



Using immersive virtual reality as an educational resource to understand the central nervous system

Uso de realidad virtual inmersiva como recurso didáctico para la comprensión del sistema nervioso central

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Abstract:

Teaching neuroanatomy through two-dimensional resources may hinder the spatial understanding of brain structures, which has encouraged the incorporation of immersive methodologies in higher education. This study aimed to evaluate the pedagogical feasibility of immersive virtual reality (VR) and to examine learning associated with its use as an educational resource for studying the central nervous system. Twenty-six first-year undergraduate Speech Therapy students participated in a practical session using the *Human Anatomy VR* application. Questionnaires and an objective test were used to assess adverse symptoms, sense of presence, satisfaction, and performance on neuroanatomical and functional knowledge. Results showed an absence of adverse symptoms in 76.44% of *Simulator Sickness Questionnaire* (SSQ) records, together with a high sense of presence and high levels of satisfaction. However, the proportion of correct responses was lower for content studied through immersive VR than for content taught through traditional theoretical instruction. Overall, immersive VR appeared to be a feasible and well-accepted educational resource, although its instructional design should be optimized and more controlled assessment procedures are needed to determine its impact on learning.

Keywords: educational innovation, virtual reality, higher education, neuropsychology.

Resumen:

La enseñanza de la neuroanatomía mediante recursos bidimensionales puede dificultar la comprensión espacial de las estructuras cerebrales, lo que ha favorecido la incorporación de metodologías inmersivas en educación superior. Este estudio tuvo como objetivo evaluar la viabilidad pedagógica de la realidad virtual (RV) inmersiva y analizar el aprendizaje asociado a su uso como recurso didáctico para el estudio del sistema nervioso central. Participaron 26 estudiantes de primer curso del Grado en Logopedia, quienes realizaron una sesión práctica con la aplicación *Human Anatomy VR*. Mediante cuestionarios y una prueba objetiva se evaluaron la sintomatología adversa, el sentido de presencia, la satisfacción y el rendimiento en conocimientos neuroanatómicos y funcionales. Los resultados mostraron ausencia de sintomatología adversa en el 76,44% de los registros del *Simulator Sickness Questionnaire* (SSQ), un elevado sentido de presencia y altos niveles de satisfacción. Sin embargo, la proporción de aciertos fue menor en los contenidos trabajados mediante RV inmersiva que en los impartidos mediante enseñanza teórica tradicional. En conjunto, la RV inmersiva se mostró como un recurso viable y bien aceptado, aunque es necesario optimizar su diseño instruccional y emplear evaluaciones más controladas para determinar su impacto sobre el aprendizaje.

Palabras clave: innovación pedagógica, realidad virtual, enseñanza superior, neuropsicología.

1. INTRODUCTION

University teaching in the health sciences, and specifically the teaching of neuropsychology as applied to disciplines such as Speech Therapy, faces the challenge of conveying anatomical and functional concepts of considerable structural complexity. Traditionally, the study of the neuroanatomical bases of behavior has relied on two-dimensional models, such as textbook illustrations, static diagrams, printed anatomical atlases, or slide projections in the classroom (Yammine & Violato, 2015). Although these resources provide a fundamental basis for the theoretical teaching of neuroanatomy, they may have limitations in facilitating a three-dimensional understanding of the spatial organization of the brain, the relationships between cortical and subcortical structures, and the neural circuits involved in cognitive functions such as attention, memory, executive functions, and language.

Neuroanatomy and neuropsychology require students to engage in a high degree of abstraction. When teaching relies predominantly on passive and two-dimensional approaches, neuroanatomical content may be perceived as abstract and remote from its future clinical application, which may reduce motivation and promote more rote or superficial learning. In this regard, recent studies have shown that incorporating three-dimensional models and virtual reality (VR) environments can enhance motivation, satisfaction, and, in some cases, performance in neuroanatomy learning compared with traditional methodologies (Alim et al., 2024; García-Robles et al., 2025). These advances highlight the need to explore more dynamic, visual, interactive, and experiential teaching methodologies that complement conventional instructional resources.

Within this context of digital and pedagogical transformation, immersive VR is a tool with the potential to enrich certain teaching and learning processes in higher education. Unlike non-immersive VR systems based on conventional computer screens, immersive VR uses head-mounted displays that allow users to interact with a simulated three-dimensional environment in real time. Applied to the study of neuroanatomy, this technology enables learners to manipulate virtual representations of the brain, rotate them in space, explore subcortical structures, and interactively visualize the spatial relationships among different regions and neurobiological circuits.

From a cognitive perspective, direct interaction with three-dimensional learning objects allows learners to control the views, perspectives, and scales of the structures being studied. Previous research suggests that this type of active exploration may facilitate spatial encoding and information retention compared with passive exploration strategies, thereby contributing to the development of conceptual knowledge (Alim et al., 2024). Interactive immersion may also enhance students' behavioral and emotional engagement and increase their motivation and perceived interest in the subject matter (García-Robles et al., 2025).

However, integrating immersive VR into university settings is not without limitations. The instructional design of these technologies should be accompanied by a multidimensional evaluation that considers ergonomic, psychological, and cognitive variables (Radianti et al., 2020). Among these, adverse symptoms associated with the use of virtual environments, commonly referred to as cybersickness, are relevant when

determining the feasibility of the tool. Cybersickness may manifest as symptoms such as eyestrain, disorientation, fullness or heaviness of the head, difficulty focusing, nausea, or general discomfort (Bouchard et al., 2021). These effects may interfere with learning experience and reduce attention during exposure to immersive environments (Mimnaugh et al., 2023). Therefore, assessing the physical tolerability of these devices during classroom use is an important component when considering their incorporation as an educational resource.

Another relevant component of the immersive experience is the sense of presence, understood as the subjective perception of “being there” or feeling physically present within the virtual environment despite remaining in the real physical space (Castro et al., 2026). It is a multidimensional construct that includes components such as attention and involvement in the virtual environment, the subjective experience of realism, and the feeling of spatial presence (Castro et al., 2026). Previous evidence suggests that the sense of presence may enhance user engagement and modulate cognitive performance during tasks performed in VR environments (Palombi et al., 2023), possibly by facilitating attentional focus and reducing interference from external stimuli.

Student satisfaction is also a relevant dimension when assessing the acceptance and potential incorporation of these methodologies into teaching practice. The evaluation of aspects such as equipment usability, ease of interaction with the interface, physical comfort of the device, and its perceived usefulness for learning may influence acceptance of these technologies (Fink et al., 2023). Consequently, barriers related to usability or comfort could limit their continued use as educational tools.

Finally, evidence regarding performance on knowledge tests after learning through immersive VR remains inconclusive. Some studies have reported improvements in learning through virtual environments compared with traditional instruction based on textual or two-dimensional materials (Alim et al., 2024; Ekstrand et al., 2018), whereas others suggest that technological immersion may increase cognitive load, promote distraction by novel interface elements, or produce mental fatigue associated with the high stimulus density of the virtual environment (Parong & Mayer, 2021). Therefore, evaluating an educational innovation experience based on immersive VR requires jointly considering tolerability, sense of presence, student satisfaction, and objective learning outcomes.

2. OBJECTIVES

The present study aimed to evaluate the pedagogical feasibility of immersive VR as an educational resource for studying and understanding the central nervous system among university students enrolled in a Speech Therapy degree, as well as to examine learning associated with its incorporation into classroom teaching. To this end, adverse symptoms associated with immersive VR use, the sense of presence experienced during the practical session, and students' degree of satisfaction were examined. Performance on the knowledge test was also compared between content studied through immersive VR and content taught through traditional theoretical instruction.

3. METHODOLOGY

3.1. Participants

The sample comprised 26 university students enrolled in a first-year course of the Speech Therapy degree during the 2024/2025 academic year. Specifically, 24 women and two men participated, ranging in age from 18 to 23 years. Overall, students reported only occasional previous use of immersive VR tools.

The immersive VR practical session was organized in small groups of six to seven students to ensure adequate instructor supervision. All participants took part voluntarily after providing informed consent for the use of their data for research purposes. The study was conducted in accordance with the ethical principles of the Declaration of Helsinki and current data protection regulations.

3.2. Materials and instruments

This study combined hardware and software technologies with psychometric assessment instruments and an *ad hoc* knowledge test.

Five immersive VR headsets were used in each practical group (Meta Quest 3). The software used was the commercial *Human Anatomy VR* application, which enables active three-dimensional exploration of different brain regions, such as the hippocampus or amygdala, associated with cognitive functions including memory and emotional processing. The application also provides volumetric and interactive representations accompanied by brief functional descriptions of each structure.

To assess the presence and severity of cybersickness, the Spanish-adapted and validated version of the *Simulator Sickness Questionnaire* (SSQ; Campo-Prieto et al., 2021), comprising 16 symptoms, was administered. Responses were recorded on a four-point Likert scale: no symptom (0), mild symptom (1), moderate symptom (2), and severe symptom (3). In the present study, a descriptive symptom-by-symptom analysis of the SSQ was conducted. The cumulative score for each symptom across the entire sample was calculated, with a possible range of 0 to 78 points per symptom. Higher scores indicate greater adverse symptomatology associated with immersive VR use.

To assess the sense of presence, a Spanish translation of the *Igroup Presence Questionnaire* (IPQ; Regenbrecht & Schubert, 2002) was used. The questionnaire consists of 14 items rated on a seven-point Likert scale, with scores ranging from 0 to 6. Mean scores were obtained for the four dimensions provided by the instrument: general presence (IPQ-GP), attention and involvement in the virtual environment (IPQ-INV), subjective experience of realism (IPQ-ER), and the feeling of being physically present in the virtual space (IPQ-SP). Higher scores indicate a stronger sense of presence.

To assess satisfaction, an *ad hoc* questionnaire (SATISF) consisting of 15 items rated on a five-point Likert scale, with scores ranging from 0 to 4, was designed and administered. Students indicated their level of agreement with a series of statements concerning the immersive VR practical session: strongly disagree (0), disagree (1), neither agree nor disagree (2), agree (3), and strongly agree (4). The instrument was organized into five three-item subscales: general evaluation of the experience (SATISF_ValoraGen), interaction with and usability of the immersive VR tool

(SATISF_InteraccUsab), application to learning (SATISF_AplicAprend), physical and comfort factors (SATISF_Comod), and overall satisfaction with the immersive VR practical session and recommendation (SATISF_Recom). The mean score for each subscale was calculated, with higher scores indicating greater satisfaction.

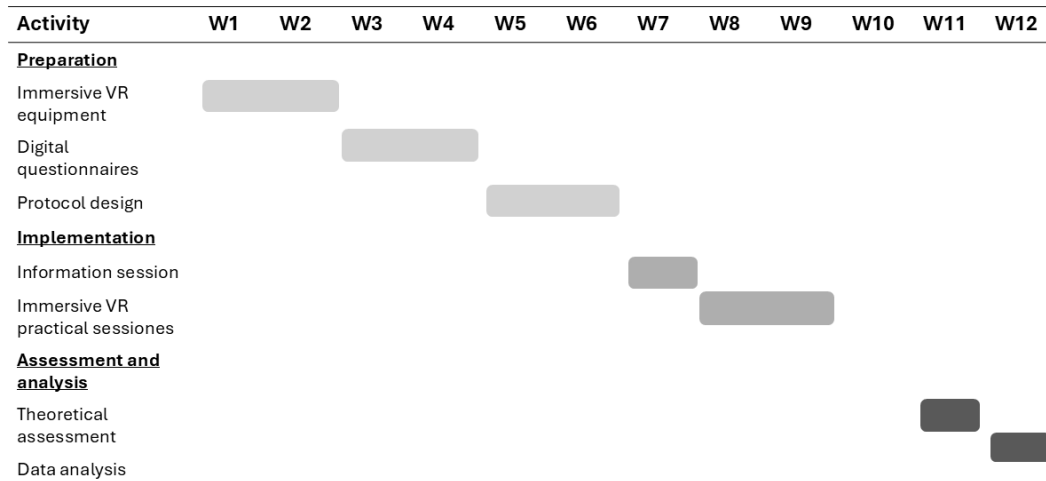
Finally, an objective test comprising five multiple-choice questions with three response options each was developed specifically to assess the neuroanatomical and functional knowledge addressed during the immersive VR practical session. These questions were included in the final written midterm examination for the course together with 15 additional questions covering content taught through traditional theoretical classes, also with three response options each. For each participant, the proportions of correct responses, errors, and omissions were calculated by dividing the number of correct, incorrect, or omitted responses by the total number of questions in each block: five items for content studied through immersive VR and 15 items for content taught through traditional theoretical instruction.

3.3. Procedure

The study was conducted through a sequence of phases spanning a total of 12 weeks (Figure 1).

Figura 1

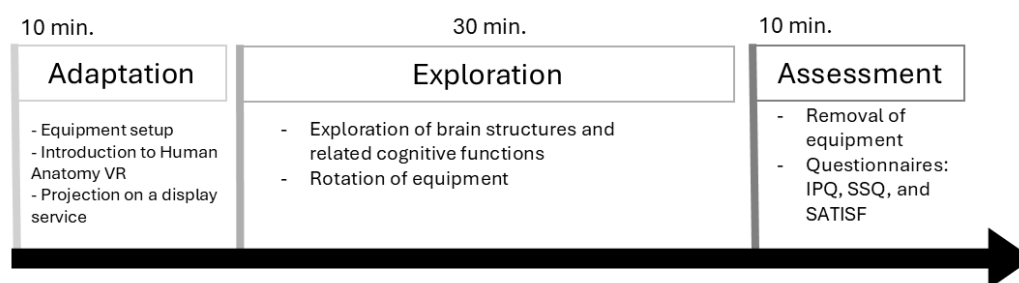
Timeline of the study phases



The practical intervention was conducted identically across all student groups. The session lasted 50 minutes and was structured into three consecutive phases: adaptation, exploration, and assessment (Figure 2).

Figure 2

Phases of the immersive VR practical session



Note. The practical session was structured into three consecutive phases: adaptation to the immersive VR device, interactive exploration of neuroanatomical structures using the application, and assessment through completion of the corresponding questionnaires.

3.4. Data analysis

Statistical analyses were performed using SPSS for Windows, version 29. A descriptive analysis was conducted to examine the frequency and severity of adverse symptoms recorded using the SSQ.

Repeated measures ANOVA was used to compare scores across the IPQ subscales. Effect size was estimated using partial eta squared (η_p^2).

Scores across the satisfaction questionnaire subscales were compared using the Friedman test for related samples. The overall effect size was calculated using Kendall's W. When the Friedman test was statistically significant, post hoc pairwise comparisons were performed using the Wilcoxon signed-rank test, with Bonferroni correction applied to control the Type I error rate.

To compare knowledge-test performance between the two teaching modalities, Wilcoxon signed-rank tests were applied to the proportions of correct responses, errors, and omissions for content studied through immersive VR and content taught through traditional theoretical instruction. To control the Type I error rate arising from the three comparisons, a Bonferroni correction was applied, setting the significance level at $\alpha = .017$. Effect size was calculated using r statistics by dividing the Z value by the square root of the number of valid observations for each comparison.

4. RESULTS

4.1. Adverse symptoms associated with immersive VR use

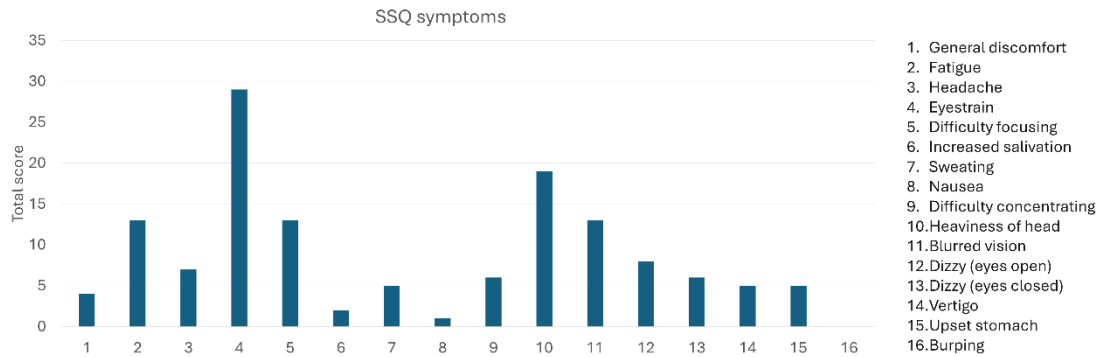
The SSQ results showed an absence of adverse symptoms associated with immersive VR use in 76.44% of the records analyzed. Of the records in which symptoms were reported, 16.35% corresponded to mild symptoms, 1.92% to moderate symptoms, and 5.29% to severe symptoms.

When symptom severity was examined, the five cybersickness symptoms with the highest cumulative scores across the sample were eyestrain (29 points), heaviness of the head (19 points), fatigue (13 points), difficulty focusing (13 points), and blurred

vision (13 points). The distribution of scores for the 16 symptoms assessed is shown in Figure 3.

Figure 3

Cybersickness symptoms assessed using the SSQ



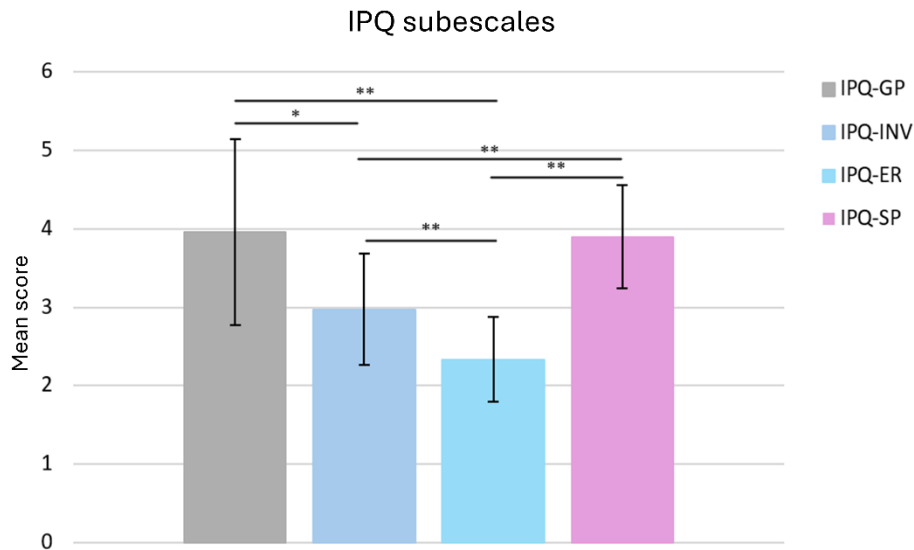
Note. The bar chart represents the total score obtained for each of the 16 symptoms assessed using the *Simulator Sickness Questionnaire* (SSQ) across the full sample. Higher scores indicate a greater frequency and/or severity of adverse symptoms associated with immersive VR use.

4.2. Sense of presence

The comparison among the IPQ subscales using a repeated-measures ANOVA showed a statistically significant effect, $F(1.834, 45.861) = 29.796$, $p < .001$, $\eta_p^2 = .544$ (Figure 4).

Figure 4

Mean scores on the IPQ subscales



Note. Bars represent mean scores and error bars represent standard deviations for the *Igroup Presence Questionnaire* (IPQ) subscales: general presence (IPQ-GP), attention and involvement (IPQ-INV), experienced realism (IPQ-ER), and spatial presence (IPQ-SP). Statistically significant pairwise differences: * $p = .003$; ** $p < .001$.

Post hoc pairwise comparisons showed that general presence scores (IPQ-GP) were significantly higher than attention and involvement in the virtual environment (IPQ-

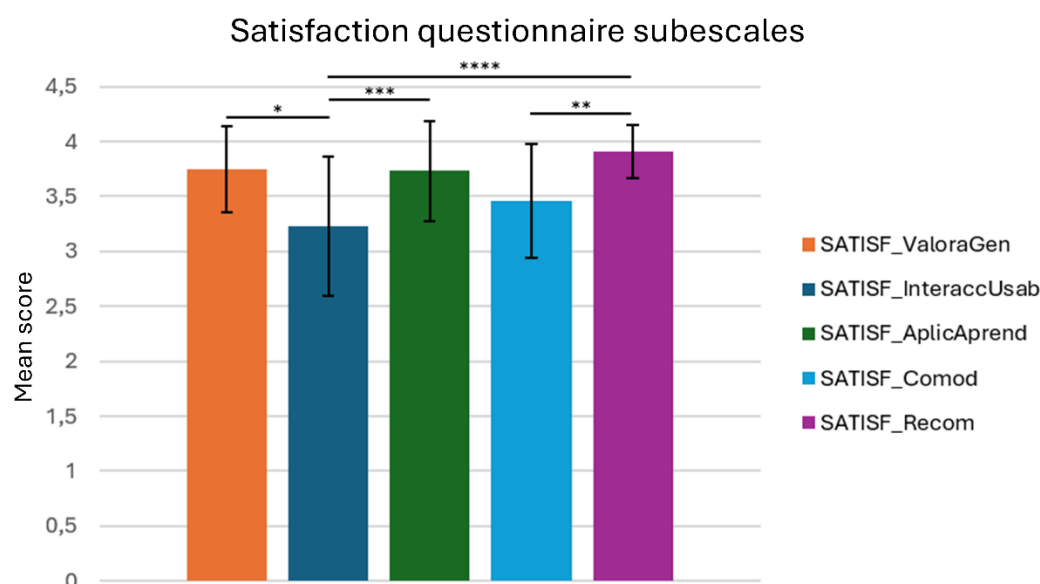
INV; $p = .003$) and subjective experience of realism (IPQ-ER; $p < .001$). No statistically significant differences were observed between general presence and spatial presence (IPQ-SP; $p = .999$). Attention and involvement scores (IPQ-INV) were also significantly higher than experienced realism scores (IPQ-ER; $p < .001$) and significantly lower than spatial presence scores (IPQ-SP; $p < .001$). Finally, experienced realism scores (IPQ-ER) were significantly lower than spatial presence scores (IPQ-SP; $p < .001$).

4.3. Satisfaction with the immersive VR experience

The Friedman test for related samples showed statistically significant differences among the SATISF questionnaire subscales, $\chi^2(4) = 44.387$, $p < .001$, $W = .427$ (Figure 5).

Figure 5

Mean scores on the SATISF satisfaction questionnaire subscales



Note. Bars represent mean scores and error bars represent standard deviations for the SATISF questionnaire subscales. Asterisks indicate statistically significant pairwise differences: * $p = .006$; ** $p = .004$; *** $p = .003$; **** $p < .001$.

Post hoc comparisons showed significantly lower scores on the immersive VR interaction and usability subscale (SATISF_InteraccUsab) than on general evaluation of the experience (SATISF_ValoraGen; adjusted $p = .006$), application to learning (SATISF_AplicAprend; adjusted $p = .003$), and overall satisfaction and recommendation (SATISF_Recom; adjusted $p < .001$). Scores for physical and comfort factors (SATISF_Comod) were also significantly lower than those for overall satisfaction and recommendation (SATISF_Recom; adjusted $p = .004$). The latter subscale yielded scores close to the maximum value of the scale ($M = 3.910$; $SD = 0.241$).

4.4. Knowledge-test performance

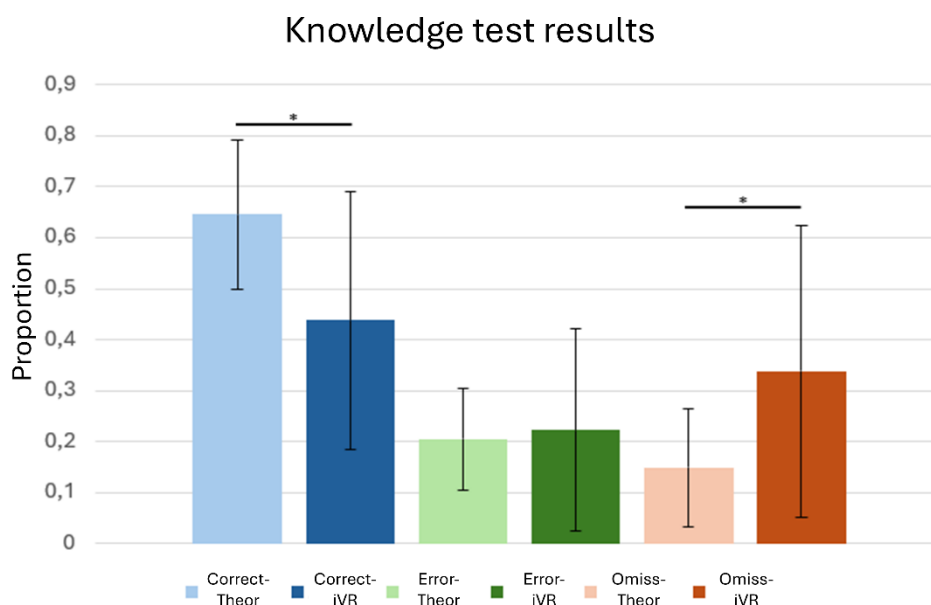
The Wilcoxon signed-rank test showed statistically significant differences in the proportion of correct responses between the two teaching modalities, $Z = -3.537$, $p < .001$.

.001, $r = .694$ (Figure 6). The proportion of correct responses was lower for questions corresponding to content studied through immersive VR than for questions concerning content taught through traditional theoretical instruction.

Statistically significant differences were also observed in the proportion of omissions, $Z = -3.297$, $p = .001$, $r = .647$, with more omissions for questions corresponding to content studied through immersive VR. No statistically significant differences were found in the proportion of errors between the two modalities, $Z = -0.280$, $p = .780$, $r = .055$. The differences in correct responses and omissions remained statistically significant after applying the Bonferroni correction for the three comparisons, with the significance level set at $\alpha = .017$.

Figure 6

Knowledge-test performance by teaching modality



Note. Bars represent the mean proportions of correct responses, errors, and omissions for content taught through traditional theoretical instruction and content studied through immersive VR; error bars represent standard deviations. Statistically significant differences between the two teaching modalities: * $p < .017$, after Bonferroni correction.

5. DISCUSSION

The main finding of this study is that the incorporation of immersive VR as an educational resource for learning neuroanatomical content was well accepted by students and showed a favorable profile in terms of tolerability and sense of presence, although these positive indicators were not accompanied by better performance on the knowledge test. Specifically, the practical session was characterized by a predominance of records without adverse symptoms, a high sense of presence in the virtual environment, and high levels of satisfaction. However, the proportion of correct responses was lower and the proportion of omissions higher for questions corresponding

to content studied through immersive VR than for those concerning content taught through traditional theoretical instruction.

Regarding tolerability, 76.44% of SSQ records indicated no adverse symptoms, supporting the feasibility of immersive VR use in the educational context examined and aligning with recent research using new-generation devices in educational settings (García-Robles et al., 2025). Nevertheless, notable scores were observed for symptoms such as eyestrain, heaviness of the head, and difficulty focusing. These findings suggest that the tolerability of technology should not be assessed solely in terms of the overall absence of symptoms but should also consider specific discomfort that may arise during use. Factors that may have contributed include the need to share devices during the practical session, with repeated alternation between the virtual and real environments, as well as the high visuospatial demands characteristic of this type of experience, which may increase visual and cognitive fatigue (Souchet et al., 2023).

Regarding the sense of presence, the IPQ results indicate that the immersive VR experience generated a perception of presence within the virtual environment. This component has previously been associated with greater attentional focus and reduced interference from external distractors (Castro et al., 2026; Palombi et al., 2023). However, the questionnaire dimensions did not show a homogeneous pattern, with experienced realism yielding the lowest scores. This lower perception of realism may be related to specific characteristics of the experience, including the absence of physical movement during exploration, as body position and interaction possibilities may modulate the sense of presence in virtual environments (Bessa et al., 2018). Exposure time may also influence the subjective experience of realism, as observed in tasks conducted using extended-reality technologies (Reisinho et al., 2024). Thus, differences among the IPQ dimensions identify specific aspects of the immersive experience that may be optimized.

High student satisfaction is another relevant finding when considering the incorporation of this innovation into the classroom. In particular, the overall satisfaction and recommendation dimension reached values close to the maximum of the scale. This finding is consistent with previous studies reporting greater motivation, involvement, and engagement with learning when complex content is presented through three-dimensional and immersive platforms (Froehlich et al., 2024). The use of resources capable of increasing student interest may be particularly relevant for content requiring a high degree of abstraction, such as neuroanatomy, as previous research has linked disengagement from more traditional teaching methodologies with poorer academic performance (Horlock, 2020). However, interaction with and usability of the tool received significantly lower scores than other satisfaction dimensions. This pattern may indicate that the initial 5- to 10-minute familiarization period with the tool controls was insufficient for all students to achieve fully autonomous and fluent use of the interface.

The finding that requires the most cautious interpretation concerns the objective knowledge test. Despite high satisfaction, sense of presence, and the favorable tolerability profile, the proportion of correct responses was lower and the proportion of omissions higher for questions related to content studied through immersive VR. These findings contrast with studies reporting benefits of active exploration in virtual

environments for experiential learning (James et al., 2002). One possible explanation is that attentional demands arising from the novelty of the technology and interaction with the interface increased cognitive load during the activity, thereby reducing the resources available for processing academic content (Parong & Mayer, 2021).

Nevertheless, the difference observed on the knowledge test cannot be attributed directly to the teaching modality because the content assessed and the number of questions differed between the two blocks. Therefore, these results do not allow the conclusion that teaching through immersive VR produces poorer learning than traditional theoretical instruction. Moreover, the absence of better immediate performance on this specific test does not rule out the possibility that immersive VR may promote other relevant educational outcomes, such as spatial understanding of structures, motivation, student engagement, or longer-term retention of content, none of which were assessed in the present study

5.1. Teaching implications

From an applied perspective, the findings indicate that incorporating immersive VR into the teaching of neuroanatomical content should not be conceived merely as a technological replacement for traditional instruction. Acceptance of the tool, sense of presence, and tolerability are favorable conditions for its integration into the classroom, but they do not in themselves guarantee improved objective learning. In this regard, the educational usefulness of immersive VR also appears to depend on how the activity is structured and on the alignment between the experience provided and the intended learning outcomes.

The findings suggest that immersive exploration should be accompanied by explicit instructional planning. Incorporating predefined learning objectives, instructions that guide the exploration of neuroanatomical structures, and directed activities during the practical session may help focus students' attention on relevant content rather than solely on the novel features of the technology. Similarly, extending the familiarization period with the device and ensuring sufficient individual interaction time could reduce usability difficulties and facilitate a more continuous experience.

In this sense, immersive VR may be particularly useful as a complementary resource alongside conventional teaching methodologies, taking advantage of its potential for three-dimensional manipulation and interactive exploration of content in which understanding spatial relationships is especially relevant. At the same time, the experience highlights the importance of evaluating such innovations using multiple indicators rather than student satisfaction alone, including objective measures of learning that can identify the conditions under which their use provides educational benefits

5.2. Limitations and future directions for improvement

The findings should be interpreted considering several methodological limitations. First, the knowledge test was not strictly psychometrically equivalent across the two teaching modalities. The block corresponding to content taught through traditional theoretical instruction comprised 15 items, whereas the block related to the immersive VR practical session included five. Although the analysis was based on

proportions of correct responses, errors, and omissions, this difference may affect the reliability and stability of the scores because each response carries proportionally greater weight in the immersive VR block. In addition, it cannot be guaranteed that the two blocks were equivalent in difficulty, content specificity, or cognitive demands.

Second, the questions corresponding to the two modalities assessed different course content. Consequently, the observed performance differences may be related not only to the modality through which the content was studied, but also to its nature, complexity, or degree of prior familiarity. The comparison should therefore be understood as preliminary rather than as a causal estimate of the effect of immersive VR relative to traditional theoretical instruction. Future studies should use equivalent content and assign it to the traditional theoretical and immersive VR modalities in a counterbalanced manner, allowing for more controlled comparisons.

Third, the availability of only five devices for groups of six to seven students made it necessary to share and rotate the equipment during the exploration phase. This circumstance may have reduced effective individual interaction time and interrupted the continuity of the immersive experience, with possible consequences for sense of presence, satisfaction, adverse symptoms, and learning.

Finally, the small sample size, recruitment from a single Speech Therapy class group, and unequal sex distribution limit the generalizability of the findings. The intervention was also conducted within a specific time slot and after previous teaching activities, circumstances that may have influenced students' fatigue, attention, and concentration.

In light of these limitations, future educational experiences should incorporate assessment instruments that are more equivalent across conditions, with comparable numbers and difficulty of items and, when possible, evidence of validity and reliability. It would also be advisable to extend the familiarization period with the device, ensure sufficient individual exposure, and examine whether a more structured practical session using guides, explicit objectives, or directed tasks facilitates the transfer of content studied through immersive VR. Finally, replication in larger samples and across different degree programs, using controlled or randomized designs, would allow more precise evaluation of the conditions under which immersive VR can contribute to learning.

6. CONCLUSIONS

The findings suggest that immersive VR is a feasible and well-accepted educational resource with a favorable tolerability profile for the study of neuroanatomical and functional content. The experience also generated a high sense of presence and high levels of satisfaction.

However, these positive indicators were not accompanied by better performance on the objective knowledge test. Given the methodological limitations of the study, these results do not allow a causal comparison between immersive VR and traditional theoretical instruction.

Overall, incorporating immersive VR into the classroom appears particularly promising as a complementary resource, provided that it is supported by appropriate instructional design and more controlled assessment procedures.

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