Analysis of an Immersive Virtual Environment in Education: Perceptions of Usability, Functionality, Interactivity, and Educational Impact Across Genders

Benjamín Maraza-Quispe*, Manuel Alfredo Alcázar-Holguin, and Walter Choquehuanca-Quispe

Faculty of Education Sciences, Universidad Nacional de San Agustín de Arequipa, Arequipa, Peru
Email: bmaraza@unsa.edu.pe (B.M.-Q.); malcazarh@unsa.edu.pe (M.A.A.-H.); wchoquehuanca@unsa.edu.pe (W.C.-Q.)
*Corresponding author

Manuscript received August 18, 2024; revised October 10, 2024; accepted November 1, 2024; published February 14, 2025

***Abstract*—The objective of the research was to analyze perceptions of an immersive virtual environment in terms of usability, functionality, interactivity, motivation, educational content, and educational impact across genders in the teaching-learning processes of human anatomy and physiology at a university in Peru. A quantitative approach was used, with a pre-experimental, descriptive, and cross-sectional design. The sample included 44 university students (20 men and 24 women) who used the virtual environment as part of their learning process. A structured questionnaire based on a Likert scale was developed to evaluate dimensions such as usability, functionality, interactivity, motivation, educational content, and gender-related impact. The collected data were compared across genders to identify differences in perceptions. The results showed that the immersive virtual environment was positively perceived by students, with scores ranging from 3.5 to 4.2 in terms of usability, functionality, interactivity, motivation, and educational content. Women rated the environment more favorably than men, highlighting the need to adjust certain design aspects to better meet user expectations. In conclusion, the immersive virtual environment proved to be an effective tool for improving student engagement and learning experiences, significantly contributing to the development of motivation. However, adjustments in its design are needed to maximize its effectiveness and ensure a more equitable and optimal educational experience for all users.**

***Keywords*—immersive virtual environment, teaching, learning, usability, functionality, interactivity, motivation, educational content**

I. Introduction

The use of Immersive Virtual Environments (IVE) in education offers a highly motivating, optimal, and high-quality learning experience due to its ability to create educational experiences that engage multiple senses, promote active interaction, and provide immediate feedback [1]. These environments allow students to immerse themselves in realistic scenarios where they can experiment, practice, and apply knowledge in a safe and controlled context, facilitating meaningful and lasting learning [2].

The problem addressed in this research focuses on improving the effectiveness of the teaching-learning process in contexts where traditional education fails to meet the demands of meaningful and personalized learning. Specifically, the teaching of human anatomy and physiology faces the challenge of providing practical and applied experiences to students that are safe and effective. The limitations of physical laboratories, such as resource scarcity, high costs, and risks associated with experimentation, have created a gap in educators' ability to offer immersive and realistic learning experiences. This research aims to address these limitations by using immersive virtual environments, offering an innovative solution to enhance the quality, motivation, and effectiveness of learning.

Immersive environments, such as those based on Virtual Reality (VR) and Augmented Reality (AR), have been shown to significantly increase student motivation by making learning more interactive and engaging. According to Korowajczenko [3], virtual laboratory simulations in scientific education not only complement traditional learning but also enhance student engagement and motivation, leading to better academic outcomes. Additionally, the immediate and immersive feedback provided by these environments reinforces students' interest, making the learning process more dynamic and rewarding [4].

Es allow students to learn at their own pace, offering a space where they can experiment without the risk of making costly mistakes. The ability to practice repeatedly in a controlled environment optimizes knowledge retention and skill development. Castillo [5] emphasizes that creating immersive learning experiences using XR (extended reality) technologies enables educators to design highly personalized and adaptive activities that cater to individual student needs, promoting more effective and focused learning.

The quality of learning is significantly enhanced in immersive environments due to the combination of visual, auditory, and tactile elements that facilitate the understanding and retention of complex concepts. García and Garzón [6] found that augmented reality improves interaction, motivation, concentration, and knowledge retention, leading to high-quality learning. This type of multimodal learning allows students to build knowledge more deeply and connectedly, which favors the transfer of what is learned to new situations.

The problem that motivated this research lies in the need to improve the effectiveness of the teaching-learning process in contexts where traditional education fails to meet the demands of meaningful and personalized learning. The teaching of human anatomy and physiology, like many other scientific disciplines, faces the challenge of providing students with practical and applied experiences that are both safe and effective. However, the limitations of physical laboratories, such as limited resources, high costs, and the risks associated with experimentation, have created a gap in educators' ability to offer immersive and realistic learning

experiences. This gap in traditional education has led to the exploration of Immersive Virtual Environments as an innovative solution to improve the quality, motivation, and effectiveness of learning, effectively addressing current limitations and providing a space where students can learn interactively and personally.

Immersive feedback refers to an advanced approach that uses interactive and multisensory technologies, such as augmented and virtual reality, to provide more effective and engaging feedback in educational and professional processes. This concept has evolved from traditional feedback, which was considered unidirectional and teacher-centered, to a dialogical model where bidirectional interaction and student self-regulation are essential [7–9]. The implementation of technologies like Intel's RealSense in educational and health applications exemplifies how these tools can significantly enhance learning by enabling practical and precise interaction with content [10]. Additionally, a dynamic and continuous approach to feedback is suggested, including practical examples and group activities to promote autonomous and effective learning [11]. Immersive feedback significantly improves the learning experience and student motivation in immersive virtual learning environments by offering real-time, contextualized interactions that promote deeper understanding and active engagement with educational content. This type of feedback, which may include visual, auditory, and haptic elements integrated into the virtual environment, facilitates adaptive and personalized learning, helping students identify their strengths and areas for improvement immediately and specifically [12]. Despite its benefits, a critical issue in developing motivation in these learning experiences lies in the need to balance technological complexity with accessibility and ease of use, ensuring that all students can benefit equally from these advanced tools without feeling overwhelmed [13]. Research indicates that overly complex or poorly designed feedback can lead to frustration, reducing motivation and interest in learning [11]. Therefore, it is essential to design immersive feedback systems that are not only intuitive and accessible but also maintain an appropriate balance between the challenge and support offered to students [14].

Developing motivation in learning experiences faces several critical issues, including a lack of personalization, inadequate design of learning environments, and insufficient integration of intrinsic and extrinsic motivational elements. The lack of personalization can result in learning activities that do not resonate with students' individual interests, diminishing their motivation [15]. Poorly designed learning environments that do not provide adequate challenges or opportunities for success can lead to demotivation, especially when students do not find the content relevant or sufficiently stimulating [16]. Additionally, an excessive reliance on extrinsic motivation, such as external rewards, can undermine intrinsic motivation, which is crucial for long-term engagement with learning [17]. The effective integration of gamification and constructive feedback is vital to maintaining student interest and motivation, ensuring that learning is both effective and enjoyable [18].

This study offers a significant contribution by exploring the use of immersive virtual environments for teaching human anatomy and physiology, areas where the integration of immersive technologies is still in development. Unlike previous research focused on the use of traditional technologies or basic simulations, this study analyzes students' perceptions of the usability, functionality, interactivity, motivation, and educational content of an immersive environment, highlighting not only the visual interaction but also the impact of the environment on motivation and meaningful learning.

A. General Objectives

The overall objective of this research is to analyze the effectiveness of an immersive virtual environment in the teaching-learning process of human anatomy and physiology, evaluating students' perceptions of different dimensions that impact their educational experience.

B. Specific Objectives

- Evaluate students' perceptions regarding the usability, functionality, interactivity, motivation, and gender-based impact of the virtual learning environment.
- Analyze the impact of the immersive learning environment on usability, functionality, interactivity, motivation, and gender-based impact.
- Identify potential differences in perceptions based on the students' gender and its influence on the future use of the environment.

This research contributes to the educational field by providing evidence on the use of immersive technologies in science education, offering empirical data on how these technologies can enhance motivation, interactivity, and comprehension in complex learning environments. It also provides a foundation for optimizing the implementation of virtual reality tools in higher education, particularly in disciplines requiring three-dimensional visualization and practical experience, such as anatomy.

The research problem is based on the gap between current pedagogical needs and the limitations of traditional teaching methods in sciences, such as anatomy, where access to physical laboratories and educational resources is often restricted due to high costs and associated risks. Previous studies have demonstrated the potential of virtual environments to improve information retention and student engagement, but few have focused on measuring students' perceptions of the usability and functionality of these environments, as well as their impact on motivation. This gap in the literature justifies the need to study how immersive virtual environments can meet these pedagogical needs, offering an effective and scalable alternative to conventional methods.

II. Literature Review

The research by Knierim *et al*. [19] significantly contributes to immersive learning by exploring the concept of immersive feedback, characterized by an intense and engaging experience that involves multiple senses and creates a strong sense of presence in virtual environments. This type of feedback is particularly effective in Virtual Reality (VR) and Augmented Reality (AR), where it provides users with a more realistic and dynamic learning experience. A notable

example is its application in virtual laboratory simulations, where students can conduct experiments in a controlled environment and receive immediate feedback on their actions, enriching their understanding of scientific concepts and improving interaction with educational content. This approach not only enhances the realism of learning activities but also boosts educational engagement and effectiveness.

According to the research by Cabiria [20], in recent decades, educators have used technologies such as television and the Internet to develop and deliver course content. More recently, another technology has emerged that could change education as it is currently practiced. Augmented reality merges manipulable digital images into real-world spaces in real time. The technologies used to create augmented environments already exist in the mass market and have begun to appear in various fields, including education. Augmented reality can be integrated into a constructivist design, allowing students to explore objects and locations based on their learning needs, enhancing engagement and learning outcomes.

The research by Tsirulnikov *et al*. [21] contributes to the field of immersive learning by demonstrating that gamified learning interventions, specifically through virtual laboratory simulations with head-mounted display technology, can significantly improve student motivation and learning outcomes in higher education. The study results, based on a mixed-methods approach, showed that participants scored better on post-simulation tests and reported high levels of motivation and engagement. Ninety-one percent of students considered virtual reality simulation a valuable complement to traditional teaching modalities, underscoring the potential of these technologies to enrich scientific education.

The research by Cevikbas *et al*. [22] contributes to immersive learning by conducting a systematic review of the impact of Augmented Reality (AR) and Virtual Reality (VR) technologies in mathematics education, an area with mixed and still unclear results. The study identifies research trends and highlights AR/VR's potential to enhance socio-emotional, cognitive, and pedagogical development in mathematics learning, especially in topics such as geometry and students with learning disabilities. However, it also points out significant challenges, such as technological failures, costs, and health issues, that limit its effective implementation in the classroom. This review provides evidence of AR/VR's benefits and drawbacks and suggests directions for future research in the field.

The research by Meccawy [23] contributes to immersive learning by offering a roadmap for educators interested in implementing extended reality (XR) technologies, including Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR) in education. Although these technologies have proven beneficial for learners, the study highlights the complexity of creating XR educational tools, noting that the adoption of these technologies may face significant delays or challenges. By examining a wide range of sources, [23] identifies key themes and critical factors that should be considered to effectively introduce immersive learning experiences, providing valuable guidance for overcoming barriers to XR implementation in the classroom.

The research by Alzahrani [24] significantly contributes to immersive learning by systematically reviewing the use of Augmented Reality (AR) in e-learning contexts. This study identifies and evaluates both the benefits and challenges of adopting AR in education. Key benefits include support for kinesthetic, collaborative, remote, and student-centered learning, as well as improvements in motivation, engagement, interactivity, and knowledge retention. However, important challenges were also identified, such as information overload, lack of technological experience, teacher resistance, technological complexity, and associated costs. This analysis offers a balanced view of the opportunities and barriers that AR presents in e-learning, providing a basis for future research and improvements in its educational implementation.

The research by Hanggara *et al*. [25] highlights the positive impact of Augmented Reality (AR) on developing critical thinking skills among secondary school students. Using a quasi-experimental design, the study showed that students who participated in AR-based math learning games significantly improved their critical thinking skills compared to those who followed traditional teaching methods. This finding underscores the benefits of integrating AR into education, not only to make learning more interactive and engaging but also to strengthen crucial cognitive skills. The results suggest that AR can be an effective tool for fostering critical thinking, encouraging educators and curriculum developers to adopt this technology in their educational practices.

The research by Fahmi *et al.* [26] contributes to immersive learning by developing and validating a virtual reality laboratory for teaching the law of inheritance of traits to improve students' technological literacy. Using a rigorous development model, the educational media created were evaluated as highly valid, practical, and effective. The study results, with an Analysis of Variance (ANCOVA) significance value of 0.000, demonstrate that using virtual reality in this context significantly improves students' technological literacy. This contribution underscores the potential of virtual reality not only to teach complex scientific concepts but also to strengthen fundamental technological skills in students.

The research [27] contributes to medical education by demonstrating that Augmented Reality (AR) holographic models are as effective as traditional teaching methods in anatomy, such as the Peer Teaching Program (PTP), in improving short-term learning. This technology enables an interactive and accessible remote learning experience, facilitating the development of visuospatial skills essential for understanding complex anatomical structures. Furthermore, it offers a scalable and cost-effective solution for institutions with limited access to dissection labs, thus contributing to the evolution of anatomy teaching in digital environments. The research [28], acceptance of Augmented Reality Technology Integrated with E-Worksheet in The Laboratory Learning" contributes to education by exploring the integration of Augmented Reality (AR) with e-worksheets in engineering courses, specifically focusing on electrical machines. The study highlights that AR enhances students' understanding of complex concepts through interactive, visual, and immersive experiences. It also identifies key factors such as perceived ease of use and perceived usefulness, which significantly

influence students' positive attitudes towards adopting AR in their learning process, offering valuable insights for improving educational strategies in engineering fields. The research [29] contributes to education by demonstrating how Augmented Reality (AR) enhances the continuity of learning in virtual environments during the COVID-19 pandemic. The study reveals that AR is highly versatile, applicable across various engineering specialties, and not limited to traditional hands-on subjects. AR promotes deeper engagement, improves learning effectiveness, and increases student motivation, making it a valuable tool for virtual education in times of limited physical interaction

According to Nielsen [30], usability is a key aspect to ensure that users can interact effectively with virtual environments. The functionality of an educational environment must guarantee that students can complete activities effectively [31]. Likewise, Deci andRyan [32] highlights those environments fostering intrinsic motivation increase student engagement. Laurillard [33] points out that well-designed educational content is essential for promoting meaningful learning.

Interactivity refers to the level of interaction between students and the virtual environment. Motivation measures the extent to which the environment stimulates students' interest and participation. Educational content evaluates the clarity and relevance of the educational material in the environment. Educational impact across genders analyzes the differences in the perception of these aspects between men and women, determining whether the environment affects each gender differently in terms of their learning experience [20].

III. Methodology

A. Research Design

The research was conducted using a quantitative approach, appropriate for analyzing students' perceptions of the immersive virtual environment used for teaching human anatomy and physiology. To effectively address the main variables of the study (1. usability, 2. functionality, 3. interactivity, 4. motivation, 5. educational content, and 6. impact of cross-gender education), a descriptive pre-experimental cross-sectional design was employed. This design was chosen because it allows for data collection at a single point in time without manipulating independent variables, making it suitable for the analysis of perceptions and attitudes without altering the teaching-learning context.

This methodological approach allowed us to identify patterns and trends in how students interact with the immersive environment, providing a clear understanding of how this type of technology can influence the learning of complex concepts such as anatomy and physiology. The choice of a cross-sectional design was key to obtaining an accurate snapshot of student perceptions, providing a solid foundation for future studies with a more experimental or longitudinal focus.

By focusing on data collection at a single point in time, this methodological design was the most appropriate to capture students' perceptions without the interference of external factors or the experimental manipulation of variables.

B. Population and Sample

The population consisted of 200 university students in the eighth semester of the education program, from which 44 students (20 male and 24 female students) were selected through non-probabilistic convenience sampling. Inclusion criteria such as willingness to participate, enrollment in the eighth semester, and basic computer skills were considered, and those who did not meet these inclusion criteria were excluded from the sample.

C. Data Collection Techniques and Instruments

The research utilized a self-developed structured questionnaire, based on a 5-point Likert scale, as the primary data collection technique, with the aim of analyzing students' perceptions of an immersive virtual environment. The questionnaire included items measuring various dimensions: usability (ease of use of the environment), functionality (the environment's ability to carry out educational activities), interactivity (level of interaction between students and the environment), motivation (degree of motivation when using the environment), and educational content (clarity and structure of the content on anatomy and physiology). These techniques are aligned with the objective of evaluating the effectiveness and usability of the immersive environment in the teaching-learning process.

To ensure the validity of the instrument, an evaluation was conducted by a panel of academic research experts, who reviewed and validated the content to ensure that the evaluated dimensions adequately represented the key constructs within the context of the study. The reliability of the instrument was verified through the calculation of Cronbach's alpha, which demonstrated high internal consistency, confirming the reliability of the measurements obtained. The test results indicated that the instrument is both valid and reliable for assessing digital competencies and research skills in the academic setting.

The data collection instrument used in this study is available at the following link: *https://bit.ly/4dLLhSf*. This structured questionnaire measures several key dimensions, including usability, functionality, interactivity, motivation, and educational content. Regarding the interactivity dimension, the data was obtained through direct observation techniques during the immersive virtual environment sessions. We used an observation rubric to assess the interaction between students and the environment, as well as between the students themselves, ensuring a precise evaluation aligned with the nature of this variable. As for the impact of cross-gender education dimension, the data was obtained based on the analysis of the collected data.

To quantitatively measure each variable in the research method, a structured questionnaire with a 5-point Likert scale was used, covering the following dimensions:

- Usability: Assessed through ease of use and interaction with the interface. It includes indicators of clarity, navigation, and response speed of the virtual environment.
- Functionality: Determined by the environment's capacity to facilitate educational activities. The utility of tools and the effectiveness of feedback were observed.
- Interactivity: Measured through the interaction between

students and the environment, with items evaluating collaboration, natural interaction with objects, and immediacy of feedback.
- Motivation: Quantified based on students' interest and engagement, with questions on the appeal and involvement in learning.
- Educational Content: Assessed by the structure and clarity of information, especially in the context of anatomy and physiology.
- Educational Impact Across Genders: Compared using variance analysis to detect significant differences in perceptions between males and females.

Each variable was evaluated in terms of validity through expert review, and reliability using Cronbach's alpha coefficient (0.973), confirming high internal consistency and reliability in the measurements

The measurement indicators for each dimension are listed below:

1) Usability dimension

- The virtual environment interface is easy to use.
- I find it easy to navigate through the different areas of the virtual environment.
- The layout of the elements on the screen is clear and understandable.
- The virtual environment responds quickly to my actions.
- I did not experience any technical issues while using the virtual environment.

2) Functionality dimension

- The tools available in the virtual environment are suitable for the proposed activities.
- I was able to complete all tasks without difficulty using the environment's functionalities.
- The feedback provided by the virtual environment is useful and relevant.
- The functions of the virtual environment allow me to complete activities effectively.
- I did not encounter any malfunctions in the virtual environment's functions during its use.

3) Interactivity dimension

- The activities in the virtual environment encourage interaction among participants.
- The virtual environment allows for effective communication with other students.
- The tasks assigned in the virtual environment require collaboration and teamwork.
- I can interact naturally with objects and characters in the virtual environment.
- The feedback I receive during the activities is immediate and useful.

4) Motivation dimension

- Participating in activities within the virtual environment is motivating for me.
- The virtual environment makes learning more interesting.
- I feel more engaged in learning when I use the virtual environment.
- Using the virtual environment encourages me to learn more about the subject.
- I would prefer to use the virtual environment for other learning activities in the future.

5) Educational content dimension

- The educational content about the human body is well-structured and easy to understand.
- The role-playing scenarios provide accurate and detailed information about human anatomy and physiology.
- The activities in the virtual environment help to better understand the functioning of body systems (digestive, circulatory, respiratory, nervous, immune).
- The role-playing games promote a deeper understanding of how different body systems interact.
- The information provided during the role-playing activities aligns with the established learning objectives.

6) Gender impact dimension

- The gender impact is analyzed to identify if there are significant discrepancies in the evaluations of key variables such as usability, functionality, interactivity, motivation, and educational content between male and female students.
- This indicator is relevant because it helps to understand whether a learning environment benefits or affects students differently based on their gender.

D. Procedure

- Implementation of the Virtual Environment: An immersive virtual environment was set up for teaching human anatomy and physiology. Students participated in activities within this environment, including role-playing and interactive simulations.
- Questionnaire Administration: After the experience with the virtual environment, students completed the designed questionnaire. The average time to complete the questionnaire was approximately 20 minutes.
- Data Analysis: The collected data was processed and analyzed using statistical software. Frequencies, means, and standard deviations were calculated for each item, and comparisons between genders were made to detect possible differences in student perceptions.

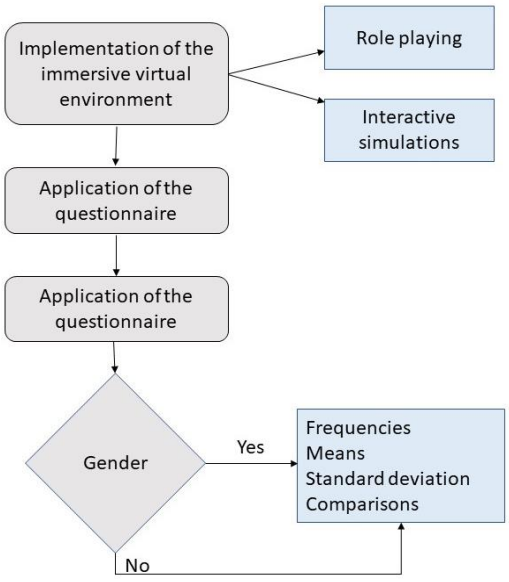

Fig. 1. Procedure followed for data collection.

Fig. 1 shows the procedure used: The implementation of the immersive virtual environment utilized role-playing, where students assumed anatomy-related roles, and interactive simulations that allowed the exploration of 3D models of the human body. These activities were key to evaluating the study's variables: the usability and functionality of the environment were measured through effectiveness and ease of use; interactivity was assessed by observing student interactions with the environment; motivation and educational content were analyzed through questionnaires, and the impact of cross-gender education was compared using statistical analyses to identify differences in perceptions between men and women.

E. Appearance of the Immersive Virtual Environment Provided for Learning

Fig. 2 shows screenshots detailing the development of the virtual environment, which was created using the platform https://www.cospaces.io. Additionally, validity tests have been conducted through evaluations by subject matter experts and virtual environment design specialists, and its reliability has been confirmed using the Cronbach's Alpha coefficient, yielding satisfactory results that ensure its effectiveness as a teaching tool.

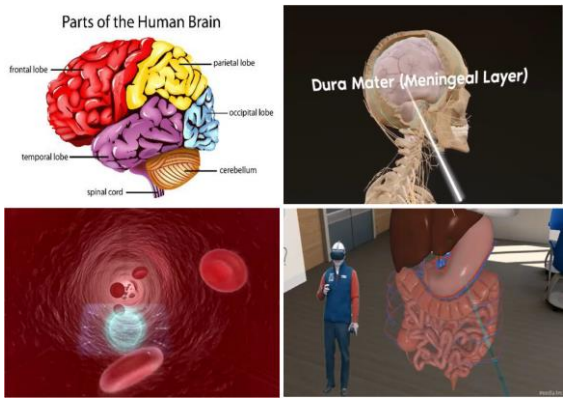

Fig. 2. Appearance of the immersive virtual environment provided for learning.

IV. Data Collection and Analysis

The data analysis in this research was conducted in a detailed, multi-stage process, ensuring clear alignment with the objectives of evaluating students' perceptions of the immersive virtual environment. First, an initial descriptive analysis was performed, calculating frequencies, means, and standard deviations for each of the questionnaire items. This step helped identify general trends in students' responses, providing a clear view of the consistency and variations in their perceptions. The evaluated dimensions included usability, functionality, interactivity, motivation, educational content, and gender impact, which are fundamental for understanding the overall student experience.

To identify significant differences between groups, Analysis of Variance (ANOVA) was employed, a robust statistical technique that allowed the detection of variations in perceptions between male and female students. This approach was crucial in exploring whether there were discrepancies in how students of different genders evaluated the virtual environment, thus fulfilling the objective of investigating differentiated perceptions based on demographic variables.

Additionally, the Chi-square test was applied to compare response proportions between genders on specific aspects. This test was key in identifying significant differences in items such as the arrangement of on-screen elements and the preference for future use of the environment, critical areas for improving user experience and ensuring that the environment is inclusive and effective for all students.

The use of these advanced techniques not only provided a deep understanding of general perceptions but also identified specific areas in need of improvement. This facilitated a comprehensive evaluation of the immersive environment's effectiveness in terms of its educational impact and its ability to engage students in an interactive and meaningful learning process.

Additionally, Analysis of Variance (ANOVA) was employed to identify significant differences among student groups. The internal reliability of the questionnaire was also considered by calculating the Cronbach's Alpha coefficient.

Table 1. Frequency distribution for the dimensions: usability, functionality, interactivity, motivation and educational content

Item	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	2	1	2	4	3	1	1	1	1	2	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1
2	2	1	3	1	4	2	1	1	0	3	0	2	1	2	0	0	1	3	0	0	2	3	3	2	4
3	8	5	10	7	11	9	11	6	7	14	9	11	10	11	8	6	6	5	10	5	11	6	5	5	4
4	17	24	18	22	21	23	24	27	25	18	27	18	24	16	25	26	15	20	17	19	21	27	26	27	23
5	15	13	11	10	5	9	7	9	11	7	7	12	8	12	10	11	21	15	16	19	9	7	9	9	12

Table 1 shows that the majority of participants' responses are concentrated at levels 4 and 5 of the Likert scale, indicating a generally positive perception of the immersive virtual environment. This is particularly evident in items such as 4, 8, 10, 12, 14, and 23, where more than 50% of participants expressed a high level of agreement. However, some items, such as 5, 21, and 22, show greater dispersion in responses, with more balanced values between low and high levels, suggesting variability in students' perceptions of those aspects, pointing to potential areas for improvement, such as the arrangement of on-screen elements and the environment's functionality. Despite these variations, the responses generally reflect consistency, as most items received positive ratings, indicating that the environment was well received by the majority of students, although there are aspects that could be optimized to enhance the educational experience.

Tables 2 show results for several key trends:

Table 2. Calculation of means and standard deviations

Item	Dimensions	Mean	Standard Deviation
1		3.48	1.18
2		3.56	1.33
3	Usability	3.14	1.41
4		3.76	3.76
5		3.00	3.00
6		3.96	3.92
7	Functionality	3.92	4.08
8		4.08	4.12

9		4.12	3.36
10		3.36	4.24
11	Interactivity	4.24	4.24
12		3.64	3.64
13		3.88	3.88
14		3.72	3.72
15		3.92	3.92
16	Motivation	4.00	4.00
17		4.28	4.28
18		3.88	3.88
19		4.08	4.08
20		4.20	4.20
21	Educational Content	3.36	3.36
22		3.24	3.24
23		3.48	3.48
24		3.52	3.52
25		3.84	3.84

A. Overall Positive Perception

The means for most items range between 3.5 and 4.2, indicating that, in general, participants have a favorable perception or agree with the statements presented in the questionnaire.

B. Consistency in Responses

The standard deviations are generally low, around 0.8 to 1.3, suggesting that most participants have similar opinions on many items. This indicates consistency in participants' perceptions regarding the evaluation of the virtual environment.

C. Items with Greater Variability

Some items have slightly higher standard deviations (around 1.3), suggesting greater dispersion in responses. This could reflect varying levels of agreement or disagreement among participants, possibly due to different experiences or interpretations of the item.

D. Areas for Improvement

Items with means close to 3.0 (such as items 5 and 21) and relatively high standard deviations indicate areas where perceptions are more neutral or varied, suggesting opportunities to improve or clarify those aspects of the evaluated environment.

In summary, the results suggest that the overall perception of the environment is positive, with some specific areas where variability in responses indicates the need to further explore participants' experiences to make improvements.

E. Analysis of Variance (ANOVA)

The ANOVA was conducted to determine if there are significant differences between genders in their perceptions of the virtual environment.

Most items do not show significant differences in perceptions between genders ($p > 0.05$). However, there is one item, "I would prefer to use the virtual environment for other learning activities in the future," that shows a significant difference between genders with a p-value of 0.0285.

F. Cronbach's Alpha Coefficient

The Cronbach's Alpha Coefficient was employed in the research to assess the internal reliability of the questionnaire used to measure students' perceptions of the immersive virtual environment. This questionnaire covered five key dimensions: usability (ease of use and navigation within the environment), functionality (the environment's ability to effectively facilitate educational activities), interactivity (degree of interaction between participants and the environment), motivation (the environment's impact on students' engagement and interest), and educational content (clarity and relevance of the educational material on anatomy and physiology). The obtained Cronbach's Alpha value of 0.973 indicates a very high internal consistency among the questionnaire items, ensuring that participants' responses were consistent across the different evaluated dimensions. This reflects that the instrument used was reliable in measuring students' perceptions of the immersive environment in terms of its effectiveness and quality in the teaching-learning process.

G. Comparative Analysis between Genders

To determine if there are significant differences in perceptions between genders, the Chi-square statistical test was performed.

After conducting the Chi-square test to compare perceptions between male and female genders in the questionnaire, significant differences were found in two items:

The layout of the elements on the screen is clear and understandable.

- Chi-square statistic: 13.27.
- p-value: 0.010.
- Degrees of freedom: 4.
- The expected frequencies suggest that men and women differ significantly in how they perceive the clarity of the layout of elements on the screen.

I would prefer to use the virtual environment for other learning activities in the future.

- Chi-square statistic: 12.58.
- p-value: 0.006.
- Degrees of freedom: 3.
- There is a significant difference in the preference for future use of the virtual environment between men and women.

These results indicate that there are significantly different perceptions between genders in these aspects of the virtual environment. This may have implications for how the virtual environment is designed and implemented to ensure a positive experience for all users.

V. Analysis and Interpretation of Results

The analysis of the results focused on the six key variables of the study: usability, functionality, interactivity, motivation, educational content, and the impact of cross-gender education. Histograms, box plots, and violin plots were used to visualize and analyze the distribution of responses in each dimension, starting with usability. The histogram showed the frequency of responses, revealing general trends in student perceptions. The box plot summarized the data distribution, highlighting the median, quartiles, and outliers, which helped assess the consistency and variability of responses regarding the usability of the immersive virtual environment. The violin plot combined these elements, providing a detailed view of both the density and spread of responses.

For the functionality variable, the analysis focused on how

the environment enabled students to perform educational activities. The visualizations showed a distribution consistent with mostly positive perceptions, but also highlighted areas where some students experienced difficulties, suggesting potential improvements in the environment's design.

Regarding interactivity and motivation, the graphs indicated a clear trend towards high levels of satisfaction. The violin plots revealed a greater density of responses at the upper levels of the scale, reflecting student engagement and active participation in the environment.

Finally, the analysis of the impact of cross-gender education revealed significant differences in the preference for future use of the virtual environment, confirmed by a p-value of 0.0285. This difference, visualized through comparative diagrams, underscores the importance of considering gender factors in the design of these environments to ensure an inclusive experience.

This analysis approach, supported by robust visualizations, not only identified patterns and trends in student perceptions but also highlighted key areas for improving the effectiveness of the immersive environment based on the variables studied.

Fig. 3 shows:

- Histogram: Most participants, both men and women, rate the usability of the virtual environment between 4 ("Agree") and 5 ("Strongly Agree"). There is a slight tendency toward a more favorable perception among women.
- Box-plot: The interquartile range of responses is higher among women, with more consistency in high responses (values of 4 and 5), while men show more variability.
- Violin Plot: The distributions are quite similar, but women tend to concentrate more around the value 4, while men show a slight dispersion toward lower values.

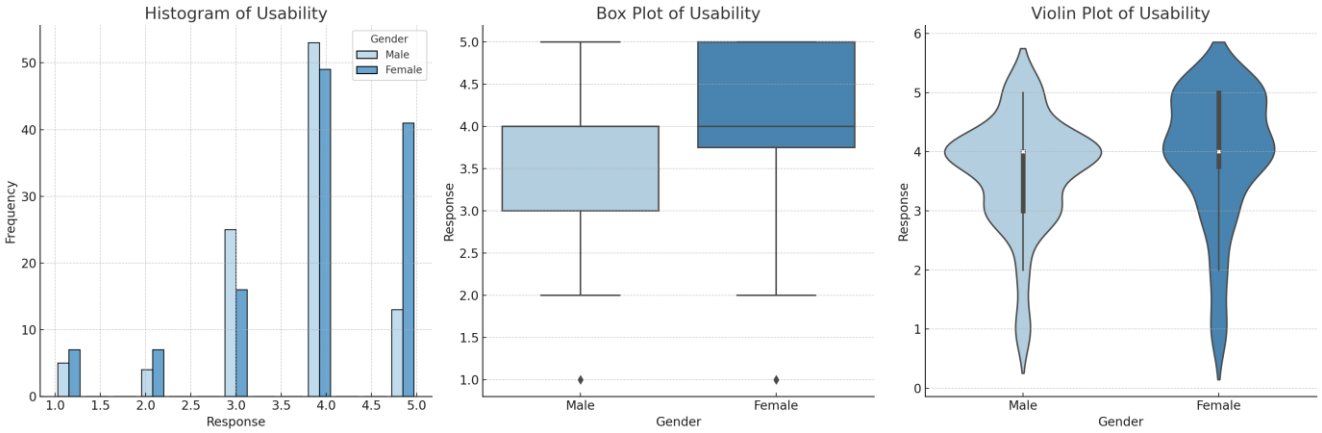

Fig. 3. Histogram, box-plot, violin plot for the usability dimension.

Fig. 4 shows:

- Histogram: Similar to usability, most responses are concentrated at values of 4 and 5, with women showing a slight tendency toward higher responses.
- Box-plot: Women display a higher median with less dispersion toward lower values. Men show greater dispersion toward medium and lower responses.
- Violin Plot: Women present a more concentrated distribution around 4 and 5, while men have a broader distribution, with responses extending more toward lower values.

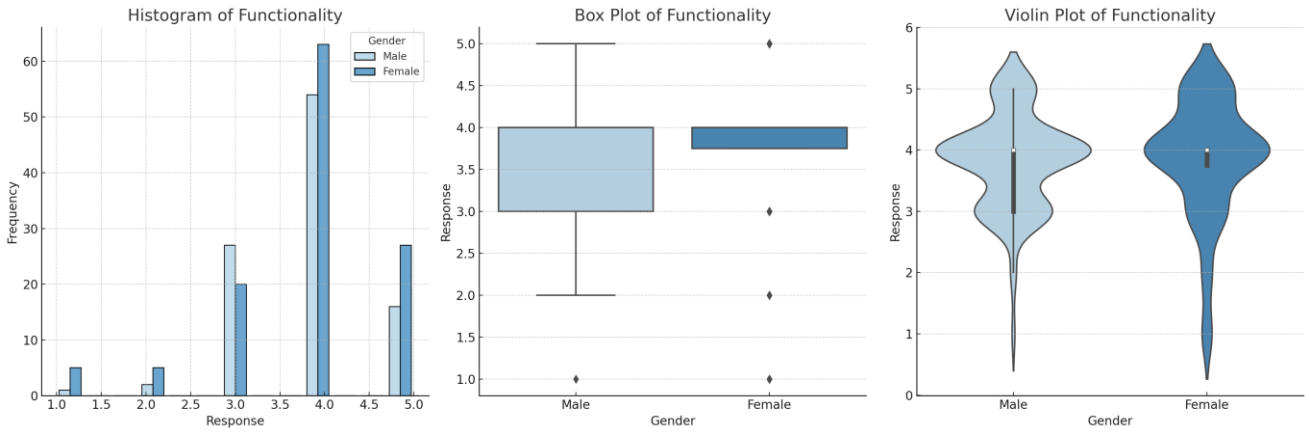

Fig. 4. Histogram, box-plot, violin plot for the functionality dimension.

Fig. 5 shows:

- Histogram: Once again, most participants report high levels of agreement (4 or 5) regarding the interaction capability of the environment, with women slightly more inclined toward the higher end.
- Box-plot: Men show greater dispersion in their responses,
- while women tend to concentrate their responses at

higher values.

- Violin Plot: Women have a distribution more concentrated around 4 and 5, while men display greater variability in their responses.

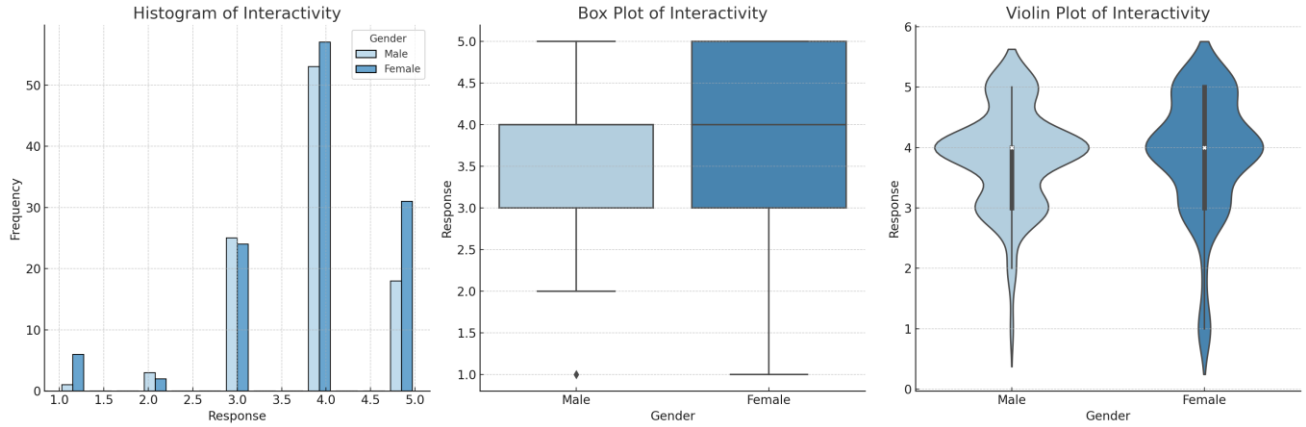

Fig. 5. Histogram, box-plot, violin plot for the interactivity dimension.

In the analysis of Figs. 3 and 4, the results are used as an argument to highlight significant differences in students' perceptions, particularly between genders, regarding the usability, functionality, and interactivity of the immersive virtual environment. Key elements such as the preference for future use of the virtual environment and the arrangement of on-screen elements are emphasized. The analysis reinforces the idea that the virtual environment was generally perceived positively, but also shows variability in some aspects, suggesting areas for improvement in the design to optimize the user experience and ensure a more effective and equitable implementation.

Fig. 6 shows:

- Histogram: Regarding motivation, both men and women show high satisfaction, although once again, women tend to report slightly more positive responses.
- Box-plot: Men's responses are more dispersed, with lower outliers. Women's responses are more consistent and concentrated at higher values.
- Violin Plot: Women have a very concentrated distribution around 4 and 5, while men show more variability, with a greater spread toward lower values.

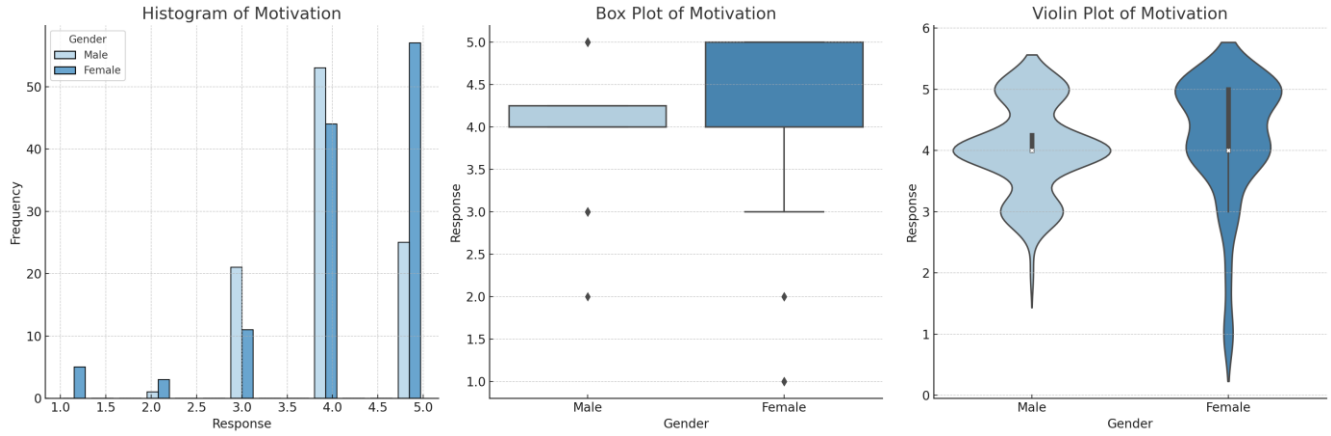

Fig. 6. Histogram, box-plot, violin plot for the motivation dimension.

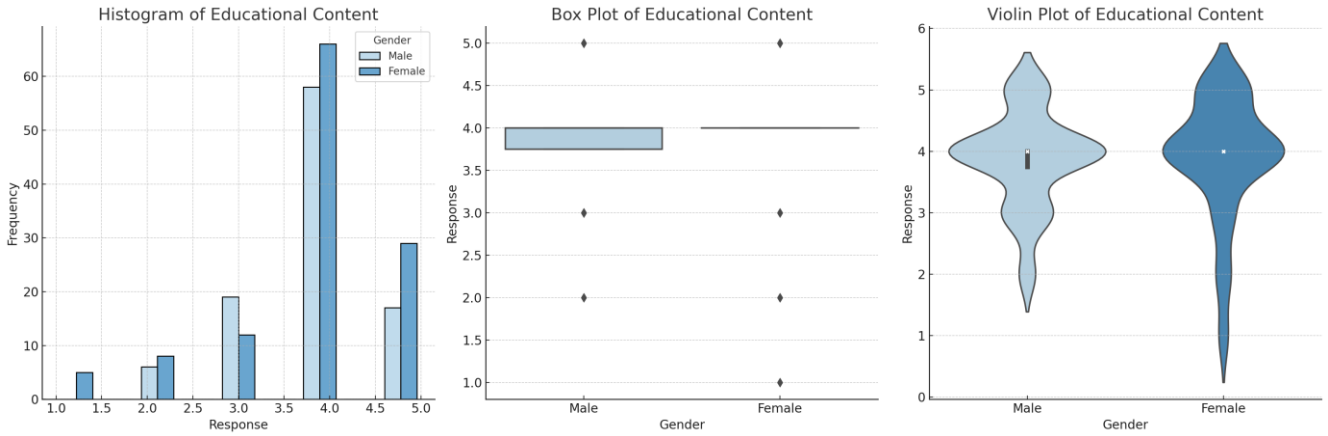

Fig. 7. Histogram, box-plot, violin plot for the educational content dimension.

Fig. 7 shows:

- Histogram: Both genders tend to rate the educational content highly, but women show a slight inclination toward more positive responses.
- Box-plot: Women's responses are consistently higher, while men's responses show greater variability with some lower values.
- Violin Plot: The distributions follow a similar pattern to the other dimensions, with women concentrated at higher values and men showing greater dispersion.

In conclusion, women tend to give slightly more positive responses across all dimensions, with less dispersion in their answers. Men exhibit greater variability in their responses, with more instances of disagreement or neutral responses, suggesting a less uniform perception of the virtual environment. Overall, both populations perceive the virtual environment positively, with responses predominantly at the higher levels (4 and 5) across all dimensions. These results suggest that, while both genders have a positive perception of the virtual environment, women tend to rate it slightly more positively and with less variability in their responses.

VI. Discussion

The discussion of the results of this research shows that the use of an immersive virtual environment in the teaching of human anatomy and physiology had a positive impact on students' perceptions, with a general tendency to rate the dimensions of usability, functionality, interactivity, motivation, and educational content favorably. These findings are consistent with previous studies that highlight the benefits of immersive technologies in education. For example, Knierim *et al*. [19] emphasized the effectiveness of immersive feedback in virtual environments to provide more engaging and realistic learning experiences, which reinforces our results regarding the high interactivity and motivation experienced by students. Similarly, the research by Tsirulnikov *et al*. [21] demonstrated that virtual laboratory simulations improve students' motivation and learning outcomes, in line with the high levels of satisfaction observed in our study in these dimensions.

Regarding functionality and usability, studies such as those by Cabiria *et al.* [20, 23] highlighted the potential of Augmented Reality (AR) and Virtual Reality (VR) to transform education by creating more dynamic and personalized learning environments. This is reflected in the positive perceptions found in our research regarding the environment's ability to facilitate learning effectively.

However, it is important to note that while most items showed favorable perceptions, some, such as the preference for future use of the virtual environment, revealed significant gender differences ($p = 0.0285$). This finding aligns with the mixed results reported by Cevikbas *et al*. [22] regarding the effectiveness of AR/VR in mathematics education, suggesting that the impact of cross-gender education remains a factor to consider in the implementation of these technologies.

Finally, as pointed out by Alzahrani *et al.* [24, 26], some challenges related to technology, such as variability in the perception of the layout of on-screen elements, could indicate areas where the functionality and usability of the environment need improvement. In summary, this research confirms the benefits reported in the literature on immersive education, but also identifies the need to address gender differences and improve certain aspects of the virtual environment to maximize its educational effectiveness.

VII. Conclusions

The conclusions of this research confirm that the immersive virtual environment implemented for teaching human anatomy and physiology was positively received by the majority of students, meeting the objective of analyzing its effectiveness and user perceptions. The analysis of the six key variables: usability, functionality, interactivity, motivation, educational content, and impact of cross-gender education, reveals that usability and functionality achieved average scores between 3.5 and 4.2, indicating a high level of satisfaction with the environment's ease of use and ability to facilitate learning activities. Notably, the dimensions of interactivity and motivation were rated particularly high, with most responses at levels 4 and 5, suggesting that the immersive experience significantly enhanced student engagement and learning outcomes.

Regarding the impact of cross-gender education, significant gender differences were observed in preferences for future use of the virtual environment, with a p-value of 0.0285. This finding emphasizes the importance of considering gender-related factors in the design of educational tools to ensure inclusivity and equity. The internal consistency of the questionnaire, reflected in a Cronbach's Alpha of 0.973, supports the reliability of the data collected.

While the results were largely positive, some variability was noted in responses related to the layout of on-screen elements, suggesting areas for improvement to enhance both functionality and user experience. Overall, the research demonstrates that the immersive virtual environment is a highly effective tool for teaching anatomy and physiology, though adjustments are needed to optimize its performance and ensure equitable experiences across different student demographics.

The main limitations include the use of non-probabilistic sampling and a small sample size, which restrict the generalizability of the results. Additionally, as the study relied on a single data collection point, it was not possible to observe how perceptions evolve over time. For future research, it is recommended to expand the sample in various educational contexts, apply a longitudinal approach, and complement quantitative results with qualitative methods to gain a deeper understanding. It is also advisable to explore the identified gender differences to further optimize and personalize immersive learning environments.

VIII. Limitations and Future Recommendations

One of the main limitations of this research is the use of a non-probabilistic convenience sample, which may limit the generalizability of the results to other populations. Additionally, the sample consisted of a relatively small number of students (44 in total), which may have reduced the ability to detect subtler differences in perceptions between subgroups, such as genders. Another limitation is the reliance

on a single data collection point, which does not allow for observing how students' perceptions change over time or with repeated use of the virtual environment. Furthermore, although the questionnaire showed high internal reliability, the quantitative approach did not allow for an in-depth exploration of the reasons behind students' perceptions, which could provide a richer and more contextualized understanding of their experiences.

For future research, it is recommended to expand the sample to different educational contexts and study levels, using a probabilistic sample to improve the representativeness of the results. Additionally, conducting longitudinal studies that assess the impact of the virtual environment over time and with repeated use would be beneficial. Complementing the quantitative approach with qualitative methods, such as interviews or focus groups, would allow for a deeper understanding of the reasons behind the perceptions and provide valuable insights for improving the design of the virtual environment. Finally, it is suggested to further investigate the gender differences identified in this research to adjust and personalize immersive learning experiences so that they are equally effective for all students.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Benjamín Maraza Quispe, has reviewed the background and literature review including the discussion and conclusions and Manuel Alfredo Alcázar Holguin has reviewed the methodology and analysis and interpretation of the results and Walter Choquehuanca Quispe has implemented the discussion and conclusions. All authors had approved the final version.

ACKNOWLEDGEMENTS

We thank the Universidad Nacional de San Agustín de Arequipa (UNSA) for funding and supporting our research under contract number PI-03-2024-UNSA. Their commitment to the promotion of knowledge and academic research has been fundamental for the development of this project.

REFERENCES

[1] B. Maraza-Quispe, O. M. Alejandro-Oviedo, K. S. Llanos-Talavera, W. Choquehuanca-Quispe, S. A. Choquehuayta-Palomino, and N. E. Caytuiro-Silva, "Towards the development of emotions through the use of Augmented Reality for the improvement of teaching-learning processes," *International Journal of Information and Education Technology (IJIET)*, vol. 13, no. 1, pp. 56–63, 2023. https://doi.org/10.18178/ijiet.2023.13.1.1780

[2] K. K. Barroso, "Augmented Reality in the teaching-learning process," *Technology Rain Journal*, vol. 1, no. 2, p. e6, 2022. https://doi.org/10.55204/trj.v1i2.e6 (in Spanish)

[3] K. T. Korowajczenko, "Augmented reality, its challenges and applications for e-learning," no. 6, 2022. http://dx.doi.org/10.13140/RG.2.1.1464.5601 (in Spanish)

[4] A. F. D. Natale, C. Repetto, G. Riva, and D. Villani, "Immersive virtual reality in K-12 and higher education: A 10-year systematic review of empirical research," *British Journal of Educational Technology: Journal of the Council for Educational Technology*, vol. 51, no. 6, pp. 2006–2033, 2020. https://doi.org/10.1111/bjet.13030

[5] G. Sánchez and G. Castillo, "Design simple immersive learning experiences using technology," *Tecnológico de Monterrey*, 2023. https://repositorio.tec.mx/handle/11285/650192 (in Spanish)

[6] S. J. P. García and J. Garzón, "Effects of a video game on the learning and motivation of students in a natural sciences course," *Universidad Católica Del Norte Virtual Journal*, vol. 71, pp. 81–104, 2024. https://doi.org/10.35575/rvucn.n71a5 (in Spanish)

[7] D. Boud and E. Molloy, "Feedback in higher and professional education," *Understanding It and Doing It Well*, vol. 2013, 2013.

[8] D. R. Sadler, "Beyond feedback: Developing student capability in complex appraisal," *Assessment and Evaluation in Higher Education*, vol. 35, no. 5, pp. 535–550, 2010. https://doi.org/10.1080/02602930903541015

[9] Educadictos. (2017). Immersive learning: Education, technology, courses, teaching. [Online]. Available: https://www.educadictos.com/aprendizaje-inmersivo/

[10] A. Jonsson, "Facilitating productive use of feedback in higher education," *Active Learning in Higher Education*, vol. 13, no. 1, pp. 63–76, 2012. https://doi.org/10.1177/1469787412467125

[11] P. Alvarez, L. Gomez, and M. Ruiz, "Designing effective feedback systems in immersive learning environments," *Journal of Educational Technology Research and Development*, vol. 71, no. 2, pp. 205–226, 2023. https://doi.org/10.1007/s11423-022-10113-x

[12] W. Y. Hwang, Y. M. Huang, and S. C. Cheng, "Real-time feedback in immersive virtual learning environments: Effects on learner engagement and performance," *Educational Technology and Society*, vol. 25, no. 1, pp. 42–54, 2022. https://www.j-ets.net/ETS/journals/25_1/5.pdf

[13] L. Johnson and A. Levine, "Challenges in virtual reality education: Balancing technological complexity with user accessibility," *Computers and Education*, vol. 180, 104494, 2023. https://doi.org/10.1016/j.compedu.2023.104494

[14] K. Smith and D. Sanchez, "Motivation and feedback in immersive learning: Designing for effective user experiences," *Learning and Instruction*, vol. 79, 101573, 2024. https://doi.org/10.1016/j.learninstruc.2023.101573

[15] E. L. Deci, R. M. Ryan, and R. Koestner, "Motivating students in digital learning environments: The role of intrinsic and extrinsic motivation," *Educational Psychology Review*, vol. 34, no. 2, pp. 361–378, 2022. https://doi.org/10.1007/s10648-021-09611-y

[16] R. M. Ryan and J. D. Stiller, "Intrinsic and extrinsic motivation in classrooms: Toward an integrative model," *Journal of Educational Psychology*, vol. 115, no. 2, pp. 275–289, 2023. https://doi.org/10.1037/edu0000684

[17] A. Wigfield, J. Gladstone, and L. Turci, *Handbook of Motivation at School*, Routledge, 2023. https://doi.org/10.4324/9781003203386

[18] Z. Dörnyei and E. Ushioda, *Teaching and Researching Motivation*, Routledge, 2023. https://doi.org/10.4324/9781003271965

[19] P. Knierim, T. Kosch, V. Schwind, M. Funk, F. Kiss, S. Schneegass, and N. Henze, "Tactile drones—providing immersive tactile feedback in virtual reality through quadcopters," in *Proc. the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, 2017. https://doi.org/10.1145/3027063.3050426

[20] J. Cabiria, "Augmenting engagement: Augmented reality in education," *Increasing Student Engagement and Retention Using Immersive Interfaces: Virtual Worlds, Gaming, and Simulation*, Emerald Group Publishing Limited, 2012, pp. 225–251. http://dx.doi.org/10.1108/S2044-9968(2012)000006C011

[21] D. Tsirulnikov, C. Suart, R. Abdullah, F. Vulcu, and C. E. Mullarkey, "Game on: Immersive virtual laboratory simulation improves student learning outcomes and motivation," *FEBS Open Bio.*, vol. 13, no. 3, pp. 396–407, 2023. https://doi.org/10.1002/2211-5463.13567

[22] M. Cevikbas, N. Bulut, and G. Kaiser, "Exploring the benefits and drawbacks of AR and VR technologies for learners of mathematics: Recent developments," *Systems*, vol. 11, no. 5, p. 244, 2023. https://doi.org/10.3390/systems11050244

[23] M. Meccawy, "Creating an immersive XR learning experience: A roadmap for educators," *Electronics*, vol. 11, no. 21, p. 3547, 2022. https://doi.org/10.3390/electronics11213547

[24] N. M. Alzahrani, "Augmented reality: A systematic review of its benefits and challenges in E-learning contexts," *Applied Sciences (Basel, Switzerland)*, vol. 10, no. 16, p. 5660, 2020. https://doi.org/10.3390/app10165660

[25] Y. Hanggara, A. Qohar, and Sukoriyanto. "The impact of augmented reality-based mathematics learning games on students' critical thinking skills," *International Journal of Interactive Mobile Technologies (iJIM)*, vol. 18, no. 7, pp. 173–187, 2024. https://doi.org/10.3991/ijim.v18i07.48067

[26] M. I. N. Fahmi, S. Zubaidah, S. Mahanal, and D. Setiawan, "Virtual reality laboratory laws of inheritance enhancing students' technological," *Literacy. International Journal of Interactive Mobile Technologies (iJIM*), vol. 18, no. 6, pp. 159–172, 2024. https://doi.org/10.3991/ijim.v18i06.47945

[27] J. Uribe, D. Harmon, B. Laguna, and Y J. Courtier, "Augmented-Reality Enhanced Anatomy Learning (A-REAL): Assessing the utility of 3D holographic models for anatomy education," *Annals of 3D Printed Medicine*, vol. 9, Feb. 2023. doi: 10.1016/j.stlm.2022.100090

[28] D. T. P. Yanto, Ganefri, Sukardi, J. P. Yanto, R. Kurani, and Y. Muslim, "Engineering students' acceptance of augmented reality technology integrated with e-worksheet in the laboratory learning," *International Journal of Online and Biomedical Engineering (iJOE)*, vol. 20, no. 03, pp. 39–54, Feb. 2024. doi: 10.3991/ijoe.v20i03.46101

[29] O. Chamorro-Atalaya *et al.*, "Contribution of augmented reality in teaching and learning, in the midst of COVID-19: Systematic review," *International Journal of Learning, Teaching and Educational Research*, vol. 22, no. 2, pp. 302–322, Feb. 2023. doi: 10.26803/ijlter.22.2.17

[30] J. Nielsen, *Usability Engineering*, Morgan Kaufmann Publishers, 2004. https://www.nngroup.com/books/usability-engineering

[31] A. Dix, J. Finlay, G. Abowd, and R. Beale, *Human-Computer Interaction*, 3rd ed. Pearson, 2004. https://paragnachaliya.in/wp-content/uploads/2017/08/HCI_Alan_Dix.pdf

[32] E. L. Deci and R. M. Ryan, *Intrinsic Motivation and Self-Determination in Human Behavior*, Plenum Press, 1985. https://link.springer.com/book/10.1007/978-1-4899-2271-7

[33] D. Laurillard, *Teaching as a Design Science: Building Pedagogical Patterns for Learning and Technology*, Routledge, 2023. https://doi.org/10.4324/9780203125083