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Immersive Learning versus Traditional Learning in the teaching of Neuroanatomy: A qualitative study with focus groups

Heberto Romeo Priego Álvarez [1] Juan Antonio Córdova Hernández [1*] Yuliana Raquel Hernández Juárez[1]
Yurislivia Ramos Jiménez [1] Mateo Ovando Arias [1] Querubin Fernandez Quintana [1]

[1] Universidad Juárez Autónoma de Tabasco, México.
*Contact for correspondence: juan.cordova@ujat.mx

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Abstract: Medical education faces challenges in integrating immersive technologies without compromising traditional rigor. We sought to compare the effectiveness of immersive versus traditional learning in neuroanatomy for medical students. **Methodology:** A retrospective qualitative study was conducted with focus groups of 12 second-semester students at UJAT, divided into two groups. An adaptation of the CEQ analyzed six categories; data were processed using hermeneutic phenomenological analysis in *Atlas.ti* version 24. **Results:** The immersive group showed positive ratings in all categories, with greater motivation, autonomy, and enrichment. The traditional group reported negative perceptions regarding motivation, objectives, and feedback. Immersive advantages include three-dimensional understanding and autonomy, but are limited by resources and time. Instructors have a significant influence; curricular integration is required. **Conclusion/Contributions:** Immersive learning surpasses traditional learning, promoting engagement and deep understanding; it is recommended as a complement to medical education based on empirical evidence.
Keywords: Learning, immersive, virtual, education, technologies.

Aprendizaje Inmersivo versus Aprendizaje Tradicional en la enseñanza de Neuroanatomía: Un estudio cualitativo con grupos focales

Resumen: La educación médica enfrenta desafíos al integrar tecnologías inmersivas sin comprometer la rigurosidad tradicional. Buscamos comparar efectividad del aprendizaje inmersivo versus tradicional en neuroanatomía para estudiantes de medicina. **Metodología:** Estudio cualitativo retrospectivo con grupos focales de 12 estudiantes de segundo semestre en UJAT, divididos en dos grupos. Adaptación del CEQ analizó seis categorías; datos procesados con análisis fenomenológico hermenéutico en *Atlas.ti* versión 24. **Resultados:** El grupo inmersivo mostró valoraciones positivas en todas las categorías, con mayor motivación, autonomía y enriquecimiento. El grupo tradicional reportó percepciones negativas en motivación, objetivos y retroalimentación. Las ventajas inmersivas incluyen comprensión tridimensional y autonomía, pero limitadas por recursos y tiempo. Los docentes influyen significativamente; requieren integración curricular. **Conclusión/Aportes:** El aprendizaje inmersivo supera al tradicional, promoviendo compromiso profundo; recomendar como complemento en educación médica las evidencias empíricas.
Palabras clave: Aprendizaje, inmersivo, virtual, educación, tecnologías.

Aprendizagem imersiva versus aprendizagem tradicional no ensino de neuroanatomia: um estudo qualitativo com grupos focais

Resumo: A educação médica enfrenta desafios ao integrar tecnologias imersivas sem comprometer o rigor acadêmico tradicional. Buscamos comparar a efetividade do aprendizado imersivo versus tradicional em neuroanatomia para estudantes de medicina. **Metodologia:** Estudo qualitativo retrospectivo com grupos focais de 12 estudantes do segundo semestre na UJAT, divididos em dois grupos. Adaptação do CEQ analisou seis categorias; dados processados com análise fenomenológica hermenêutica no *Atlas.ti* version 24. **Resultados:** Grupo imersivo mostrou avaliações positivas em todas as categorias, com maior motivação, autonomia e enriquecimento. Grupo tradicional reportou percepções negativas em motivação, objetivos e retroalimentação. Vantagens imersivas incluem compreensão tridimensional e autonomia, mas limitadas por recursos e tempo. Docentes influenciam significativamente; requer integração curricular. **Conclusão/Aportes:** Aprendizado imersivo supera o tradicional, promovendo compromisso e compreensão profunda; recomendar como complemento na educação médica com evidência empírica.
Palavras-chave: Aprendizagem, imersivo, virtual, educação, tecnologias.

Apprentissage immersif versus apprentissage traditionnel dans l'enseignement de la neuroanatomie : Une étude qualitative avec des focus groupes

Résumé : L'éducation médicale est confrontée à des défis liés à l'intégration de technologies immersives sans compromettre la rigueur traditionnelle. Nous avons cherché à comparer l'efficacité de l'apprentissage immersif par rapport à l'apprentissage traditionnel en neuroanatomie pour les étudiants en médecine. **Méthodologie :** Etude qualitative rétrospective avec focus groups de 12 étudiants du deuxième semestre de l'UJAT, répartis en deux groupes. L'adaptation du CEQ a analysé six catégories : données traitées par analyse phénoménologique herméneutique dans *Atlas.ti* v 24. **Résultats :** Le groupe immersif a montré des évaluations positives dans toutes les catégories, avec une plus grande motivation, autonomie et enrichissement. Le groupe traditionnel a fait état de perceptions négatives en matière de motivation, d'objectifs et de feedback. Les avantages immersifs incluent la compréhension tridimensionnelle et l'autonomie, mais limitées par les ressources et le temps. Les enseignants ont une influence significative ; nécessite une intégration scolaire. **Conclusion/Contributions :** L'apprentissage immersif surpasse le traditionnel, favorisant l'engagement et la compréhension profonde ; recommander comme complément à la formation médicale avec des preuves empiriques.
Mots clés : Apprentissage, immersif, virtuel, éducation, technologies.

1. Introduction

Contemporary medical education faces the constant challenge of integrating technological innovations that optimize the teaching and learning process without compromising traditional academic rigor. Neuroanatomy, due to its three-dimensional complexity and fundamental importance in medical training, represents a particularly challenging field for both students and faculty (Suárez-Escudero et al., 2020). Traditional methodologies, based predominantly on lectures, two-dimensional atlases, and limited cadaveric dissections, have proven effective but present significant limitations for the spatial visualization of complex neurological structures.

Immersive technology, including virtual reality (VR), augmented reality (AR), and 360° videos, has emerged as a promising pedagogical alternative in the last decade. These technologies allow students to interact with three-dimensional representations of anatomical structures, manipulate them from multiple perspectives, and experience simulated clinical scenarios in controlled environments (Kalunga & Elshobosky , 2023). The three-dimensional representation of environments that incorporates visual, auditory, and kinesthetic elements offers unique opportunities to improve educational outcomes through increased engagement, enriched learning experiences, and enhanced understanding and retention of knowledge.

Recent research has demonstrated favorable results for immersive learning in medical education. Choi et al. (2021) verified the positive effects of immersive virtual environments on the learning of nursing students, while Hamilton et al. (2020) documented significant advantages of immersive VR through a systematic review, despite technological limitations in classrooms. In the Latin American context, Jaramillo et al. (2023) implemented a virtual museum for teaching neuroanatomy, demonstrating significant increases in student satisfaction and knowledge acquisition. Similarly, Castro-Gutiérrez et al. (2023) highlighted the importance of virtual laboratories in higher education in engineering, demonstrating improvements in the understanding of complex concepts.

The COVID-19 pandemic accelerated the adoption of digital educational technologies, generating both challenges and opportunities. Campuzano et al. (2021) documented the challenges faced by Mexican teachers and students during the migration to virtual environments, highlighting the need for adequate training and appropriate technological resources. This historical context has created favorable conditions for systematically evaluating the effectiveness of immersive methodologies compared to traditional approaches.

neuroeducational perspective, immersive learning artificially activates visuospatial skills and facilitates the storage of information in episodic memory through meaningful experiences (Meyer et al., 2019). Manipulating three-dimensional models of the nervous system allows students to interactively explore anatomical structures, promoting deep understanding and the development of practical skills applicable in real clinical contexts.

At the Academic Division of Health Sciences (DACS) of the Juárez Autonomous University of Tabasco (UJAT), an institution committed to educational innovation, an immersive classroom equipped with virtual reality technology has been implemented to complement the traditional teaching of neuroanatomy. This initiative represents a valuable opportunity to systematically evaluate the impact of immersive methodologies on Mexican medical training, contributing empirical evidence to the debate on the integration of educational technologies into health sciences curricula.

The objective of this work is to compare the effectiveness of immersive learning through virtual reality, augmented reality and 360° videos with traditional learning in the teaching of neuroanatomy, evaluating student perceptions on teacher teaching, clarity of objectives, development of competencies, evaluation, workloads and academic independence in second semester students of the Bachelor of Medicine and Surgery at DACS-UJAT.

2. Methodology

A qualitative study with a retrospective, observational, and descriptive design was conducted using focus groups. The methodological approach was based on Paul Ricoeur's (2001) hermeneutic phenomenological method, which focuses on lived experience, the intentionality of consciousness,

and the exploration of how language and interpretations influence our understanding of reality. This approach seeks the meaning of the text within the participant's experience, leading to a deeper understanding of human phenomena and fostering critical analysis from multiple perspectives (Lindseth & Norberg, 2021; Andrade et al., 2023).

The study population consisted of 256 students enrolled in the second semester of neuroanatomy in the Bachelor of Medicine and Surgery program at the Academic Division of Health Sciences. A non-probability sample of 12 students was selected using convenience sampling, forming two focus groups of six participants each.

Inclusion criteria - Immersive group:

- Students from group "H" who completed the neuroanatomy course using immersive methodology
- Regular attendance at sessions in the immersive classroom equipped with functional screens and virtual reality glasses
- Compliance with instructor guidelines and participation in scheduled activities

Inclusion criteria - Traditional group:

- Students from different groups in the second semester who studied neuroanatomy using traditional methodology
- Passing grades between 8 and 10
- Adaptation to the established teaching workload

Exclusion criteria - Immersive group:

- Students who did not belong to group "H"
- Irregular attendance at immersive course sessions

Exclusion criteria - Traditional group:

- Students belonging to the "H" immersive learning group
- Students who did not complete the course
- Overall average between 0 and 7

As a data collection tool data **was** used an adaptation of the Course Experience Questionnaire (CEQ), structured in six categories of analysis with specific trigger questions (Table 1).

Table 1. Analysis Categories

Analysis Category	Conceptual definition	Triggering question	Items
Teaching	Characteristics of the teaching provided by the teacher: it does motivate and promote the academic development of the students.	What is your opinion about the teacher's teaching in the subject of neuroanatomy?	-Motivates students to do their best work -Take time to comment on the students' work -He strives to understand students' difficulties -Promotes interest in the subject
Clear objectives and standards	Purposes, parameters and defined guidelines for learning.	How clear was the teacher in defining the objectives and guidelines at the beginning and throughout the course?	-Definition of the expected work level -Clarity in goals and objectives
Generic skills	Skills , knowledge, aptitudes, attitudes and resources of a person that allow them to function appropriately in any academic environment and achieve the proposed goals.	How did the teacher promote the development of students' skills, knowledge, aptitudes, and attitudes during the neuroanatomy course?	-Knowledge acquisition -Development of problem-solving skills -Development of analytical skills -Development of the ability to work in a team -Development of the ability to plan one's own work.

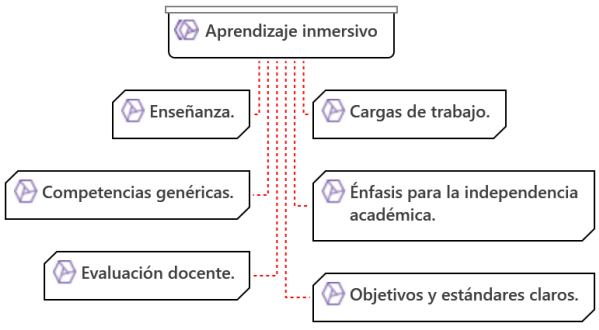
Teacher evaluation	Feedback and evaluation of the course content, as well as the teacher's learning	How did the teacher assess and provide feedback on the learning achieved during the course?	-Forms of evaluation -Forms of feedback
Workloads	Number of tasks, commitments, time commitments, and pressure exerted during the teaching-learning process.	What is your opinion about the workload during the course?	-Consideration of workloads -Extension of the syllabus -Time to understand things -Pressure on the student
Emphasis on academic independence	An approach that allows the student to work autonomously and self-directed in different ways.	How was autonomous learning fostered during the neuroanatomy course?	-Encourages the development of one's own academic interests - Learning options are presented -Discussions with teachers or tutors about learning -Various assessment options are provided.

Data collection took place during June 2024 at the facilities of the Academic Division of Health Sciences at UJAT. The principal investigator coordinated focus group sessions lasting approximately 40 minutes per group, using guided questions based on the established categories of analysis.
The process was developed in two phases: I) A 30-minute group interview with participants from the traditional learning group, generating a fluid discussion about academic experiences, and II) A similar group interview with participants from the immersive learning group, focused on experiences with immersive technologies applied to neuroscience .
The sessions were audio-recorded with the informed consent of the participants. Subsequently, the responses were transcribed verbatim in Microsoft Word 365. The transcribed testimonies were then uploaded to ATLAS.ti version 24 for qualitative analysis. Thematic coding was applied based on predefined categories of analysis, identifying patterns, convergences, and divergences in the experiences reported by both groups. Semantic networks and word clouds were generated to visualize recurring concepts and relationships between categories. Hermeneutic phenomenological analysis allowed for the interpretation of deeper meanings within the student experiences, contextualizing individual perceptions within the institutional educational framework.

Ethical considerations
All participants provided verbal informed consent before participating in the focus groups. Confidentiality was ensured by identifying participants with numerical codes in the transcripts. The study was conducted in accordance with the ethical principles of educational research.

3. Results

Figure 1 shows the semantic networks obtained through the Atlas.ti software according to the analysis categories.
Figure 1. Semantic networks



Traditional Learning Group

Teaching: Participants expressed predominantly negative perceptions of the instructor's teaching. They reported a lack of motivation, poor punctuality, and little interest on the part of the instructor: "The instructor was often late to class and didn't really care much about it" (Student 5). Feedback on group work was practically nonexistent: "He didn't make many observations, so we only got feedback from what our classmates provided" (Student 6). Students perceived that the instructor dedicated insufficient time to addressing questions and resolving conceptual difficulties.

Clear Objectives and Standards: Students expressed significant confusion regarding the course objectives and expectations: "It was always a mystery to us, not knowing what information we were supposed to retain and which data wasn't as relevant to the syllabus" (Student 3). The absence of a formal syllabus from the beginning and the lack of clarity in the recommended reading list led to academic disorganization. Participants described the course as rushed and lacking direction: "It wasn't clear what they wanted us to cover; we just went through topics and moved on to the next one..." (Student 4). This dynamic hindered the optimal acquisition of knowledge and generated uncertainty about the expected level of depth in each topic.

Generic Competencies: Students reported that the instructor did not actively encourage them to acquire knowledge outside of class or to develop effective collaborative skills. Although teamwork was the predominant methodology, participants did not perceive substantial benefits: "The whole class worked in teams with slides, so the whole group had to work together, but there wasn't much knowledge gained since everyone just learned their part of the presentation." There was an atmosphere that inhibited asking questions: "When we had a question, even a silly one, he would get annoyed, so we preferred not to ask to avoid upsetting him. Because of this, some topics weren't clear" (Student 2). Participation was perceived as competitive: "He encouraged us to learn in a very competitive way" (Student 1), creating a tense academic environment.

Teaching evaluation: The evaluation process was a significant source of confusion for students: "The evaluation method for my course was very confusing... I think some things carried more weight than others, but nothing was clearly defined. The professor might say that a certain criterion was more important one day and then change it the next" (Student 2). Evaluation criteria were modified throughout the course without clear explanation: "He established some criteria, but didn't maintain others, and at the end of the course, that affected us, I think, because some students were evaluated using the same criteria, while others were evaluated with different ones" (Student 6). Formal feedback was nonexistent, limited to superficial peer comments: "There was no feedback; the little feedback we gave each other, we did as a group, among ourselves" (Student 4). This situation led to a focus on passing the course rather than learning: "There wasn't a good approach because we were focused on passing the course and not on learning" (Student 4).

Workload : Participants agreed that workloads were minimal, with only one or two assignments per term: "The workload was minimal. The professor only assigned one task per term. And that was just for the evidence the institution required" (Student 1). Although the number of activities increased towards the end of the semester due to the incomplete syllabus, the overall pace was perceived as light and manageable: "There was no problem, because everything was at a relatively easy pace. For the last term, when he saw we wouldn't be able to finish the entire syllabus, he decided to give us a few more assignments and cover more topics than we were used to, but we were still able to manage" (Student 5). The general lack of interest in the subject allowed students to focus their efforts on courses they considered more important.

Emphasis on academic independence: Students recognized alternative learning options, particularly online classes when in-person sessions were not held: "Sometimes the classes he couldn't teach in the classroom, he held online. He would present the slides, and on a Saturday morning or weekday afternoon, we could connect, and he would leave the classes recorded" (Student 2). However, teacher-student communication was limited, a situation that, paradoxically, the participants did not perceive as entirely negative: "There was no communication from him to us, nor from us to him, but this is also relatively good because there are more important subjects. I think they

are all important, but this one in particular was much easier" (Student 6). The low demands of the subject allowed students to prioritize other courses without facing significant academic consequences.

Immersive Learning Group

Teaching: Participants consistently expressed positive feedback on the immersive teaching methodology. They highlighted the instructor's supportive and motivating environment: "I think the instructor's attitude was excellent in terms of motivating us to explore the functions and applications of the virtual reality equipment. He always showed great interest in making sure we felt comfortable" (Student 1). The instructor constantly encouraged study before and after sessions, implementing question rounds at the end of each class to check understanding: "I think the instructor motivated us to learn and helped us learn how to use the resources we had. He made an effort and ensured that there was feedback at the end on what we had learned" (Student 3). Students perceived a genuine interest from the instructor in their academic and emotional well-being: "The instructor made a real effort to ask us individually how we felt about the course, whether it was dynamic or boring, and even gave feedback at the end of the sessions" (Student 5).

Clear Objectives and Standards: At the beginning of the course, the instructor clearly established that it was an educational supplement to reinforce prior knowledge: "From the start, the instructor pointed out the objective of using the virtual classroom and mentioned that it was a supplementary course to reinforce previously acquired knowledge" (Student 1). However, during the course, some disorganization arose: "I think that the objectives for using virtual reality were well defined at the beginning. However, during the course, I think those objectives were lost because there wasn't a clear order in how to develop the topics or the classes" (Student 4). Despite this limitation, the students understood that they had to prepare beforehand to take advantage of the technological tools: "I think there was a lack of clarity, but he did say that the instruction he was giving us was a supplement, that we should read first to use the program and expand our knowledge" (Student 2).

Generic Competencies: Participants highlighted the promotion of independent learning and the development of analytical skills. The instructor suggested complementary applications compatible with personal devices, promoting continuity of learning outside of formal class time: "He always tried to motivate us to supplement what we saw in class, in our free time, with another application for phones, precisely because the equipment was somewhat individualized, and that limited teamwork" (Student 1). Three-dimensional visualization facilitated spatial understanding superior to traditional two-dimensional representations: "It definitely motivated us to investigate on our own and it was very helpful to have the technology and see a structure in three dimensions, because many images we saw in books are nothing like how they appear in real life" (Student 4). Students valued the autonomy they developed: "I feel that it greatly encouraged autonomy and that we simply supplemented the material with images that were more useful than seeing them directly from a book" (Student 5).

Teacher Evaluation: Given the supplementary nature of the course, traditional formal assessments were not implemented. Students expressed that this absence left the process incomplete: "There were no general assessments or a specific conclusion. In the end, we wrote down our experience, and the professor asked questions throughout the sessions, but I feel like it lacked closure" (Student 5). However, they acknowledged alternative forms of assessment: "There was a television that had a program with multiple quizzes, and occasionally at the end of class, we would do the assessment it contained; we graded ourselves. It was never a strict evaluation format from the professor; it was more of a type of self-assessment" (Student 1). The professor conducted continuous assessment through individual questioning during the sessions: "The professor would make rounds during the class while the equipment was being used and ask about what you were seeing, requesting feedback and an explanation of what you were observing" (Student 6).

Workload: Participants agreed that the workload was not severe, although the pace of the course felt rushed due to the limited time available: "At no point were we overwhelmed with activity, but I think

the time was limited, precisely because of the lack of equipment, and it would have been optimal, perhaps, to include another day of practice during the week" (Student 1). The absence of a formal, structured syllabus limited the potential learning: "I feel that the workload was light, and I think that if a proper syllabus had been followed, the impact of the learning would have been greater" (Student 3). The extensive course content led to a fast pace: "The large number of topics made the pace of the course fast and there wasn't enough time to cover all the topics; it also meant that the topics were covered in a rushed manner" (Student 5). Nevertheless, the students perceived a sense of responsibility for studying content that they would later apply with immersive tools.

Emphasis on academic independence: Self-directed learning was a central element of the immersive course. Students reported that the complementary nature of the immersive classroom motivated prior preparation and subsequent study: "Self-directed learning predominated during the virtual reality course" (Student 1). The instructor provided multiple resources and technological tools: "The professor encouraged us to be independent, providing us with different information, such as the virtual reality program he used. I didn't know that program, and thanks to the professor, I was able to discover it. He also showed 360 videos" (Student 2). The dynamic and interactive nature of the sessions sparked intrinsic curiosity: "During the classes, the professor always made recommendations about where to find information and also about other applications we could use at home, and above all, the dynamic nature of the class sparked curiosity about the topics" (Student 4). The students appreciated the diversity of learning options provided: "During the course he mentioned other applications that we could use when we didn't have the Oculus , I think that in this way and also by showing the videos, he made us take the initiative to investigate the topic further" (Student 3).

4. Discussion

This study reveals substantial differences between traditional and immersive learning methodologies in neuroanatomy instruction, with significant advantages for the immersive approach across multiple pedagogical dimensions. The findings support the hypothesis that implementing virtual reality, augmented reality, and 360° video technologies can positively transform the educational experience in the health sciences.

Teacher motivation and the learning environment emerged as key factors in the student perceptions of both groups. While the traditional group reported teacher demotivation, tardiness, and disinterest, the immersive group highlighted pedagogical commitment, constant feedback, and genuine interest in student well-being. These findings are consistent with recent research that underscores the importance of the teacher's role as a facilitator in educational technology environments (Sandralegar et al., 2024). Technology alone does not guarantee better results; it requires intentional pedagogical integration and an active teacher presence that guides, motivates, and provides feedback on the learning process.

The three-dimensional representation of neuroanatomical structures constituted a crucial pedagogical advantage of immersive learning. Students reported that immersive visualizations enabled them to understand complex spatial relationships more effectively than traditional two-dimensional atlas representations. Kalunga and Elshobosky (2023) have noted that VR presents unique opportunities to improve educational outcomes through increased engagement, enriched learning experiences, and enhanced knowledge comprehension and retention. Our qualitative findings support these assertions, documenting student perceptions of greater conceptual understanding and spatial visualization ability through immersive technologies.

Academic autonomy and self-directed learning showed notable differences between the two groups. The immersive group reported significant development of academic independence, motivated by the complementary nature of the course and the diversity of technological resources provided.

Conversely, the traditional group reported limited teacher-student communication and restricted learning options, although paradoxically some students valued this situation as it allowed them to prioritize other subjects. This finding suggests that an excessively light workload and a lack of academic rigor can be counterproductive to deep learning, a topic that warrants further investigation. Assessment proved problematic in both groups, albeit for different reasons. The traditional group faced confusion due to inconsistent and changing assessment criteria throughout the course, generating uncertainty and focusing efforts on passing rather than learning. The immersive group, by its very nature, lacked formal assessment, which students perceived as a limitation that left the process incomplete. These findings underscore the importance of clear, consistent assessment systems aligned with learning objectives, regardless of the pedagogical methodology employed. Herrington and Panesar-Aguilar (2022) reported that 95% of students participating in immersive learning simulations reported that their learning objectives were met "to a large extent" or "to a great extent," highlighting the importance of establishing clear objectives from the outset.

The results obtained are consistent with recent research in the Mexican context. Priego et al. (2023) concluded that educational intervention with immersive technology was a significant incentive for students at the same institution. Jaramillo et al. (2023) demonstrated that immersion in a digital neuroanatomy museum increased learning with a high degree of student satisfaction. These studies reinforce the validity of our qualitative findings and suggest that immersive learning can be successfully implemented in diverse Latin American educational contexts.

A significant limitation of immersive learning identified in this study was the individualization of the process due to the limited number of technological devices. Students reported that this situation limited collaborative work, although the instructor implemented compensatory strategies by projecting content for group discussion. This finding highlights the logistical and economic challenges of implementing immersive technologies at an institutional scale. Future research should evaluate hybrid models that combine individual experiences with immersive devices and collaborative activities without technology to optimize both deep learning and the development of interprofessional skills.

Limited time was another significant constraint of the immersive course. Students indicated that, although the pace was fast, they would have appreciated more time to practice with the technology. This observation suggests that integrating immersive learning into the curriculum requires adequate time planning, possibly by distributing immersive experiences across multiple sessions rather than concentrating them into short, intensive periods.

The lack of a structured, formal syllabus in the immersive course led to a perceived disorganization among the students. Although they understood the course's complementary nature, they expressed that a clear syllabus would have maximized the use of the available technologies. This finding underscores the importance of rigorous pedagogical planning, even in contexts of technological innovation. Immersive technologies must be integrated within well-defined curricular frameworks, with specific objectives, logical thematic sequences, and alignment with professional profile competencies.

From a neuroeducational perspective, immersive learning in neuroanatomy offers fundamental theoretical advantages. Meyer et al. (2019) found that prior instruction in immersive virtual reality reduced cognitive overload, leading to positive effects on learning new techniques. Manipulating three-dimensional models activates visuospatial skills and facilitates the storage of information in episodic memory through meaningful and emotionally relevant experiences. Our qualitative findings suggest that students in the immersive group experienced this type of deep learning, demonstrating intrinsic curiosity, sustained motivation, and a desire to continue exploring content outside of formal class time.

The institutional context also influenced the reported experiences. The Juárez Autonomous University of Tabasco has made significant investments in educational technology infrastructure,

creating immersive classrooms equipped with virtual reality devices, interactive displays, and specialized software for health sciences. This institutional investment reflects a commitment to pedagogical innovation that should be recognized and continued. However, as documented by Campuzano et al. (2021), the effective implementation of educational technologies requires not only physical infrastructure but also ongoing teacher training, adequate technical support, and systematic curriculum development.

An important consideration is that the two groups in this study had qualitatively different experiences, not only due to the pedagogical methodology but also because of specific teacher characteristics. The traditional group encountered a teacher with limitations in motivation, organization, and feedback, while the immersive group had a committed and enthusiastic teacher. This introduces a confounding variable that must be acknowledged: it is difficult to determine what proportion of the observed differences is due to the pedagogical methodology per se versus individual teacher characteristics. Future research should employ experimental designs that control for this variable, ideally with the same teacher implementing both methodologies or with multiple teachers applying each approach.

Finally, it is important to contextualize these findings within the broader debate on educational innovation in medicine. As Elmore (2019) points out, educational innovation can manifest itself at various levels: structural, curricular, methodological, professional, and socio-political. Immersive learning in neuroanatomy represents a methodological innovation that can catalyze transformations at other levels. However, for this innovation to be sustainable and scalable, it must be systematically integrated into curricular structures, accompanied by professional development for faculty, and supported by long-term institutional policies.

This qualitative study demonstrates significant advantages of immersive learning over traditional learning in the teaching of neuroanatomy, particularly in terms of student motivation, development of academic autonomy, spatial understanding of complex anatomical structures, and satisfaction with the educational experience. Students who participated in the immersive course reported consistently more positive perceptions across all evaluated categories, highlighting the pedagogical effectiveness of virtual reality, augmented reality, and 360° video technologies when implemented with genuine teacher commitment and appropriate curriculum planning.

Immersive learning allowed students to interact with three-dimensional models of neuroanatomical structures, providing more dynamic, participatory, and clinically realistic learning experiences than traditional methodologies based on lectures and two-dimensional atlases. The enhanced spatial visualization, combined with the ability to manipulate and explore structures from multiple perspectives, facilitated deep conceptual understanding and long-term knowledge retention.

Academic autonomy and self-directed learning were particular strengths of the immersive approach. Students demonstrated greater intrinsic motivation to study before and after sessions, explored supplementary resources suggested by the instructor, and developed their own criteria for delving deeper into topics of individual interest. This academic independence contrasts sharply with the experience of the traditional group setting, where the lack of rigor and structure generated widespread disinterest in the subject matter.

However, the study also identified significant limitations in the current implementation of immersive learning. The limited number of technological devices restricted collaborative work, the available time proved insufficient to cover the extensive curriculum content, and the absence of a structured formal syllabus led to a perceived lack of organization. These limitations underscore that technology alone does not guarantee educational excellence; it requires careful integration within well-defined curricular frameworks, with clear objectives, adequate time planning, and systematic evaluation of outcomes.

Assessment emerged as a problematic aspect in both pedagogical approaches. The traditional group faced inconsistent and arbitrarily modified assessment criteria, while the immersive group lacked a

formal assessment to conclude the learning process. Regardless of the pedagogical methodology, assessment systems must be clear, consistent, aligned with learning objectives, and provide meaningful feedback to guide ongoing student development.

The teacher's role proved fundamental in both groups. Differences in pedagogical commitment, student motivation, feedback, and curriculum organization between the two participating teachers significantly influenced student perceptions, potentially confounding effects attributable to the pedagogical methodology per se versus individual teacher characteristics. Future research should employ experimental designs that control for this variable to isolate specific effects of immersive technologies.

From an institutional educational policy perspective, this study supports continued investment in technological infrastructure for medical education, but simultaneously underscores the need to accompany these investments with rigorous teacher training, systematic curriculum development, adequate technical support, and ongoing evaluation of educational outcomes. Immersive learning should not be implemented as a substitute for traditional learning, but rather as a strategic complement that enriches, diversifies, and deepens educational experiences when thoughtfully integrated within coherent academic programs.

The practical implications of these findings suggest that medical education institutions should: (1) invest in immersive technologies as a complement to, not a replacement for, effective traditional methodologies; (2) train faculty in the pedagogical use of these technologies, not just their technical operation; (3) develop formal curricula that integrate immersive experiences with specific learning objectives and appropriate assessments; (4) allocate sufficient curricular time for students to fully utilize the capabilities of available technologies; and (5) establish assessment mechanisms that measure not only student satisfaction but also objective learning outcomes, such as conceptual understanding, long-term retention, and clinical application of knowledge.

Future research should employ mixed-methods designs that combine qualitative data on student experiences with quantitative assessments of learning outcomes, ideally using randomized experimental designs that control for confounding variables . It would be particularly valuable to evaluate long-term knowledge retention, transfer of learning to real-world clinical settings, and effects on the development of clinical reasoning and diagnostic decision-making. Longitudinal studies that follow students throughout their medical training and subsequent professional practice could determine whether the benefits of immersive learning observed in educational settings translate into improvements in clinical skills and professional performance.

5. Conclusion

Immersive learning in neuroanatomy demonstrated considerable advantages over the traditional method, promoting greater student engagement, active participation, development of autonomous criteria, and three-dimensional understanding of complex anatomical structures, supporting its implementation as a complementary pedagogical strategy in medical education.

The study contributed empirical evidence to the growing body of research supporting the pedagogical value of immersive learning in medical education, specifically in neuroanatomy. The qualitative findings demonstrated that, when implemented with genuine faculty commitment, appropriate curriculum planning, and sufficient technological infrastructure, immersive learning can positively transform the student educational experience, fostering greater engagement, academic autonomy, and a deeper understanding of complex anatomical content. These technologies represent promising tools for 21st-century medical education that deserve continued investment, rigorous research, and thoughtful implementation within coherent pedagogical frameworks.

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Heberto Romeo Priego Álvarez (25%): Conceptualization, Methodology
Juan Antonio Córdova Hernández (25%): Resources
Yuliana Raquel Hernández Juárez (20%): Original draft.
Yurislivia Ramos Jiménez (20%): Validation and Visualization.
Mateo Ovando Arias (5%): Writing – revision and editing
Querubín Fernández Quintana (5%): Supervision.

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