the forethought stage [11, 12]. In performance, VR is able to offer real-time feedback and new interaction affordances to affect the use of strategy [13]. The immersive experience can encourage deeper thought after the task: in fact, the analysis of VR usage indicates that most learners view VR as the means of self-directed learning and creativity [14, 15]. Providing an engaging background, VR can be seen to facilitate initiative-taking and metacognitive skills on the part of the learner.

Although VR has potential in learning, there is little information regarding the specific effects of the VR on self-regulation. Previous analysis will be biased towards learning results (i.e., test scores) or group dynamics [3, 16]. We found a gap in the knowledge of the processes that learners engage in during VR environments. Specifically, the planning, strategy application, and reflection of the learner in immersive environments have been studied by few studies. To answer this, we examine the enactment of SRL strategies by students learning among VR. We asked:

- RQ1 (Forethought): What is the approach of learners to goal-setting, planning and motivation prior to a VR learning activity? As an example, do they make their own goals or do they expect to meet difficulties in the immersive environment?
- RQ2 (Performance): How do the learners perform on the VR task with what strategies and behaviors? We discuss strategies of cognitive and emotional regulation, attention management, and the utilization of VR-specific features.
- RQ3 (Reflections): What do the learners think and change upon the conclusion of the VR task? We take into consideration self-assessment and attribution of results, future learning intentions.

To respond to these questions, we have interviewed students that used the VR learning system qualitatively and analyzed their answers in a thematic manner. We have based our strategy on previous research studies of VR education that emphasize that VR can be used to promote problem-solving, critical thinking, and self-directed learning [17, 10]. Following the SRL and constructivist learning theories, we consider learners as active agents who build knowledge [18]. We will unravel the impact of immersive setting of VR on the plans, strategies, and self-assessments of the learners by concentrating on the forethought, performance, and reflection stages.

The three stages of SRL are used to organize this paper. Having explained our approach, we provide thematic findings separated into Forethought, Performance and Reflection. We next comment on the relevance of these findings to VR and research on learning and conclude with implications on the design of VR learning experiences.

2 LITERATURE REVIEW

2.1 Extended reality technologies in social-emotional learning

Social-emotional learning (SEL) refers to important ability in emotional control, empathy, relationship development and decision-making essential to success in and out of school. Recent developments in extended reality (XR), which is an umbrella term of immersive technologies such as VR, augmented reality (AR), and mixed reality (MR) have led educators and researchers to consider their possibilities in improving SEL experiences. XR platforms enable learners to interact in simulated physical and digital environments that provide new experiences of exercising social and emotional abilities in controlled environments [4, 17]. VR-based learning in general education settings has been identified to enhance student engagement, motivation, and knowledge retention because the technique allows creating immersive experiences that would be challenging to achieve in a traditional classroom [8, 18]. As an illustration, VR may introduce students to complicated, real-life environments to explore together, hence developing teamwork and problem-solving that traditional approaches frequently fail to deliver [19, 20].

2.2 Virtual reality development and immersion, presence, and empathy

One of the areas of XR that SEL is studying is the creation of empathy and social awareness through the application of VR. Empathy—the facet of feeling the emotions of another person and sharing them with him/her—is long discussed as being trainable, as well as essential in positive social interactions [21]. VR is particularly best applied to empathy training since it brings greater levels of presence and embodiment and enables the participants to physically walk in the shoes of another individual in a simulated environment [22, 23]. Immersive VR experiences could also lessen the cognitive burden on the learner when contrasted with traditional perspective-taking practice, which usually involves imagination or written story, as they give the learner a realistic feel and impression of the situation of another person [15]. This feature suggests that such characteristics of VR as high immersion and realism place it at the forefront of perspective-taking media to develop empathy [24, 25]. XR to Collaborate, Communicate and Include.

2.3 Combining extended reality and biofeedback to adaptive SEL experiences

The combination of biofeedback and XR is an interdisciplinary approach, which extends past immersion, attempting to establish adaptive learning experiences that react to the emotional and physiological condition of a learner in real time [26]. The argument of integrating these technologies is convincing. On the one hand, the immersive XR creates an interesting environment and situational context of the social-emotional practice; on the other hand, biofeedback provides objective information about the internal processes of the learner (e.g. stress, engagement, attention) that may be used to adjust the experience or teach the learner self-regulation. Early studies indicate that this kind of integration is able to deal with some shortcomings that are realized when the two approaches are applied individually. To give an illustration, neurofeedback training alone usually needs numerous repetitive procedures and may experience waning user motivation, particularly in young learners [15].

2.4 Difficulties and future projections

Though the results are promising at the initial stages, the XR and biofeedback practice of SEL remains a young area with a number of technical and pedagogical concerns. A key challenge is that real-time interpretation of physiological data in dynamic, complex learning tasks is a reliable method. The signals, such as heart rate or skin conductance, can also be noisy and sensitive to personal differences and thereby make it hard to accurately determine the emotional state of a learner [27]. As Qu et al. [27] note, VR offers a very favorable controlled environment to generate certain emotions and measurements, and those methods using multimodal (a combination of bio signals) have been found to give better emotional recognition. Nevertheless, existing systems continue to grapple with the problem of signal noise, adjustment to the baseline of individual users, and overall generalizability of emotion models [13].

The other factor is the usability and acceptability of such technologies in the schools. The wearable sensors and VR headsets should be comfortable, inexpensive, and user-friendly to be acceptable at the classroom level [18]. Educators need to be also trained to read physiological feedback and incorporate such tools into SEL curriculum in a meaningful way that adds a human factors aspect to the technology. Research wise, additional research is required to assess the long-term effects of XR+biofeedback interventions on the outcome of SEL. Numerous available studies show that they can improve in the short term in the laboratory (e.g. immediate reduction of stress or increase in empathy), but nothing is said about how lasting it is and whether it applies to real-life behavior, not within the virtual environment [28, 29].

3 METHODOLOGY

We utilized a qualitative research design. The participants were 12 undergraduate students (seven female, 19–22 years old) selected in an engineering program in a university. Everyone had regular or corrected vision and minimum computer skills; none had a substantial previous experience in VR. The ethics board of the university gave the study a green light and all the subjects provided informed consent.

The participants worked with a training simulation as VR training to learn about the fundamental concepts of engineering (e.g. circuit assembly) in a simulated immersive environment. Each participant was provided with a brief orientation to read beforehand and made individual learning objectives (e.g. Learn how circuit components connect) with minimal prompting. The interactive activities included during the VR session (around 20 minutes each) involved, among other things, constructing a simple circuit with the help of hand controllers. The VR system also gave visual and auditory feedback on success (e.g. circuit completed) but not actual performance scores. Semi-structured interviews (30–45 minutes each) were carried out after the session, during which the respondents were asked open-ended questions concerning their preparation, strategies and their thoughts on the VR task. Some of the sample questions were: How did you make the decision what to do in the VR task? What steps did you apply in solving the problem? How do you feel about your performance? The interviews were tape-recorded and word-to-word transcribed.

To perform data analysis, we resorted to the inductive thematic analysis, which is guided by the SRL framework (forethought, performance, and reflection). The transcripts were reviewed by two authors, and they coded passages of text concerning the processes involved in pre-task (forethought), during-task (performance), and post-task (reflection). The first codes were of such notions as goal-setting, help-seeking, self-evaluation, and so on. We discussed and grouped codes into themes in each SRL phase by means of an iterative process. Likewise, under we found the themes of Planning Strategy and Motivational Belief under the forethought phase. During the performance stage we were able to detect such themes as Cognitive Strategy Use and Emotional Regulation. Self-Evalation and Adaptation were found in the reflection stage. These themes were narrowed down through re-reading of transcripts and providing consistency. Coding inconsistencies were ironed out through consensus. During the analysis process, we were open to emergent ideas [30], and oriented the themes according to the SRL theory.

4 THEMATIC ANALYSIS AND RESULTS

Our thematic analysis showed that there were different patterns of how students self-regulated their learning in different stages of Forethought, Performance and Reflection of the VR experience. Below, we outline main themes in each of the phases.

4.1 Forethought phase

Participants started the VR task with the different approaches to goal setting and planning. One of the themes was Personal Goal Formation: the majority of the students made specific learning goals (e.g., I want to complete the circuit successfully, I hope that I will know how the component works together, or with others). This purpose was frequently connected with self-confidence; e.g., one participant stated that he kept telling himself that he could complete it, so he was already motivated. This is in line with the ability of VR to enhance self-efficacy: previous studies observe that immersive activities may increase the levels of confidence and motivation in learners [31]. It is interesting to note that students stated that the realism of VR made the objective more important: Since it was real, I cared more about completing it correctly, which highlights VR as a technology that allows creating the self-directed learning experience: students took the initiative since the simulation was realistic [32].

Another one was the Task anticipation and Planning. Students reported mental preparation in the VR task through the recall of related knowledge (i.e., the memory of what a circuit looked like in class) or plan development. As an illustration, one student observed, I thought that I needed to select the main component of the battery first followed by others. Students in some instances were briefly exposed to the VR environment (e.g. moving virtual hands) as a war-up. These planning behaviors mean involvement of thought plans prior to action (Kim et al. [33]). Following the principles of constructivism, VR enabled them to model a realistic problem solving situation [31], and called learners to configure their actions.

The theme of Emotional Preparedness also appeared. Some respondents acknowledged that they experienced excitement or anxiety before the exercise. One of them claimed that she is a little nervous, as it is her first time, yet eager to experience something new. These affective forethought remarks point out the effect of novelty that VR has. It is important to note that both students who were positively motivated (excitement, curiosity) were more likely to express more specific plans and goals. This is in line with the literature that positive use of VR facilitates SRL objectives [34]. Comprehensively, during the forethought stage students employed motivation and planning: they established personal objectives and detailed plans, which in most cases was affected by the immersive functionality of virtual reality.

4.2 Performance phase

The students used various strategies and behaviors to keep up with each other during the VR tasks. One of the major themes was Active Strategy Use. There were many descriptions of explicit strategies to solve tasks, including step-by-step processing or trial-and-error. An example is that one of the students remarked, I did it one part at a time and made sure the circuit was functioning. There is also one who used visual scanning: I saw the parts I needed on the table in VR, and fitted them. Such actions depict the processes of cognitive involvement: learners actively controlled information within the VR environment. This observation follows the existing literature which has shown that VR has the potential to facilitate learning because it allows the learners to engage with the digital objects as though they were real [8]. Actually, participants also tended to compare their behavior in VR with real-life learning, which supports the affordance of VR as learning through doing.

Self-Monitoring and Feedback was second theme. Since the VR system was capable of providing instant feedback (e.g. a light coming on when the circuit was hooked up in the right way), students often paid attention to such signals. A number of the participants took time to decode system feedback: I could look and see the green light and then I knew I was correct; when it did not change, I tried a different set-up. This validation check is a manifestation of self-monitoring – a vital SRL. It is important to mention the real-time feedback in VR: as one of the learners observed, it was necessary to see something happening immediately to be able to readjust one approach right away. This is in agreement with studies that have noted that instant feedback provided by VR can improve learning outcomes by helping the learners through the performance [35, 36, 37].

Emotional Regulation During Task was third theme. Immersive VR could cause stress or frustration, and respondents reported coping mechanisms. Indicatively, one student said that he/she would breathe deeply when not able to proceed: I took a second, relaxed and figured out the process of switching wires. When they failed to achieve first attempts, others reminded themselves of the goal (I told myself it is okay to make a second attempt). It is interesting to note that these methods are reminiscent of VR therapy studies: adaptive breathing cue-use has been demonstrated to assist users to manage the stress levels in VR spaces [38]. Similar regulation was intuitively used by our participants, without any formal biofeedback prompts, which suggests that users carried with them metacognitive coping strategies to the VR task.

Environment and Tools were also used. Other students could also abuse VR-specific capabilities, such as a virtual notebook or hints (when they had them). One replied, for instance, that he opened the help panel in VR when he was confused. Some were also comments related to environmental controls: This shows that the learners were active in the virtual environment as it was part of their performance strategy. Overall, in the performance phase the students were equal between the cognitive strategies (solving problems, tool usage) and self-regulation (monitoring feedback, emotion control), using VR affordances such as immersive feedback, interactivity to aid their learning [21, 8].

4.3 Reflection phase

Students did self-evaluation and plans after the completion of VR task. Self-Evaluation of Performance was one of the themes. Virtually all respondents rated their performance. Some of them said they were pleased or surprised by their accomplishment: "I am glad that I made it right the first time." Others mentioned imperfections: I noticed I had missed one wire so it was not flawless. These were self-evaluations that were correlated with the task feedback (the green light, or absence thereof). Success was attributed to actions of the participants (because I planned well) or failure to strategy mistakes (I should have checked the manual). This is indicative of metacognitive reflection: the learners rated their knowledge and pinpointed the things that affected the results. This reflective practice also plays a crucial role in SRL; in our case, the straightforward feedback of VR (signs of success, or trial and error) provided students with tangible information to judge themselves.

One more theme was Learning Transfer and Adaptation. Numerous students talked about their applications of learning. Indicatively, one student remarked, "Now I am more confident working on real circuits in the lab." Some of them said that VR task served to reaffirm textbook ideas thus they were planning to remember this experience in future laboratories.

Notably, the students also made future modifications: one of the participants stated that, next time, he/she will remember that it is more efficient to select the components in another order. The following considerations indicate that the VR experience led to strategic adaptation. The experience of reality provided by VR probably contributed to the perceived transferability of the learning, as participants commented about it, saying that it felt like the real thing, so it will stick with me. This is reminiscent of the literature regarding the capacities of VR to facilitate self-directed and adaptative learning [39, 22].

Lastly, Emotional Reflection came into being. The students used to complain of their affective responses post task. Most reported being either proud or relieved more so when they had made it. Some told that they were frustrated or disappointed when they had trouble. As an example, one of them said: I was happy I got one, yet, I felt I could have done better. All these feelings led to their future; some claimed that the slight infantile frustration drove them to practice even more. This is in line with the results that VR may cause powerful emotional reactions (joy, challenge) [34, 27], and, therefore, influence motivation and reflection. Overall, in the reflection stage, the learners assessed their own performance and attributed either success or failure and future learning, commonly affected by immersive feedback of the VR task.

5 DISCUSSION

Our results illuminate the impact of immersive VR environment on self-managed learning process throughout the three phases. All in all, students utilized VR as an interactive means of learning, goal setting, strategy application and reflection in a way that is both consistent and projected within the developed frameworks of self-regulated learning.

During the Forethought stage, there was deliberate goal-setting and planning, usually driven by the immersive setting. The reality that nearly all learners have specific learning objectives is also aligned to SRL theory which underlines the role of forethought in motivation. It is particularly worth noting that the level of motivation that we have recorded is high which can be explained by the engagement that VR provides. Previous studies have reported the fact that VR enhances the motivation and positivity of the learner [14, 40]. Indicatively, Haetami and Khan [4] concluded that more motivation was achieved in VR collaborative activities compared to traditional tasks. The novelty and the presence of VR appeared to increase the commitment to goals in our study. We also saw proactive planning plans, which implied that learners approached the VR situation as a real problem. This correlates with the review of Radianti et al. [5] who state VR because it allows self-directed processes via motivational and metacognitive planning [41]. Overall, VR also seemed to increase the engagement of students regarding the forethought phase: since goals become more tangible during the immersive experience, students develop detailed plan and high self-efficacy.

Students were active VR affordance exploiters in the Performance phase. They employed practical approach of problem-solving in the virtual setting, which is consistent with the conclusion that VR learning is an activity and sensemaking process [42]. The instantaneous feedback of the senses in VR, say, lights or sounds that one has achieved success, was a factor. This enabled the learners in self-monitoring. In fact, our participants often took some time to decipher VR feedback and change their actions accordingly. This action is an indication of traditional SRL monitoring, but with the new benefits of VR real-time cues. It has been proposed in literature that this form of real-time performance feedback can significantly enhance the results of learning [43, 6]. In line with this, a participant indicated the advantage of instant feedback with regard to correction and learning.

The students were also able to regulate their affective state during their performance. There is metacognitive emotion regulation because some of them employed self-calming methods when they became stuck or frustrated. This is similar to the findings of VR therapy studies; such as adaptive VR-biofeedback systems (with breathing cues) can assist users with dealing with stress [44, 13]. Our system was not that explicit in measuring physiology, but similar calming strategies were intuitively applied by the participants. It implies that immersive VR may induce natural self-regulation: learners would self-treat as in a real-life situation and use coping mechanisms where necessary.

There was an interesting performance theme that was a strategic use of the VR environment in itself. There were the students who changed settings or used VR tools (help panels, brightness controls) to maximally improve performance. This is one of the parts of SRL, which is environmental structuring. We conclude that VR learners do not only engage in cognitive techniques, but also interact with the virtual environment to seek the learning process. This builds on the research by demonstrating that design of VR features (e.g. easy access to hints, adjustable parameters) can be integrated into the repertoire of self-regulation of learners [45, 5].

During the Reflection stage, the participants were engaged in the process of closely assessing their personal learning and performance as anticipated in SRL. They attributed realistic self-assessment to immersive feedback of VR. It is interesting to note that a large number of learners claimed that the experience was authentic and resulted in high emotional responses (satisfaction, challenge). This is in line with the social media evidence of VR learning, which document that VR is often characterized by users as an environment that encourages creativity and is a self-directed learning experience [46, 47]. To illustrate, the VR was reported to encourage students to investigate on their own and solve issues in different perspectives [48, 49], via tweets. Likewise, our learners also indicated that they planned to transfer VR-learned skills to real life activities, which indicated that VR facilitated transfer.

There was also adaptive planning after the task: learners started to make new tasks or revise the approach to the next practice. This is consistent with the results of VR research in higher education, where the users said they felt empowered to participate actively in the content [50, 51]. The fact that the majority of students changed their methodology or tried to get some more practice highlights the idea that VR can be used to promote continued learning.

Our paper supports and broadens current knowledge about VR and learning. In line with the review of immersive learning by Balalle [39], the users enjoyed the capabilities of VR to deliver the content in various manners. As an example, one learner has cited that the study of a 3D circuit in VR provided a better understanding than 2D diagrams, which aligns with the results of Muzata et al. [8] stating that VR enhances the learning of complex concepts [3]. Furthermore, the sense of presence was also strong and probably contributed. The high degree of immersion, embodiment, and presence, as Khukalenko and Khanolainen [21] point out, makes VR the sole medium to be used in learning. We find that these immersive qualities varied all stages of SRL these included increased motivation and goal focus during forethought, real-time strategy during performance, and rich experiences during reflection.

It is also notable that there were also some difficulties. Some students said that they were confused with the VR interface controls in the beginning, which impaired initial performance. This is aligned to previous studies that stated that the usability of technology can influence learning and self-regulation (Bödding et al., 2025). Nevertheless, the majority did not take long to overcome such problems. The other possible weakness is that the newness of VR can lead to an increase in motivation, yet to be examined is whether this effect will be maintained across successive sessions.

6 CONCLUSIONS

VR simulated environments provide an abundant setting in self-directed learning. We have concluded that learners received VR tasks with well-defined goals and significant motivation, applied active strategies and observed feedback during the performance, and reflected thoughtfully afterward. These patterns are similar to the SRL traditional processes but are enhanced by the affordances of VR. To illustrate, the feedback and the level of realism in VR promoted learners to self-direct their learning and real-time adaptation. These results are consistent with the previous evidence that VR may be used to induce self-driven learning and promote active, immersive interact 'Tion. Practically, the benefits of VR can be used by educators and designers to focus on planning, timely feedback, and reflection. In this way, the forethought, performance, and reflection of SRL can be facilitated by VR-based instruction, and the learning outcomes will be more effective. One of the participants said that VR helped me feel that I was actually doing it; I believe I will recall this task in the future. According to a systematic review, VR has a strong potential in developing self-directed learning in students. As VR technologies are getting more mature, incorporating the technologies with SRL-supportive capabilities provides an interesting avenue to enrich learning at higher education and further.

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