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Impact of immersive learning environments on the development of technological competencies in students

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ABSTRACT

This research identifies the need to enhance students' technological competencies in designing and building technological solutions through immersive learning environments. The study proposes the use of immersive technologies, such as virtual and augmented reality (AR), to foster creativity and improve students' ability to develop effective solutions. The aim was to evaluate the impact of immersive learning on the competence of "designing and building technological solutions" in higher education students, focusing on four specific capacities: determining, designing, implementing, and validating solutions, as well as promoting innovation. Using a quantitative, descriptive cross-sectional experimental design, structured questionnaires were administered to 35 students engaged in an immersive technology program. Data were analyzed using descriptive and comparative techniques, revealing a significant positive impact on technological competencies. Students found these experiences to be relevant, engaging, and conducive to creativity, improving their ability to design and test solutions. However, challenges such as resource availability and the need for continuous teacher training were noted. The study concludes that immersive technologies are effective in enhancing academic performance and practical skills, emphasizing their integration in various educational contexts to strengthen key competencies essential for the 21st century.

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1. INTRODUCTION

The growing demand for technological competencies in the 21st century has generated the need to innovate teaching methodologies, especially in critical areas such as problem-solving and the design of technological solutions [1]. Traditional education, centered on the passive transmission of knowledge, has proven insufficient to prepare students for the complex challenges of today's world [2]. In this context, there is a need to explore new educational strategies that not only impart knowledge but also develop practical skills and essential competencies. One approach that has gained attention in recent years is immersive learning [3], which uses technologies such as virtual reality (VR) and augmented reality (AR) to create interactive and highly engaging environments [4]. These environments have the potential to transform the way students learn and apply knowledge, facilitating a deeper understanding and greater capacity to solve complex problems [5].

The problem addressed by the research is the insufficiency of traditional teaching methods in developing technological competencies in students, particularly in designing and building technological solutions. Although efforts have been made to integrate technology into the classroom, the lack of a structured approach has created a significant gap between theoretical knowledge and practical application. This study aims to investigate how immersive learning environments, such as virtual and AR, can enhance these practical competencies, fostering key skills for the technological challenges of the 21st century. Despite efforts to integrate technologies into the classroom, the lack of a structured and effective approach has resulted in a significant gap between the theoretical knowledge students acquire and their ability to apply it in practical contexts [6]. This situation highlights the urgent need to investigate how the implementation of immersive learning can impact the development of these competencies, offering an educational approach that not only motivates students but also prepares them to face future technological challenges.

This research is crucial because it addresses a gap in both the literature and educational practice. While previous studies have explored the general benefits of immersive learning [7], few have investigated its specific impact on the competence of designing and building technological solutions among students. By focusing the study on this competence, the research not only contributes to the existing body of knowledge but also provides empirical evidence on the effectiveness of immersive environments in developing practical and transferable skills. The results of this research have the potential to influence educational policy and teaching practices, promoting the adoption of immersive technologies to improve the quality of education and better prepare students for the future.

Immersive learning is an educational approach that uses technologies, such as VR, AR, and 360° videos to create interactive three-dimensional environments that allow students to actively participate in their learning process. According to Merchant *et al*. [8], this type of learning is developed in three-dimensional environments, while Viloria [9] highlights that it facilitates the presentation of concepts and practice in virtual environments. The advantages of immersive learning include promoting attention, practicing skills in safe environments, and accessing experiences that would otherwise be inaccessible [10]. Additionally, this approach provides new perspectives and a deeper understanding of educational content due to its ability to simulate complex realities and allow direct interaction with content [11]. The integration of these technologies in the classroom transforms the way teaching and learning are conducted, offering a more dynamic and personalized teaching method that responds to the educational needs of the 21st century.

On the other hand, achieving competence in designing and building technological solutions to solve problems involves developing several key skills. First, determining a technological solution alternative requires students to identify a problem and propose creative solutions based on scientific, technological, and local practices, evaluating their relevance [12]. Second, the ability to design and build technological solutions allows students to create objects, processes, or systems that solve problems in the social context by integrating scientific and technological knowledge with creativity and perseverance [12]. Third, implementing and validating the technological solution alternative refers to executing the proposed solution, verifying that it meets design specifications and functions properly [12]. Finally, evaluating and communicating the solution’s performance and impacts involves analyzing how well the solution addresses the problem, communicating its effectiveness, and considering environmental and social impacts during its development and use [12]. These skills are essential for students to develop comprehensive and effective technological competencies.

2. LITERATURE REVIEW

The reviewed studies present a detailed view of how immersive learning, particularly AR and VR, is transforming education at various levels. Hurtado-Mazeyra [13] investigated the use of digital storytelling in 2D and AR to develop creativity in preschool children. Their study revealed that, although both modalities improved creativity, AR proved to be more effective, suggesting that emerging technologies can offer more enriching learning experiences. This finding highlights the potential of AR to enhance key skills from an early age.

On the other hand, Delgado [14] analyzed the impact of immersive learning in medical education through VR training games. Their bibliometric and qualitative analysis showed a growing interest in integrating VR into medical training, emphasizing the importance of developing new tools and applications that promote innovation in education and health. The results underscore interdisciplinary collaboration as a key factor for the effective and sustainable implementation of VR in these fields. Rodríguez *et al*. [15] complemented these findings with a study on a mobile AR application in secondary education. The results showed that AR can significantly improve the learning process, although they also pointed out the need for ongoing training for teachers, especially older ones. This study underscores that, while technology has the potential to improve student performance, it is crucial to properly train educators to maximize its effectiveness.

In an approach that combines the emotional and educational dimensions, Maraza-Quispe *et al*. [16] demonstrated that AR not only facilitates the understanding of complex content like cell biology but also creates a positive emotional environment that enhances the teaching-learning process. This study used ARToolkit software and a 3D model in Unity3D, finding that students who used AR showed significant improvements in their academic performance and emotional satisfaction compared to a control group. This approach highlights how emotions can influence the achievement of technological and educational competencies, underscoring the importance of immersive learning in modern education. Research by Antón-Sancho *et al*. [17] addressed the use of VR in higher education, analyzing the evaluations of 1,638 university professors regarding its didactic application. Their study revealed a positive assessment of VR, although it also identified a perceived lack of digital skills, especially in less technological areas. These findings highlight the need to improve training in digital competencies to maximize the potential of VR in university teaching. Rios [18] explored the implementation of a virtual training system for immersive learning in human anatomy. The results indicated that students perceived traditional methods of teaching anatomy negatively, highlighting the need to adopt innovative methods such as virtual trainers. This study reinforces the importance of adapting medical education to modern technologies to enhance the learning experience. Lampropoulos *et al*. [19] investigated the effectiveness of a VR program in emotional regulation in children and adolescents, comparing it to a non-virtual intervention. The results showed significant improvements in both groups, suggesting that VR is an effective tool for developing emotional skills in educational contexts. Canales [20] explored how mixed reality can improve educational methods and offer personalized learning experiences. Their study showed that mixed reality creates virtual spaces that increase participation and learning for both students and teachers, emphasizing the need to promote this technology to modernize teaching methods. Salas [21] investigated the relationship between virtual environments and meaningful learning in university students, finding a high positive correlation. The results suggest that virtual platforms can be powerful tools for achieving effective educational outcomes. Studies like Rodríguez [22], which highlighted the relationship between AR and the teaching-learning process in a chemistry course, and Yang [23], which developed an AR model to improve academic performance in children, reinforce the importance of integrating immersive technologies into education. These studies not only show improvements in student performance and satisfaction but also propose AR as a key educational tool for the future.

In this same context, Harrington [24] highlighted the positive impact of AR on the teaching-learning process in secondary education, emphasizing its ability to improve acquired knowledge, student satisfaction, and critical thinking. Camps-Ortueta [25] highlighted the effectiveness of an AR application at the National Museum of Natural Sciences to promote interest in STEM disciplines, showing how immersive technologies can attract and maintain interest in educational activities. López-Bouzas and Pérez [26] demonstrated that AR is effective in improving academic performance in secondary education in a project-based learning environment. Makransky and Petersen [3] developed the cognitive affective model of immersive learning (CAMIL) model, which explains how cognitive and affective components interact in VR environments to optimize learning. Osadchyi *et al*. [27] highlighted the usefulness of AR in STEM education, emphasizing the need to adjust teaching methods for its effective implementation. The integration of AR can improve the health-preserving competence of physical education teachers [28]. In addition, Shvardak *et al*. [29] analyzed the positive impact of digital technologies on the professional training of primary school teachers, while Martzoukou *et al*. [30] emphasized the need to integrate digital literacy into nursing curricula. Aramburuzabala *et al*. [31] explored how service-learning and digital empowerment can promote sustainable educational practices in higher education. Finally, Aguilar [32] demonstrated the effectiveness of virtual and AR in surgical planning and training, highlighting their growing importance in improving surgical outcomes.

These studies highlight the growing importance and effectiveness of immersive technologies and AR in various educational and professional contexts, emphasizing the need for continuous training and adaptation of these tools to maximize their potential in the teaching-learning process and in the development of key competencies. Together, this review underscores that immersive learning has a significant and positive impact on education, from creativity in childhood to advanced medical training. These approaches not only improve academic outcomes but also transform the educational experience, suggesting a strong need for their continuous and adaptive integration in various educational contexts.

Immersive learning, while promising, presents several disadvantages that must be considered. One of the main issues is the technological complexity and the lack of familiarity of educators with these tools, which can hinder their effective implementation in the classroom [33]. Additionally, the high costs associated with the development and maintenance of technologies such as AR and VR can be prohibitive for many educational institutions, limiting their accessibility [15]. Another significant challenge is the cognitive overload that students may experience, especially when interacting with complex environments without adequate guidance, which could negatively affect their learning [34]. Moreover, the lack of adequate continuous training for educators may result in the ineffective use of these technologies, preventing their full potential from being realized. Finally, there is the risk that excessive reliance on technology may diminish students' intrinsic motivation if the experiences are not well designed to foster deep and meaningful learning [14].

3. METHOD
3.1. Research design
The research followed a quantitative approach with a descriptive transactional experimental design. A structured questionnaire was applied to assess students' perceptions of their experience with immersive virtual environments across different key dimensions of designing and constructing technological solutions. The questionnaire covered four main dimensions: determining technological solution alternatives, designing technological solutions, implementing and validating technological solutions, and innovation and creativity in technological design.

3.2. Population and sample
The sample consisted of 35 students who actively participated in a program integrating immersive technologies as part of their learning process. The sample was selected through a non-probabilistic convenience sampling method from a population of 100 students. The inclusion and exclusion criteria are explained in sub-section.

3.2.1. Inclusion criteria
The research targets students enrolled in the eighth cycle of the educational informatics program, who actively participated in immersive learning activities during the designated period. These students form the core of the study, ensuring that the analysis focuses on participants with direct experience in immersive educational methodologies. To be included in the study, participants had to meet specific criteria: they must be available and willing to complete the survey, providing their responses based on their immersive learning experiences. This ensures that the collected data reflects genuine participation and engagement in the evaluated activities. Additionally, eligibility required that participants have access to the necessary technologies for the immersive learning activities. This criterion guarantees that all respondents had the resources needed to fully engage in and experience the educational interventions under investigation.

3.2.2. Exclusion criteria
The study excludes students who did not participate or had minimal participation in immersive learning activities. This ensures that the analysis focuses only on participants with substantial experience in the evaluated educational interventions. Students without access to the necessary technologies for participating in immersive activities are also excluded. Additionally, individuals unable to complete the survey due to personal, health, or technological reasons do not form part of the sample. Moreover, students who did not provide consent to participate or were significantly absent during the immersive activities are excluded. Their limited involvement prevents them from offering relevant insights based on the learning experiences.

3.3. Data collection instruments
The data collection instrument used in this research was a structured questionnaire designed to assess students' perceptions of the implementation of immersive learning in their teaching-learning process, specifically regarding achieving competencies related to designing and constructing technological solutions. The questionnaire was based on a 5-point Likert scale, where participants could express their level of agreement or disagreement with various statements. The questionnaire covered four main dimensions, each composed of several specific items.

3.3.1. Determining technological solution alternatives
The study assessed students' ability to identify and propose technological alternatives to address various problems. This evaluation focused on their capacity to analyze challenges and generate creative solutions using technological tools. Additionally, the research measured how frequently students used immersive technologies during problem-solving activities. This aspect highlights their engagement with digital tools in practical learning scenarios. The effectiveness of immersive technologies in supporting the problem-solving process was also evaluated. This included analyzing how these tools contributed to developing innovative and viable technological solutions.

3.3.2. Designing technological solutions
The study included items that assessed students' ability to design detailed and effective technological solutions. This evaluation aimed to measure their competence in creating innovative responses to technological challenges. A key focus was on how immersive experiences supported the design process. The research examined how virtual environments contributed to developing students' creativity and problem-solving skills. Additionally, the evaluation considered how students applied technological tools within

immersive settings to create practical and functional solutions. This analysis highlighted the role of digital experiences in enhancing their design capabilities.

3.3.3. Implementing and validating technological solutions

This dimension assessed the effectiveness of immersive tools in the implementation of technological solutions. The evaluation focused on students' ability to apply their designs in practical scenarios using digital environments. Additionally, the study measured how well students could validate their proposed solutions. This included verifying that their technological designs met the intended objectives and functioned as expected. The analysis also explored the role of immersive tools in supporting the practical application process. It highlighted how these technologies contributed to improving the accuracy and feasibility of students' technological solutions.

3.3.4. Innovation and creativity in technological design

Evaluated the impact of immersive environments on students' creativity and originality in developing technological solutions, as well as their ability to innovate. Each dimension included four items, carefully formulated to capture key aspects of immersive learning. For example, in the "determining technological solution alternatives" dimension, the items focused on students' active participation, the authenticity of immersive experiences, and the ease of use of the involved technologies. In the "innovation and creativity in technological design" dimension, the items evaluated how immersive experiences foster originality and students' ability to generate novel technological solutions. The questionnaire was reviewed and validated by experts in education and technology to ensure its content and relevance. Additionally, the Cronbach's alpha coefficient was calculated to evaluate the internal reliability of the questionnaire, resulting in a high value, indicating that the instrument is reliable for measuring perceptions in the evaluated dimensions.

3.4. Procedure

The procedure for applying the questionnaire began with the preparation and validation of the instrument by experts in education and educational technology, ensuring the clarity and relevance of the items. A non-probabilistic sample of 35 students who had participated in immersive learning experiences was selected. Before the application, students were informed about the research's purpose, ensuring their understanding of the voluntary and anonymous nature of their participation. The questionnaire was administered in person during a class session, with 20 minutes allocated for its completion.

3.5. Proposed activity in the immersive learning experience

This activity aimed to help students design technological solutions for studying the cell using immersive VR. Through interactive 3D environments, students explored cellular structures and processes, gaining a deeper understanding of biological concepts. The activity involved several stages, including virtual exploration, problem identification, and solution design. Students used design software to create prototypes that addressed challenges observed during their virtual experiences. Finally, students presented their technological solutions, demonstrating how immersive tools enhanced their understanding of cell biology. The process fostered creativity, collaboration, and practical application of technological design skills.

3.5.1. Objective

This activity utilizes immersive VR to help students design and construct innovative technological solutions for studying the cell. Through interactive experiences, students engage with 3D models, exploring cellular structures and biological processes in detail. The virtual environment allows students to identify challenges in understanding cell functions and develop technological solutions to address them. This hands-on approach enhances their problem-solving skills and fosters creativity in designing educational tools. By constructing and presenting their solutions, students strengthen their competence in technological design. The immersive experience not only deepens their understanding of cell biology but also builds their ability to create practical and innovative technological applications.

3.5.2. Activity description

The instructor will select a VR platform or application that allows students to explore the cell in detail. This tool will enable them to visualize organelles, functions, and cellular processes in an interactive 3D environment. Students will be organized into teams to promote collaboration and teamwork. Each group will be assigned a specific problem related to cell study, encouraging them to apply their knowledge and analytical skills. The assigned challenges will focus on key aspects of cell biology, such as visualizing complex cellular processes, understanding organelle interactions, or explaining cellular responses to external stimuli. These tasks will guide students in developing targeted technological solutions.

3.5.3. Activity development

This sub-section outlines a hands-on, immersive learning experience designed to deepen students' understanding of cell biology through the integration of virtual reality (VR) and technological design. The activity not only encourages exploration and conceptual understanding of cellular processes but also promotes creativity, problem-solving, and interdisciplinary thinking by engaging students in the development of educational technological tools. Each phase is structured to progressively build students' capacity to identify learning challenges and develop innovative solutions using digital design software and VR environments.

a. Virtual exploration: students will immerse themselves in a VR experience to explore the cell, allowing them to "enter" the cell, observe its components from various angles, and witness cellular processes such as mitosis and protein synthesis. During this exploration, teams will identify specific areas where technology can enhance their understanding or the teaching of cellular concepts.
b. Problem identification and brainstorming: each team will discuss and define a specific problem they encountered during their VR exploration, such as difficulty visualizing mitochondria in action or understanding DNA replication within the nucleus. Following this, teams will brainstorm to design a technological solution that addresses the identified problem, which may include enhanced VR applications, interactive simulations, or other educational tools.
c. Solution design: using design software, such as Tinkercad, SketchUp, or VR design tools, students will create a prototype of their solution, which may include a conceptual design for a new VR application, an educational interface, or a 3D model illustrating a cellular process. Additionally, they will develop a written proposal detailing the identified problem, the proposed technological solution, and how it will enhance the study or teaching of cell biology.
d. Project presentation: teams present their technological solution to the class, using their prototype and VR experience as the basis to demonstrate the feasibility of their design. Discussions include the challenges encountered during the design process and potential improvements.
e. Evaluation: the evaluation is based on the creativity of the design, the relevance and effectiveness of the proposed solution, and the quality of the presentation. The team's ability to work collaboratively and solve problems innovatively will also be considered.
f. Expected results: students will enhance their technological design skills specifically applied to cell biology while gaining a deeper understanding of cellular structure and functions through a practical and creative approach. Additionally, they will experience VR tools not only as consumers but also as creators of educational solutions, fostering both engagement and innovation in their learning process. This activity fosters deep learning of the cell while promoting competence in designing and constructing innovative technological solutions, integrating biology with cutting-edge technology

4. DATA COLLECTION

Descriptive and comparative statistical techniques were used to analyze responses and assess the impact on the four capabilities, considered as dimensions of the technological solutions construct. The analysis of Table 1 reveals several significant trends in students' perceptions of immersive technologies in their learning processes. Students report a high level of active participation (Mean: 4.43, SD: 0.655) during immersive sessions, supported by a low standard deviation that indicates shared agreement. The frequency of use is also perceived as high (Mean: 4.37, SD: 0.598), reflecting consensus among students. They believe immersive experiences realistically simulate real-world situations (Mean: 4.57, SD: 0.608) and are seen as authentic and relevant (Mean: 4.54, SD: 0.561). While immersive technologies are generally viewed as easy to use (Mean: 4.34, SD: 0.765), some variability exists in perceptions. Access to resources has the lowest mean score (Mean: 3.80, SD: 0.868), indicating difficulties for some students in consistently obtaining necessary resources. The quality (Mean: 4.46, SD: 0.657) and speed (Mean: 4.49, SD: 0.507) of feedback received are perceived positively, with near-unanimous agreement. Students feel that immersive technologies aid in identifying technological problems (Mean: 4.46, SD: 0.561) and enhance their ability to generate solutions (Mean: 4.23, SD: 0.547). They also believe these tools improve their capacity for developing detailed plans (Mean: 4.54, SD: 0.701) and enable more complex and viable designs (Mean: 4.31, SD: 0.676). Furthermore, immersive technologies are seen as critical for the successful implementation of technological solutions (Mean: 4.46, SD: 0.561) and for enhancing the effectiveness of testing and validation (Mean: 4.31, SD: 0.631). Additionally, they foster originality (Mean: 4.40, SD: 0.553) and significantly increase creativity in designs (Mean: 4.49, SD: 0.562), both of which are highly valued by students.

Table 2 presents the results of the frequency distribution of responses for the 16 items evaluated by 35 participants. Each item was evaluated using a 5-point Likert scale, ranging from "strongly disagree" to "strongly agree." A detailed analysis of the results explained in following sub-section.

Table 1. Descriptive statistics of collected data

Dimensions	Items	N	Minimum	Maximum	Mean	Deviation
Determine a technological solution alternative	Students actively participate during immersive learning sessions	35	3	5	4.43	0.655
	The frequency of immersive technology use is high in my learning process	35	3	5	4.37	0.598
	Immersive learning experiences realistically simulate real-world situations	35	3	5	4.57	0.608
	I perceive immersive experiences as authentic and relevant	35	3	5	4.54	0.561
Design a technological solution alternative	Immersive technologies are easy to use	35	3	5	4.34	0.765
	I have consistent access to the resources necessary for immersive activities	35	2	5	3.80	0.868
	The feedback received during immersive activities is of high quality	35	3	5	4.46	0.657
	The feedback is quick and helps me improve	35	4	5	4.49	0.507
Implement and validate a technological solution alternative.	The use of immersive technologies helps me identify technological problems more effectively	35	3	5	4.46	0.561
	Immersive experiences increase the number of proposals I generate to solve problems	35	3	5	4.23	0.547
	Immersive tools improve my ability to develop detailed plans for technological solutions	35	2	5	4.54	0.701
	Immersive experiences allow my designs to be more complex and viable	35	3	5	4.31	0.676
Innovation and creativity in technological design	The implementation of immersive technologies improves my success in implementing technological solutions	35	3	5	4.46	0.561
	Testing and validating my solutions are more effective when using immersive technologies	35	3	5	4.31	0.631
	Immersive experiences foster originality in my technological solutions	35	3	5	4.40	0.553
	Creativity in my designs increases significantly with the use of immersive tools	35	3	5	4.49	0.562

Table 2. Frequency distribution of collected data

Measurement	N°	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Frequency
Strongly disagree	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Disagree	2	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	2
Neutral	3	3	2	2	1	6	14	3	0	1	2	1	4	1	3	1	1	45
Agree	4	14	18	11	14	11	11	13	18	17	23	11	16	17	18	19	16	247
Strongly agree	5	18	15	22	20	18	9	19	17	17	10	22	15	17	14	15	18	266
Total	-	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	560

4.1. Response distribution

The responses reflect a strong positive consensus, with the majority of participants selecting “agree” or “strongly agree.” This indicates a favorable perception of the immersive learning experience and its impact on their technological competencies. Neutral responses were moderate, particularly regarding access to resources. This suggests some uncertainty or variability in students' experiences with the availability of technological tools. Despite this, overall perceptions remained highly favorable. The results highlight a general agreement on the effectiveness of immersive technologies in supporting learning and skill development.

4.2. Item interpretation

The responses indicate a strong positive perception of immersive technologies, with most participants agreeing or strongly agreeing with items related to realistic simulation (item 3), authenticity (item 4), skill improvement (item 11), and design complexity (item 12), suggesting that these aspects are highly valued. High agreement was also observed for items related to active participation (item 1) and creativity (item 15), reinforcing the positive impact of immersive technologies on engagement and originality. However, item 6, focused on consistent access to resources, received the highest number of neutral responses (14), suggesting some perceived inconsistency in technological resource availability. Overall, the low frequency of disagreement responses reflects minimal opposition or dissatisfaction, while neutral responses in item 6 highlight areas for potential improvement in resource accessibility for immersive activities.

The frequency analysis reveals a strong positive perception towards immersive technologies in the evaluated items. The high concentration of responses in “agree” and “strongly agree” for most items indicates that participants consider these technologies beneficial in various aspects, such as participation, creativity, and effectiveness in developing technological solutions. However, the number of neutral responses suggests that some areas, such as resource availability, could benefit from further improvements.

5. RESULTS

Previous research has explored the general benefits of immersive learning environments, such as VR and AR, across various educational fields, demonstrating their ability to enhance knowledge retention, engagement, and student creativity. However, few studies have specifically focused on evaluating the impact of these technologies on developing practical competencies in designing and building technological solutions among higher education students. This research offers a novel approach by quantitatively analyzing how these immersive environments can bridge the gap between theory and practice, providing empirical evidence of their effectiveness in developing essential technical skills to tackle current technological challenges.

Figure 1 reveals a strong positive perception among respondents in the "determination of technological solution alternatives" dimension, with most responses clustered in the "agree" and "strongly agree" categories. Items addressing the realistic simulation of real-world scenarios and the authenticity of immersive experiences (items 3 and 4) received the highest "strongly agree" responses, highlighting their impact. Items related to active participation and frequency of immersive technology use (items 1 and 2) were also well-regarded, though with slightly more responses in the "agree" category. Minimal neutral responses and no "strongly disagree" responses indicate a broad consensus on the effectiveness of immersive technologies in this area.

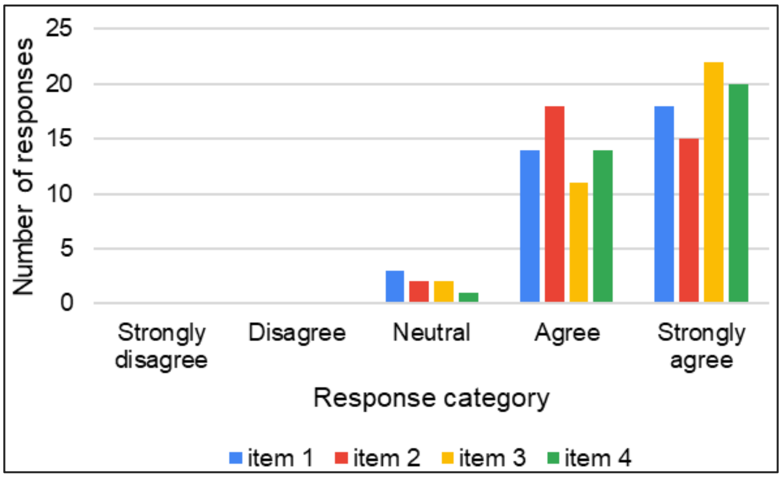

Figure 1. Comparison of responses for items related to the dimension: determination of technological solution alternatives

Figure 2 shows the distribution of responses in the "design of technological solutions" dimension for four specific items (5, 6, 7, and 8). Most participants expressed "agree" or "strongly agree" with the statements related to this dimension, highlighting a generally positive evaluation of the aspects assessed. However, item 6 shows lower agreement compared to the others, with some neutral responses and one disagreement. This suggests that while participants value the design of technological solutions, there are areas, such as consistent access to necessary resources (item 6), where perception is less favorable. This information can be useful for identifying areas for improvement in implementing immersive technologies in the design of technological solutions.

Figure 3 for the "implementation and validation of technological solutions" dimension shows a strong positive trend, with most participants favorably viewing the use of immersive technologies. However, a higher number of "neutral" responses in item 11 indicates some uncertainty about the effectiveness of specific tools, suggesting that certain aspects may need improvement or clearer guidance to enhance their impact. Figure 4 for the "innovation and creativity in technological design" dimension shows that most participants agree that immersive experiences enhance innovation and creativity, especially highlighted in item 16. The high concentration of positive responses, with few "neutral" and almost no disagreements, indicates a strong, widely positive perception of the impact of immersive tools on creative design.

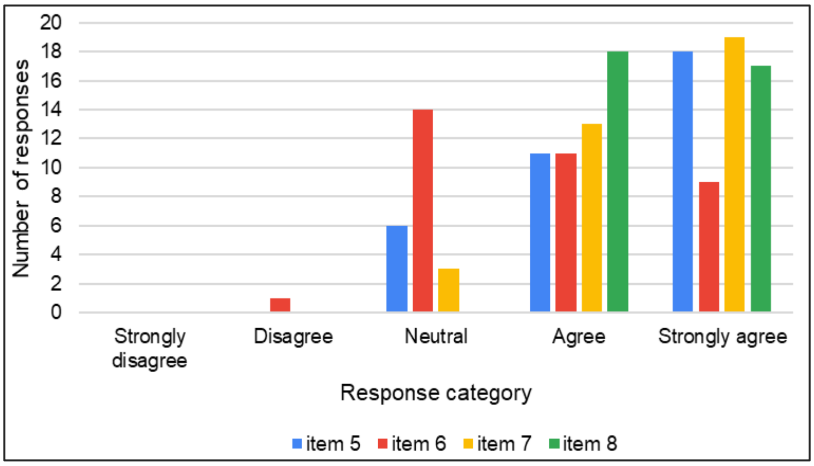

Figure 2. Comparison of responses for items related to the dimension: design of technological solutions

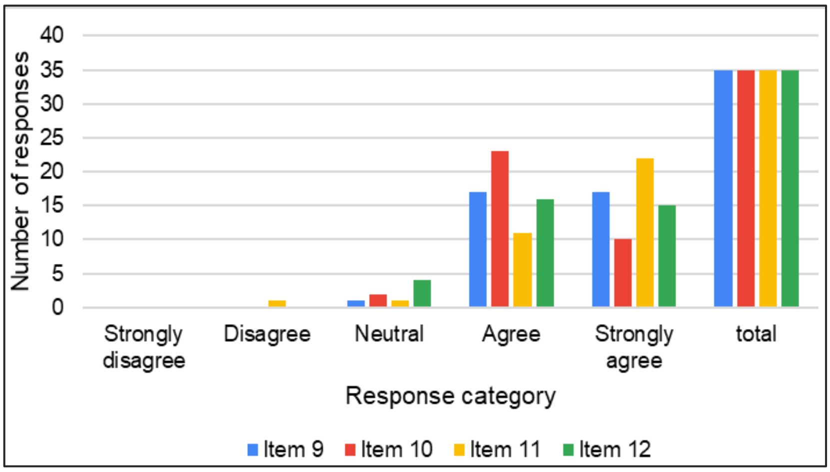

Figure 3. Comparison of responses to the items corresponding to the dimension: implementation and validation of technological solutions

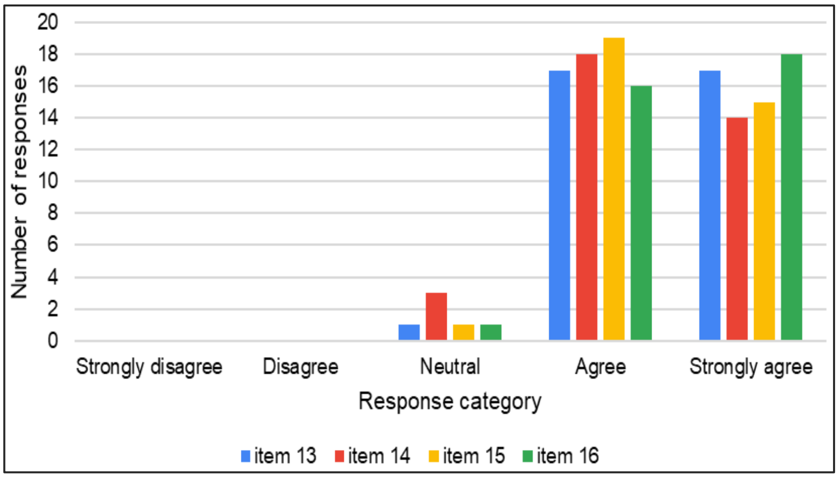

Figure 4. Comparison of responses to the items corresponding to the dimension: innovation and creativity in technological design

Figure 5 represents the key functions of VR and AR software in an educational environment to enhance students' problem-solving skills. The main modules and their interconnections are:

a. User interface (UI): located at the top left in light blue, this module provides an intuitive platform for students and teachers to interact with the VR/AR software. It includes navigation menus, start buttons, and gesture or touch controls, allowing users to select scenarios, interact with virtual objects, and access educational tools and resources.
b. Simulation module: located at the top right in light green, this module generates realistic virtual or augmented environments for immersive student experiences. Utilizing 3D graphics engines, it creates interactive scenarios, like virtual labs, engineering workshops, or anatomical explorations, where students can safely experiment and manipulate various variables.
c. Interactivity module: located at the center left in light coral, this module allows students to directly manipulate virtual objects and interact with elements within simulated scenarios. It offers real-time feedback on user actions, enhancing hands-on learning and problem-solving through experimentation.
d. Evaluation module: located at the center right in light yellow, this module analyzes student performance in VR/AR activities by providing statistics on progress, identifying errors, and generating evaluation reports. It helps pinpoint areas for improvement, ensuring that students grasp essential concepts and techniques.
e. Collaboration module: located at the bottom left in light pink, this module enables real-time interaction among multiple users within a shared virtual environment. It supports collaborative problem-solving, allowing students to work together, exchange ideas, and find solutions collectively in a common virtual space.
f. Adaptive feedback module: located at the bottom right in light gray, this module dynamically adjusts activity difficulty and content based on student performance. Utilizing artificial intelligence algorithms, it provides a personalized learning experience, ensuring each student receives challenges suited to their skill level and learning needs.
g. Connections between the modules: arrows depict the workflow among modules: the UI connects to the simulation module to start the experience, while the interactivity, evaluation, collaboration, and adaptive feedback modules interlink to create an interactive, personalized learning environment.
h. Additional visual elements: the diagram uses icons for virtual environments, interactive objects, real-time feedback, collaboration, and adaptive content to illustrate how VR and AR modules combine to enhance problem-solving skills in an immersive, interactive learning experience.

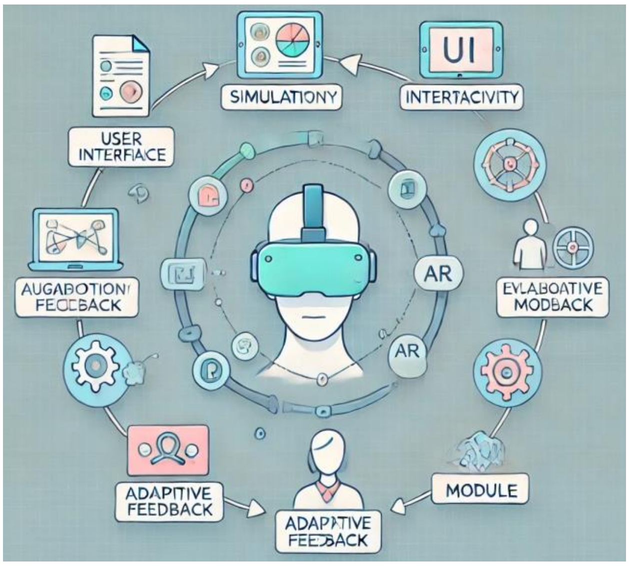

Figure 5. Functions of VR/AR software for the improvement of problem-solving skills

6. DISCUSSION

Comparison between the results of our research and previous studies on immersive technologies reveals both significant similarities and differences in the educational impact of these tools. Our research shows that students positively value the use of immersive technologies, especially in terms of realism, authenticity, relevance, creativity, and active participation. These findings align with the study by Hurtado-Mazeyra *et al*. [13], which found that AR is more effective than 2D digital storytelling in developing creativity in preschool children. Similarly, Rodríguez *et al*. [15] highlighted that AR significantly improves learning in secondary education, although they noted the need for ongoing training for educators—a challenge also reflected in our study, where some variability in the perceived ease of use of these technologies was observed.

In the field of medical education, Delgado [14] emphasized the growing interest in integrating VR into medical training, underscoring the importance of innovation and interdisciplinary collaboration for its effective implementation. This approach aligns with the positive results reported by our students regarding rapid and high-quality feedback. Similarly, Maraza-Quispe *et al*. [16] found that AR not only facilitates the understanding of complex content, such as cellular biology, but also creates a positive emotional environment, which corresponds with our students' positive perceptions of the authenticity and relevance of immersive experiences.

Additionally, our research identified an area for improvement in access to technological resources, consistent with the findings of Antón-Sancho *et al*. [17], who identified a lack of digital skills among university professors for the effective use of VR, highlighting the need to enhance training in digital competencies. Regarding the perception of traditional technologies, our results contrast with those of Rios [18], who reported a negative perception of traditional methods in teaching anatomy, emphasizing the need to adopt innovative methods such as virtual trainers. Other studies [21]–[23] have demonstrated a high correlation between immersive technologies and meaningful learning, which aligns with the positive perceptions observed in our research regarding the ability of these technologies to foster originality and creativity in designing technological solutions. Overall, our findings and those of previous studies highlight the significant and positive impact of immersive technologies in education, although they also emphasize the need for continuous training and adequate access to resources to maximize their effectiveness in various educational contexts.

In the context of STEM disciplines, several research [25], [28] demonstrated that AR applications can not only attract and maintain student interest but also improve the effectiveness of teaching these disciplines. These findings align with our observation that immersive technologies are positively valued by students in terms of realism and relevance. Additionally, López-Bouzas and Pérez [26] demonstrated that AR is effective in a project-based learning environment, which is reflected in our study, where students perceive those immersive technologies foster originality and creativity in their technological solutions.

On the other hand, the research by Makransky and Petersen [3] that developed the CAMIL model highlights how cognitive and affective components interact in VR environments to optimize learning, an aspect also identified in our research through the high valuation of rapid and quality feedback that students receive in immersive environments. This emphasis on cognitive-affective interaction was also underscored by Maraza-Quispe *et al*. [16], who demonstrated that AR not only facilitates the learning of complex content but also creates a positive emotional environment. Professional training and digital competence are other areas of common interest. Previous research [17], [30] highlighted the need to improve educators' digital competencies to maximize the potential of immersive technologies, a need that also emerged in our study, particularly concerning the variability observed in the ease of use of these technologies. Similarly, Shvardak *et al*. [29] showed how AR can enhance health preservation competencies among physical education teachers, highlighting the utility of these technologies in specific professional contexts, which was also reflected in our students' perceptions of the effectiveness of immersive tools in identifying and solving technological problems.

Finally, in the context of higher education, previous research [32], [33] emphasized the importance of integrating immersive technologies such as AR and VR to promote sustainable educational practices and improve surgical outcomes, respectively. Our research confirms the positive perception of these technologies in the context of technological education, highlighting their impact on creativity, realism, and effectiveness in the teaching-learning process. However, the need for continuous training and adequate access to resources, identified in our research, resonates with the challenges mentioned in previous studies [17], [25], [30].

7. CONCLUSION

The research demonstrated that the use of immersive technologies, such as AR and VR, has a significant positive impact on the learning process, improving not only academic performance but also creativity and originality in solving technological problems. Students actively participated and perceived these experiences as authentic and relevant, supporting the continued integration of these technologies into the educational environment. The results indicated that immersive technologies facilitate a more complex and viable design of technological solutions, enhancing students' ability to develop detailed plans and achieve successful implementations. Students who used these technologies reported an increase in the quantity and quality of proposed technological solutions.

The research confirmed that the implementation of immersive technologies significantly improves the process of validating and testing technological solutions. Students were able to identify technological problems more effectively and conduct more rigorous tests, resulting in more robust and efficient technological solutions. Immersive tools proved to be highly effective in fostering innovation and creativity in technological design. Students reported a significant increase in their creative capacity when using these tools, suggesting that immersive technologies are essential for developing innovative skills in educational contexts. The research confirms that immersive technologies significantly enhance learning, design, implementation, and innovation in education. However, challenges related to teacher training and technological accessibility need to be addressed to fully realize their potential in the future.

The research faced limitations due to a small sample size, varying familiarity with immersive technologies, and restricted access to resources and time, which may have impacted results. Future studies should involve larger, diverse samples, provide prior training, and conduct longitudinal analysis to assess long-term effects. Exploring adoption barriers, like technological and economic challenges, could enhance the integration and effectiveness of immersive tools in education.

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AUTHOR CONTRIBUTIONS STATEMENT

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
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R : **R**esources
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Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that there are no financial, personal, or professional conflicts of interest that could have influenced the results or interpretations of this research.

INFORMED CONSENT

All participants in this study provided informed consent prior to their participation, ensuring their understanding and acceptance of the study's objectives, procedures, and potential implications.

ETHICAL APPROVAL

The research related to human use has been complied with all the relevant national regulations and institutional policies in accordance with the tenets of the Helsinki Declaration and has been approved by the authors' institutional review board or equivalent committee.

DATA AVAILABILITY

The data that support the findings of this study will be available in OSFHOME https://osf.io/5nex7/?view_only=6422f5776bf2417699c52590ea9cddb0.

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