Enhanced VR Learning with Dynamic Somatosensory Feedback to Assist in Understanding the Dynamic Process of Blood Circulation

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***Abstract*—With the rapid development of Virtual Reality (VR) and haptic technology, their applications in education have demonstrated tremendous potential. However, traditional VR learning that incorporates haptic feedback usually has a limited body coverage, and there is a weak alignment between the haptic feedback and the educational content. To address the above-mentioned issues, this study established an environment that combines VR with dynamic somatosensory feedback. Through the simulation of the human blood circulation, it explored the impacts of VR and somatosensory feedback on learning effects. Sixty participants were randomly divided into three groups: the computer-based group, the VR-only group, and the VR with somatosensory feedback group. Self-efficacy, perceived enjoyment, and knowledge retention were evaluated through targeted questionnaires. The results showed that VR with somatosensory feedback significantly outperformed the computer-based and VR-only learning modes. This study provides new insights and practical support for the effective integration of VR and somatosensory feedback technology in educational environments.**

***Index Terms*—virtual reality, somatosensory feedback, medical education**

I. Introduction

The rapid advancement of VR technology is catalyzing a transformative shift in education, creating unprecedented opportunities to enhance traditional teaching methodologies. With its immersive and interactive features, VR has revolutionized the delivery of educational content in specific contexts, enabling learners to engage with material in innovative ways. However, most current VR applications in education focus primarily on visual and auditory modalities, often under-exploring the crucial role of haptics, particularly somatosensory feedback. Existing research on haptic feedback in education faces notable limitations, which can be categorized into two key aspects. First, the current application of haptic feedback in educational scenarios is often restricted to localized body areas, such as the hands [1], rather than employing full-body somatosensory feedback. This constrains the ability of haptic technology to fully demonstrate its potential for enhancing educational outcomes. Second, there is often a weak alignment between haptic feedback and the educational content it is designed to support, such as educational video [2].

To address the above limitations, this study adopts the learning of human blood circulation processes and pathways as a case study, developing an immersive VR learning environment integrated with full-body somatosensory feedback. Based on this environment, a comprehensive evaluation was conducted using targeted questionnaires designed to assess self-efficacy, perceived enjoyment, and knowledge retention. The evaluation results demonstrate that VR with somatosensory feedback can significantly enhance learning outcomes compared to traditional learning modes. By systematically exploring the specific contributions of VR with somatosensory feedback in educational contexts, our study seeks to provide both theoretical insights and guidance for its practical implementation.

(a) Participant wears experimental equipment.

(b) HTC VIVE Pro Eye (top) and TactSuit X40 (bottom).

Fig. 1: A participant wears the HTC VIVE Pro Eye VR display and the bHaptics TactSuit X40 somatosensory suit to learn knowledge about blood circulation.

II. Related Work

A. VR in Education

According to a comprehensive analysis by Radianti et al. [3] on the application of immersive VR in higher education, modern VR technology can generate highly realistic learning scenarios within a virtual environment. This not only helps students better understand and master course content but

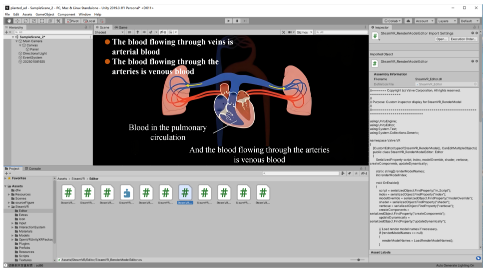

Fig. 2: The HTC VIVE Pro Eye VR display provides a Unity interface, allowing the device to be programmed through the Unity development environment for playing the educational video on human blood circulation.

also significantly improves knowledge retention and information recall. For example, Morgado et al. [4] proposed a recommendation tool for immersive learning to help educators plan and implement educational activities that align with available resources and teaching objectives. Müser et al. [5] demonstrated the effectiveness of VR in teaching with programmable tools within virtual environments. It has been widely recognized that VR technology not only offers students diverse and personalized learning experiences but also breaks the constraints of space and time, enabling more flexible and efficient teaching models [6]. Furthermore, due to the rapid development of haptic technologies, there is a trend of integrating haptic feedback into VR for a more immersive and interactive learning experience.

B. Haptic Feedback with VR in Education

In VR environments, students can experience the shapes, textures, and dynamic interactions of virtual objects through haptic devices, immersing themselves fully in the educational content. This approach has demonstrated unique advantages across various academic disciplines. For example, in medical education, haptic technology can be used to simulate surgical procedures, providing students with a realistic hands-on experience [7]. In music education, haptic feedback is employed to simulate virtual guitar playing, providing a more interactive and engaging learning experience [8]. Similarly, in physical education, haptic feedback is utilized to enhance training effectiveness by improving learners' sensory awareness and technique execution [9]. However, the effectiveness of haptic feedback in these studies is constrained by its limited coverage, primarily focusing on hand-based feedback rather than full-body somatosensory feedback. Moreover, there is often weak alignment between the haptic feedback and the educational content, such as educational videos.

III. Methodology

This study utilized a professionally produced, 90-second educational video demonstrating the human blood circulation process. To provide a fully immersive educational experience, this study employed an HTC VIVE Pro Eye head-mounted VR display and a bHaptics TactSuit X40 somatosensory suit (Figure 1). Participants interacted with a 90-second professionally produced educational video illustrating the human blood circulation process. To achieve seamless device integration and precise control, a Python-based solution was implemented. First, the VR display was launched via the Unity platform (Figure 2), where the educational video was imported. Next, the TactSuit X40's client, "bHapticsPlayer", was used to activate path control mode (Figure 3), enabling precise coordination of all 20 vibration points within the suit. Using pre-programmed Python scripts, the TactSuit X40's somatosensory feedback was synchronized with the educational video's playback. The overall technical workflow is illustrated in Figure 4.

In order to accurately assess the learning outcomes of the participants, we employed a questionnaire encompassing three aspects: self-efficacy [10], perceived enjoyment [11], and knowledge retention to measure the effectiveness of the experiment. Both the self-efficacy and perceived enjoyment questionnaires use a 7-point Likert scale for quantitative scoring, where 1 represents "strongly disagree" and 7 represents "strongly agree". Finally, a knowledge retention questionnaire was specifically designed to assess participants' mastery of the experimental educational content. The questionnaire covers different aspects of the circulatory system as presented in the educational video, such as "which organ blood enters after passing through the capillaries". The total score (in the range of 0 to 10) obtained by each participant is normalized to a 0–7 scale to align with the data format of the other two questionnaires.

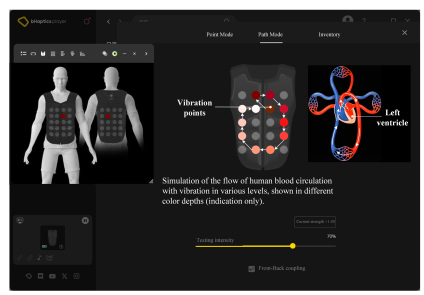

Fig. 3: The TactSuit X40 is programmed using the bHapticsPlayer software, enabling the vibration points at specific locations to vibrate in synchronization with the simulated blood flow shown in the educational video, providing an immersive and realistic experience.

To comprehensively evaluate the learning effectiveness of combining VR and somatosensory feedback, 60 participants (38 males and 22 females, with a mean age of 27 years and SD = 2.35) were invited to participate in the experiment. The participants were randomly assigned to one of three groups: computer-based group, VR only-based group, and VR with somatosensory feedback group. Prior to the experiment, a brief survey was conducted to assess participants' prior knowledge, ensuring minimal differences across the groups. During the experiment, the computer-based group viewed the educational video on a MacBook computer. The VR only-based group experienced the same video but through the HTC VIVE Pro Eye VR display. The VR with somatosensory feedback group not only wore the VR display but also donned the TactSuit X40 suit for somatosensory feedback. Upon completion of the evaluation, participants were asked to fill out a the questionnaire.

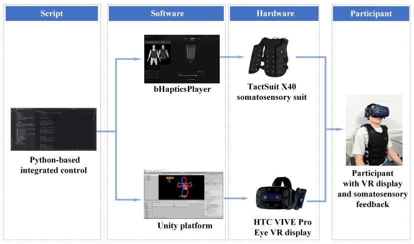

Fig. 4: The overall technical workflow: The synchronization between the bHaptics TactSuit X40 and HTC VIVE Pro Eye VR display is accomplished by leveraging Python scripts to control both the bHapticsPlayer and the Unity.

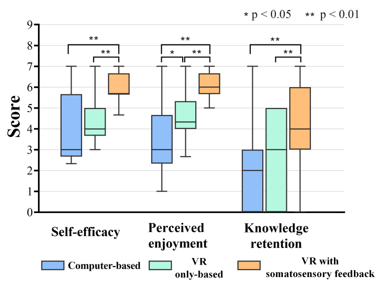

Fig. 5: The t-test significance analysis results among the computer-based group, VR only-based group, VR with somatosensory feedback group, covering the three dimensions of self-efficacy, perceived enjoyment, and knowledge retention.

IV. Evaluation Results

The experimental results are shown in Table 1. In the three aspects of self-efficacy, perceived enjoyment, and knowledge retention, VR with somatosensory feedback achieved the highest scores (6.017, 6.017, and 4.368). This indicates that VR with somatosensory feedback can not only enhance learners' confidence and sense of pleasure but also improve their immediate knowledge comprehension and retention. To further explore the potential relationships within the evaluation data, we conducted t-tests to assess the significant differences between different groups, as shown in Figure 5. The results revealed that the VR with somatosensory group significantly outperformed both the pure VR only-based group and the computer-based group across all evaluation metrics ($p < 0.01$). Additionally, the VR only-based group also demonstrated significant improvements over the computer-based group in all three metrics ($p < 0.05$ or $p < 0.01$). These findings suggest that the introduction of somatosensory feedback not only significantly boosted participants' motivation and interest in learning but also led to substantial improvements in learning outcomes.

V. Discussion and Conclusion

This study experimentally explored the application of VR combined with somatosensory feedback technology in educational contexts. The results demonstrate that the integration of VR and somatosensory feedback can significantly enhance self-efficacy, learning enjoyment, and knowledge retention in understanding the dynamic process of blood circulation. Nevertheless, the study was primarily centered around blood circulation learning as a case study. Future research should broaden its scope to include other educational domains to assess the generalizability of these findings. Despite this limitation, our proposed approach and findings demonstrate that the VR and somatosensory feedback-based learning holds substantial promise for educational applications. We anticipate plenty of opportunities for further exploration building on the idea and methodology presented in this paper.

TABLE 1: Self efficacy, perceived enjoyment, and knowledge retention scores in three learning modes.

	Computer-based	VR only-based	VR with somatosensory feedback
Self-efficacy	3.773	4.473	**6.017**
Perceived enjoyment	3.470	4.667	**6.017**
Knowledge retention	2.264	2.472	**4.368**

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