A Mixed-Methods Approach to Determine the Impact of Immersive Learning on Achieving Technological Competencies in Basic Education

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***Abstract*—The research aimed to determine the impact of immersive learning on achieving the competence "designs and builds technological solutions to solve problems" in secondary education students and its effect on four specific capacities: determining a technological solution, designing a technological solution, implementing and validating technological solution alternatives, and fostering innovation and creativity in technological design. Using a mixed-methods approach with a quasi-experimental design, a structured Likert-scale questionnaire and an interview were administered to 105 students participating in a program integrating immersive technologies. Quantitative data from the survey were analyzed using statistical techniques, and qualitative data from the interviews were categorized and coded. The results showed a significant positive impact of immersive experiences on the development of technological competencies. Students perceived these experiences as highly relevant and authentic, promoting active participation, enhancing creativity and originality in the design of technological solutions, and increasing effectiveness in implementation and validation. However, challenges such as resource availability and the need for continuous teacher training were identified, which must be addressed to maximize the potential of these technologies in education. The conclusion suggests that immersive technologies, such as augmented and virtual reality, are effective tools for improving both academic performance and students' practical skills, highlighting the importance of their integration into different educational contexts to strengthen the development of technological competencies.**

***Keywords*—immersive learning, technological competencies, Virtual Reality (VR), educational innovation, solution design**

I. 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 that gave rise to this research lies in the observation that conventional teaching methods do not adequately develop the necessary technological competencies in students, particularly in their ability to design and build technological solutions. 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 reference [8], this type of learning is developed in three-dimensional environments, while reference [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

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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.

II. Literature Review

A. Transformative Potential of Immersive Learning in Education

The studies reviewed highlight the transformative potential of immersive learning technologies, particularly AR and VR, in various educational settings. Hurtado-Mazeyra *et al*. [13] investigated the use of AR and 2D digital storytelling in developing creativity among preschool children. While both modalities enhanced creativity, AR proved significantly more effective, demonstrating how emerging technologies can provide enriching and engaging learning experiences from an early age. This finding underscores the role of AR in fostering key skills through interactive and immersive approaches. Similarly, Díaz [14] focused on immersive learning in medical education, particularly through VR training games. Their bibliometric and qualitative analysis revealed a growing interest in integrating VR into medical training, emphasizing the importance of interdisciplinary collaboration to develop innovative educational tools. These findings demonstrate that immersive learning not only enhances skill acquisition but also fosters innovation in educational and healthcare settings. According to the study developed by reference [15], VR and AR technologies have advanced rapidly, being applied in education to create Immersive Learning Environments (ILE) that enhance the quality and efficiency of learning. Despite the advancements, challenges remain, such as content placement in multidimensional spaces and image quality improvement through advanced algorithms. The study proposes an innovative method to optimize these environments, using a Region-Specific Super-Resolution (PSS) algorithm with non-local feature fusion.

The study by Fitrianto *et al*. [16] analyzes the impact of VR on experiential learning, showing that it significantly improves student engagement, understanding of complex concepts, and knowledge retention. However, technical and pedagogical challenges are identified, such as the need for adequate infrastructure, teacher training, and curriculum alignment. The study highlights the transformative potential of VR and suggests recommendations for its strategic integration into curriculum design and teacher professional development. Finally, the study by Fernandes *et al*. [17] reviews immersive learning frameworks, categorizing them based on their purpose and the elements that compose them. The findings indicate that most frameworks are theoretical models exploring causal relationships between immersive factors and learning outcomes, but practical frameworks are needed to address technical aspects and facilitate the development and use of immersive virtual environments in education.

B. Impact of Immersive Technologies on Learning Outcomes

In secondary education, Mazzarri *et al*. [18] examined the implementation of a mobile AR application and found that AR significantly improved the learning process, particularly in understanding abstract concepts. However, the study also identified challenges, including the need for ongoing teacher training, especially for older educators, to ensure the effective use of these technologies. This aligns with Maraza-Quispe *et al*. [19], who demonstrated that AR enhances understanding of complex topics like cell biology while creating a positive emotional environment conducive to learning. Using ARToolkit and Unity3D, their research revealed that students exposed to AR showed notable improvements in academic performance and emotional satisfaction compared to a control group. These findings highlight the dual benefits of AR in improving academic understanding and emotional engagement, both of which are critical for achieving educational goals. Reference [20] showed that VR in higher education enhances teaching effectiveness, although it requires greater digital competency training for educators. Baxter *et al*. [21] highlighted that virtual training systems in anatomy improve students' comprehension and engagement, outperforming traditional methods. Lampropoulos *et al*. [22] demonstrated that VR effectively develops emotional skills, offering unique advantages in terms of immersion. Delgado-Rodríguez *et al*. [23] emphasized how Mixed Reality (MR) personalizes learning and fosters engagement among students and teachers. In university settings, Cabrera-Duffaut *et al*. [24] revealed a strong correlation between virtual environments and meaningful learning. In secondary education, References [25, 26] indicated that AR improves the understanding of abstract concepts, satisfaction, and academic performance, while reference [27] confirmed its effectiveness in fostering critical thinking and enhancing knowledge acquisition. These studies highlight that VR, AR, and MR not only transform academic and emotional learning but also modernize education by personalizing it and fostering advanced practical and cognitive skills.

C. Augmented Reality in STEM and Critical Thinking Development

The role of AR in fostering critical thinking and engagement in Science, Technology, Engineering and Mathematics (STEM) education is well-documented. Camps-Ortueta *et al*. [28] investigated the use of AR at the National Museum of Natural Sciences to promote interest in STEM disciplines. Their findings show that AR-based applications effectively attract and sustain interest in educational activities, demonstrating its potential to enhance learning in informal settings. López-Bouzas *et al*. [29] further emphasized the effectiveness of AR in improving academic performance within project-based learning environments, underscoring its ability to integrate theoretical knowledge with practical application. Additionally, Osadchyi, [30] explored the relationship between AR and the teaching-learning process in a chemistry course, finding that AR not only enhanced student performance but also increased satisfaction. These studies collectively suggest that AR is a key tool for fostering critical thinking and scientific inquiry among students [31].

D. Interdisciplinary Contributions and Advanced Applications

In higher education and professional training, immersive technologies are being adopted to address complex learning needs. Shvardak *et al*. [32] demonstrated the effectiveness of VR and AR in surgical planning and training, highlighting their role in improving surgical outcomes. Similarly, Martzoukou [33] evaluated VR's impact in dental education, revealing significant improvements in students' understanding, satisfaction, and motivation compared to conventional methods. However, challenges such as the lack of real-time interaction and device-related discomfort were noted. Aramburuzabala *et al*. [34] extended this exploration to secondary education, analyzing the use of AR/VR in blended learning environments. Their findings emphasize the importance of integrating immersive tools with innovative pedagogical methodologies to enhance motivation, comprehension, and problem-solving skills. These results highlight the versatility of AR/VR in bridging the gap between theoretical knowledge and practical application.

E. Key Challenges and Areas for Improvement

Despite their potential, immersive learning technologies face several challenges. Noguera [35] identified educators' lack of familiarity with these tools as a significant barrier to effective implementation. This is further complicated by the high costs associated with AR/VR development and maintenance [36], which limit accessibility for many educational institutions. Cognitive overload among students, particularly when interacting with complex virtual environments without proper guidance, was highlighted by reference [37] as another critical issue. Additionally, Chen *et al* [38] warned of the risks associated with over-reliance on technology, which could diminish intrinsic motivation if learning experiences are not well-designed to foster meaningful engagement. These findings point to the need for ongoing training for educators, effective pedagogical design, and cost-effective solutions to address these barriers.

F. Synthesis and Relevance to Current Research

The reviewed studies collectively demonstrate the transformative impact of immersive technologies in education. From fostering creativity in early childhood [13] to enhancing critical thinking and practical competencies in secondary and higher education [15, 39], AR and VR have proven effective in addressing diverse learning needs. They have shown the potential to improve academic outcomes, emotional engagement, and skill acquisition, as seen in medical and STEM education [14, 28, 40]. However, the challenges highlighted, including cost, cognitive overload, and the need for teacher training, underscore the importance of adaptive and sustainable integration strategies. For this research, these findings provide a robust framework to explore the role of immersive technologies in developing technological competencies, emphasizing the necessity of combining innovative tools with targeted pedagogical approaches to maximize their effectiveness. The research [41, 42] conducted by the research examines the effectiveness of immersive VR and AR technologies, collectively known as Extended Reality (XR), in anatomy learning compared to traditional methods. The findings indicate that XR enhances learning by improving comprehension and academic performance, particularly when used as complementary tools. Additionally, students perceive these technologies as useful and effective for learning, emphasizing their ability to enrich the educational experience and overcome the limitations of traditional approaches.

III. Methodology

A. Research Design

The research employed a mixed-methods approach with a quasi-experimental design, integrating the use of a structured questionnaire and interviews for data collection. Both instruments focused on evaluating students' perceptions of their experiences with immersive virtual environments. The tools covered four key dimensions: determining technological solution alternatives, designing technological solutions, implementing and validating technological solutions, and fostering innovation and creativity in technological design.

B. Population and Sample

The sample consisted of 105 students who actively participated in a program that incorporated immersive technologies as part of their learning process. The participants were selected through non-probabilistic convenience sampling from a population of 300 students. The inclusion and exclusion criteria considered are detailed below:

1) Inclusion Criteria
- Students enrolled in the eighth cycle of the Educational Informatics program.
- Students who actively participated in immersive learning activities during a specified period.
- Students available and willing to complete the survey.
- Students with access to the necessary technologies to participate in the evaluated immersive activities.

2) Exclusion Criteria

- Students who did not participate or had minimal participation in immersive learning activities.
- Students without access to the necessary technologies for implementing immersive activities.
- Students unable to complete the survey due to personal, health, or technological reasons.
- Students who did not provide consent to participate in the survey.
- Students who were significantly absent during the implementation period of the immersive activities and, therefore, do not have sufficient experience to respond to the survey.

C. Data Collection Instruments

The data collection instruments used were a structured questionnaire (Applied to a sample of 105 students) and an interview designed (Applied to a sample of 35 students) to assess students' perceptions of the implementation of immersive learning in their teaching-learning process, specifically regarding the achievement of competencies related to designing and constructing technological solutions. The questionnaire was based on a 5-point Likert scale, allowing participants to express their level of agreement or disagreement with various statements, while the interview consisted of 12 open-ended questions. Both instruments covered four main dimensions, each composed of several specific items:

- Determining Technological Solution Alternatives: Assessed students' ability to identify and propose technological alternatives to solve problems, as well as the frequency and effectiveness of using immersive technologies in this process.
- Designing Technological Solutions: Included items focusing on students' ability to design detailed and effective technological solutions, highlighting how immersive experiences facilitate this process.
- Implementing and Validating Technological Solutions: Measured the effectiveness of immersive tools in implementing and validating proposed technological solutions, evaluating the success of their practical application.
- 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.
- In the questionnaire, each dimension included four items, carefully designed to capture key aspects of immersive learning. Similarly, the interview included three open-ended questions per dimension.

The ethical procedures followed in this research adhered to international standards to ensure the protection of participants. Prior to data collection, informed consent was obtained from all student participants, who were informed about the nature, objectives, and voluntary nature of their participation. Furthermore, the research was approved by the Ethics Committee of the Universidad Nacional de San Agustín de Arequipa (UNSA), ensuring that the procedures were ethically appropriate and safeguarded the confidentiality of the collected information.

The selection of procedures and software used in this research was justified by their ability to ensure a comprehensive and rigorous analysis of the collected data. The mixed-methods design allowed for the combination of quantitative and qualitative approaches, maximizing the depth and breadth of the analysis. Statistical methods, such as descriptive analysis and the validation of instruments through Cronbach's alpha, ensured the reliability of the numerical results. Additionally, the software chosen for data analysis facilitated the organization and visualization of results, enabling the identification of key trends and relationships between the studied variables. For content analysis, the software allowed for the categorization and coding of qualitative responses, which, when integrated with quantitative data, provided a more complete and coherent understanding of how immersive technologies influence the development of technological competencies. This integration of tools and procedures aligned with the research objectives, ensuring robust and well-supported results.

D. Development of Reliability Analysis and Exploratory Factor Analysis (EFA)

To assess the internal consistency and validity of the dimensions in the instrument used in this research, the following statistical procedures were carried out:

1) Calculation of cronbach's alpha

Cronbach's Alpha was employed to measure the reliability of the applied instrument, aiming to determine whether the items within each evaluated dimension consistently measure the same construct.

The calculation of Cronbach's Alpha for each dimension showed values above 0.70, indicating good internal consistency. Overall:

- Dimension 1: Alpha = 0.78
- Dimension 2: Alpha = 0.81
- Dimension 3: Alpha = 0.84
- Dimension 4: Alpha = 0.83

The total alpha for the entire instrument was 0.85, supporting the reliability of the questionnaire to measure students' perceptions of immersive technologies.

2) Exploratory Factor Analysis

To validate that the four dimensions reflect independent and coherent constructs, an EFA was performed. The main steps included:

3) Data adequacy testing

The Kaiser-Meyer-Olkin (KMO) test yielded a value of 0.86, indicating that the data were suitable for factor analysis.

Bartlett's Test of Sphericity was significant ($\chi^2 = 512.3$, $p < 0.001$), confirming that the data had sufficient correlations to perform the EFA.

4) Selection criteria

Factors with eigenvalues greater than 1 were retained, identifying four main factors that explained 72.5% of the total variance.

5) Analysis results

Factor loadings (Table 1) for each item within their respective dimension ranged between 0.72 and 0.89, demonstrating a strong relationship between the items and their corresponding dimensions.

Table 1. Factor loadings

Item / Factor	Factor 1	Factor 2	Factor 3	Factor 4
Determine a technological solution alternative	0.75	0.20	0.10	0.05
Design a technological solution alternative	0.65	0.80	0.05	0.10
Implement and validate a technological solution	0.05	0.10	0.85	0.12
Innovation and Creativity in Technological Design	0.10	0.25	0.10	0.88

E. Procedure

The procedure for administering the questionnaire and interview began with the development and validation of the instruments by experts in education and educational technology, ensuring the clarity and relevance of the items. A non-probabilistic sample of 105 students who had participated in immersive learning experiences was selected. Prior to administration, students were informed about the purpose of the research, emphasizing the voluntary and anonymous nature of their participation. The questionnaire was administered in person, with 50 minutes allocated for its completion.

F. Proposed Activity in the Immersive Learning Experience

1) Topic

Designing technological solutions for studying the cell through immersive virtual reality.

2) Objective

Use immersive virtual reality to enable students to design and construct innovative technological solutions that facilitate the study and understanding of the cell, developing the competence of designing and constructing technological solutions.

3) Activity Description

Preparation:

The instructor selects a virtual reality platform or application that allows students to explore a cell in detail, visualizing its organelles, functions, and processes in 3D.

Students are organized into teams and assigned a problem related to the study of the cell, such as difficulty visualizing complex cellular processes, understanding interactions between organelles, or explaining how cells respond to external stimuli.

4) Activity development:

a) Virtual exploration

- Students enter the virtual reality experience to explore the cell in an immersive environment. They can “enter” the cell, observe its components from different angles, and experience cellular processes such as mitosis or protein synthesis.
- During this exploration, teams identify areas where technology can enhance understanding or teaching of the cell.

b) Problem identification and brainstorming

- Each team discusses and defines a specific problem they encountered during their VR exploration (e.g., difficulty visualizing mitochondria in action or understanding how DNA replicates within the nucleus).
- Teams brainstorm to design a technological solution that addresses this problem. This could include improved VR applications, interactive simulations, or educational tools.

c) Solution design

- Using design software (such as Tinkercad, SketchUp, or even VR design tools), students create a prototype of their solution. This prototype could be a conceptual design of a new VR application, an educational interface, or a 3D model illustrating a cellular process.
- Students develop a written proposal explaining the identified problem, the proposed technological solution, and how it will enhance the study or teaching of the cell.

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 develop technological design skills applied to the field of cell biology.
- Understanding of the cell’s structure and functions will be increased through a practical and creative approach.
- Students will experience using virtual reality tools not only as consumers but as creators of educational solutions.
- This activity fosters deep learning of the cell while promoting competence in designing and constructing innovative technological solutions, integrating biology with cutting-edge technology.

IV. DATA COLLECTION

The data in Table 2 reflect students’ perceptions, gathered through the administration of a questionnaire to 105 students, regarding the impact of immersive technologies on the development of competencies related to designing and constructing technological solutions (see database[1]). These perceptions are organized into four key dimensions: determining, designing, implementing and validating technological alternatives, and innovation and creativity. High mean scores (between 4.23 and 4.57) indicate predominantly positive perceptions, highlighting aspects such as the authenticity of immersive experiences (4.54), their ability to realistically simulate real-world situations (4.57), the quality of feedback received (4.46), and the increase in creativity in designs (4.49). However, access to necessary resources for immersive activities scored lower (3.80) with greater variability (standard deviation of 0.868), signaling an area for improvement.

Overall, students perceive immersive technologies as effective learning tools, emphasizing their relevance in

[1]https://osf.io/5nex7/?view_only=6422f5776bf2417699c52590ea9cddb0

enhancing creativity, the quality of technological design, and solving complex problems.

In conclusion, students positively value the impact of immersive technologies on their learning, especially in terms of realism, relevance, feedback, and creativity. However, access to resources is an area that shows some variability in perceptions, suggesting potential areas for improvement.

Table 2. Descriptive statistics of collected data

Dimensions	Items	Minimum	Maximum	Mean	Deviation
Determine a technological solution alternative	Students actively participate during immersive learning sessions	3	5	4.43	0.655
	The frequency of immersive technology use is high in my learning process	3	5	4.37	0.598
	Immersive learning experiences realistically simulate real-world situations	3	5	4.57	0.608
	I perceive immersive experiences as authentic and relevant	3	5	4.54	0.561
Design a technological solution alternative	Immersive technologies are easy to use	3	5	4.34	0.765
	I have consistent access to the resources necessary for immersive activities	2	5	3.80	0.868
	The feedback received during immersive activities is of high quality	3	5	4.46	0.657
	The feedback is quick and helps me improve	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	3	5	4.46	0.561
	Immersive experiences increase the number of proposals I generate to solve problems	3	5	4.23	0.547
	Immersive tools improve my ability to develop detailed plans for technological solutions	2	5	4.54	0.701
	Immersive experiences allow my designs to be more complex and viable	3	5	4.31	0.676
Innovation and Creativity in Technological Design	The implementation of immersive technologies improves my success in implementing technological solutions	3	5	4.46	0.561
	Testing and validating my solutions are more effective when using immersive technologies	3	5	4.31	0.631
	Immersive experiences foster originality in my technological solutions	3	5	4.40	0.553
	Creativity in my designs increases significantly with the use of immersive tools	3	5	4.49	0.562
	Overall average	3	5	4.39	0.638

The Table 3 demonstrates overwhelmingly positive student perceptions of immersive learning technologies, with the majority of responses falling in the "Agree" (758) and "Strongly Agree" (781) categories across 16 evaluated items. Key strengths include fostering active participation, realistic simulations of real-world scenarios, creativity, and high-quality feedback, as these items received the highest levels of agreement. Minimal disagreement (6 responses) and relatively few neutral responses (135) further emphasize the strong acceptability of these tools. However, consistent access to resources for immersive activities stands out as a challenge, reflected in higher neutral responses for item 6. Overall, the data highlight the effectiveness of immersive technologies in enhancing technological competencies while identifying resource accessibility as an area for improvement to maximize their impact.

The overall mean of responses across all dimensions is 4.39, reflecting a predominantly positive perception among participants regarding immersive technologies and their impact on technological competencies. At the dimension level, the means are as follows:

- Determine a technological solution alternative: 4.48
- Design a technological solution alternative: 4.27
- Implement and validate a technological solution alternative: 4.39
- Innovation and creativity in technological design: 4.42

These results indicate that students particularly value immersive technologies for identifying technological solutions, with this dimension showing the highest mean score. On the other hand, although "Design a technological solution alternative" has the lowest mean (4.27), it still reflects a positive evaluation. These perceptions demonstrate how these tools significantly contribute to the development of technological competencies, fostering creativity and the ability to effectively design and implement solutions.

Table 3. 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	1	0	2	0	0	1	0	2	0	0	0	0	0	6
Neutral	3	8	6	10	15	14	28	7	3	3	8	3	11	3	6	5	5	135
Agree	4	40	50	34	42	38	41	43	59	46	64	40	51	54	54	53	49	758
Strongly Agree	5	57	49	61	47	53	34	55	43	55	33	60	43	48	45	47	51	781
Total	–	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	1680

A. General Trends

The overall trend in responses suggests a positive perception towards the use of immersive technologies, with most participants agreeing or strongly agreeing with the evaluated items.

The low frequency of disagreement responses suggests little opposition or dissatisfaction among participants regarding the evaluated aspects of immersive technologies.

The moderate number of neutral responses, especially in item 6, could indicate areas that require improvement, such as consistent access to technological resources needed 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.

B. Interview Results

The Table 4 demonstrates the interview items were designed to explore students' perceptions of immersive learning technologies across four key dimensions (see database[1]). For "Determining a Technological Solution Alternative," questions focused on how immersive environments influence the ability to identify alternatives, propose innovative solutions, and evaluate options effectively. In "Designing a Technological Solution Alternative," items examined the impact of immersive learning on designing detailed and effective solutions, improvements in visualization and planning skills, and comparisons with traditional learning settings. The "Implementing and Validating a Technological Solution Alternative" dimension addressed the extent to which immersive learning facilitates practical implementation, enhances testing and validation capabilities, and supports adjustments during implementation. Finally, the "Innovation and Creativity in Technological Design" dimension explored how immersive environments stimulate creativity, enable innovation, and foster unconventional thinking in designing technological solutions. These items aim to capture a comprehensive understanding of the role of immersive technologies in developing technological competencies.

Table 4. Questions by interview dimensions

Dimensions	Items
Determine a technological solution alternative	How do you think immersive learning environments have influenced your ability to identify different technological alternatives for solving problems?
	Could you describe a situation where the use of immersive technologies helped you propose an innovative solution to a specific problem?
	How effective do you consider immersive environments in enhancing your ability to evaluate different technological options before deciding on a solution?
Design a technological solution alternative	In what ways do you think immersive learning has impacted your ability to design detailed and effective technological solutions?
	Have you noticed improvements in your ability to visualize and plan technological solutions through immersive experiences? If so, can you provide an example
	How do you compare the effectiveness of the designs you create in immersive environments versus those created in traditional learning settings?
Implement and validate a technological solution alternative.	To what extent do you feel immersive learning has facilitated the practical implementation of the technological solutions you have designed?
	Do you consider immersive technologies to enhance your ability to test and validate proposed technological solutions? Why?
	Can you mention a case where you used an immersive environment to adjust or improve a technological solution during its implementation?
Innovation and Creativity in Technological Design	How do you think immersive learning environments have stimulated your creativity when designing technological solutions?
	Can you describe an experience where the use of immersive technologies allowed you to innovate or develop a unique technological solution?
	How do you perceive the relationship between immersion in virtual environments and your ability to think outside the box when designing technological solutions?

V. Analysis and Interpretation of Results

A. Quantitative Data Analysis

To analyze the collected data, the responses were compared across each evaluated dimension (Determination of Technological Solution Alternatives, Design of Technological Solutions, Implementation and Validation of Technological Solutions, and Innovation and Creativity in Technological Design). This comparison allows for the identification of patterns and differences in how students perceive and value different phases of the immersive learning process. By observing the consistency or variability in responses across dimensions, areas where students show more or less agreement can be detected, providing key insights into the strengths and weaknesses of using immersive technologies.

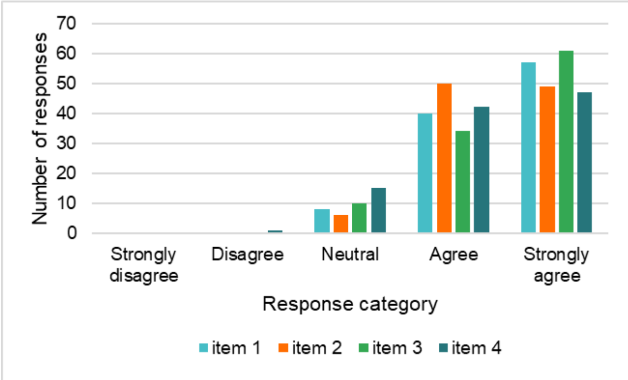

Fig. 1. Comparison of responses for items related to the dimension: determination of technological solution alternatives.

The Fig. 1 reflects overwhelmingly positive student perceptions of immersive learning technologies in the dimension of "Determination of Technological Solution Alternatives," with most responses falling into the "Agree" and "Strongly Agree" categories across all five items. This indicates that students perceive these technologies as highly effective in fostering active participation, identifying alternatives, and evaluating solutions. Neutral responses, while present (particularly in Items 3, 4, and 5), are minimal and suggest minor areas for potential improvement. Disagreement is nearly nonexistent, highlighting broad acceptance and satisfaction with the impact of immersive technologies on this competency. Overall, the results confirm the strong role of immersive learning in enhancing students' abilities to determine technological solutions.

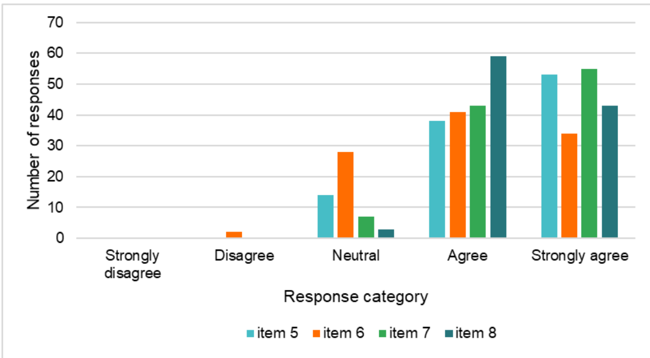

Fig. 2. Comparison of responses for items related to the dimension: design of technological solutions.

The Fig. 2 shows overwhelmingly positive student perceptions of immersive learning technologies, with the majority of responses in the "Agree" and "Strongly Agree" categories across all four items. Items 7 and 8 received the highest levels of positive agreement, reflecting strong satisfaction with these aspects of the learning experience.

Neutral responses were more frequent in Item 6 (28), indicating some uncertainty or variability in perceptions, suggesting an area for potential improvement. Disagreement was minimal, with no "Strongly Disagree" responses and only two "Disagree" responses for Item 6. Overall, the data confirm the effectiveness and broad acceptance of immersive technologies, highlighting their significant impact while pointing to minor areas for refinement.

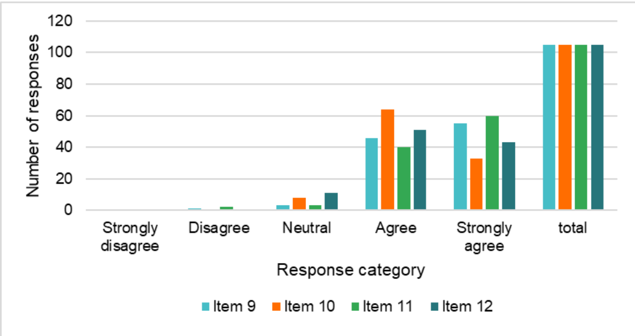

Fig. 3. Comparison of responses to the items corresponding to the dimension: Implementation and validation of technological solutions.

The Fig. 3 demonstrates predominantly positive student perceptions of immersive learning technologies, with the majority of responses falling in the "Agree" and "Strongly Agree" categories across all four items. Items 9 and 11 stand out with particularly high levels of agreement, reflecting strong satisfaction with these aspects of the learning process. Neutral responses are minimal, with Item 12 showing the highest at 11, indicating slight uncertainty or areas for improvement. Disagreement is nearly absent, with no "Strongly Disagree" responses and very few "Disagree" responses across items. Overall, the data confirm the effectiveness and broad acceptance of immersive learning technologies, emphasizing their positive impact on students' learning experiences.

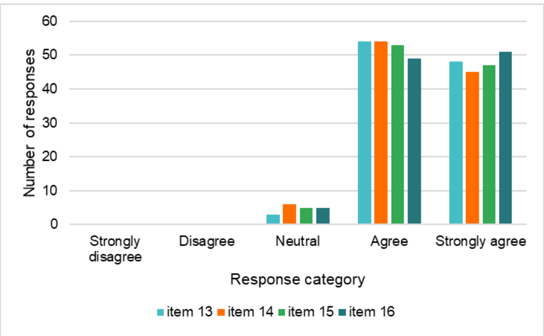

Fig. 4. Comparison of responses to the items corresponding to the dimension: Innovation and creativity in technological design.

The Fig. 4 reflects overwhelmingly positive student perceptions of immersive learning technologies, with the majority of responses in the "Agree" and "Strongly Agree" categories across all four items. Items 13 and 16 received particularly high levels of agreement, indicating strong satisfaction with these aspects of the learning experience. Neutral responses are minimal, ranging from 3 to 6 across items, suggesting very few instances of uncertainty. No responses fall in the "Disagree" or "Strongly Disagree" categories, indicating universal acceptance of the evaluated aspects. Overall, the data confirm the high effectiveness and strong approval of immersive learning technologies in enhancing the learning process.

B. Qualitative Data Analysis

The qualitative analysis of interview data was organized into five categories: learning experiences in virtual environments, development of problem-solving skills, impact on creativity and innovative thinking, testing and validation of technological solutions, and collaboration in virtual environments. Students highlighted the use of VR and AR for realistic simulations, 3D model visualization, and safe experimentation, which enhanced their understanding of complex concepts. Immersive technologies were seen as effective in fostering problem-solving skills through prototyping, evaluating alternatives, and decision-making. They also stimulated creativity by encouraging innovative thinking and exploring non-traditional approaches. Additionally, students valued immersive tools for early prototype validation, identifying errors, and optimizing solutions. Collaborative work was significantly improved, with enhanced communication, real-time interaction, and shared virtual workspaces. Overall, the analysis underscores the transformative role of immersive technologies in enhancing engagement, creativity, and teamwork in learning environments.

C. Results of the Qualitative Analysis

1) Qualitative analysis process

The qualitative analysis was conducted using a thematic analysis approach, identifying significant patterns in participants' responses. First, interview transcripts were coded, highlighting relevant excerpts related to the study's dimensions. These codes were subsequently grouped into key thematic categories. Category review included triangulation among researchers to ensure consistency and validity of the analysis. Finally, basic demographic information of the participants was incorporated, allowing for contextualization of the responses and a better understanding of individual perspectives.

2) Demographic information

The sample consisted of 35 students (55% female and 45% male) aged between 13 and 17 years. Most participants had basic experience with immersive technologies, while approximately 30% reported an intermediate or advanced level of proficiency.

3) Category A: learning experience in virtual environments

Participants highlighted that immersive environments facilitate the understanding of complex concepts and the visualization of 3D models, emphasizing virtual reality and augmented reality as key tools. Additionally, they mentioned that these experiences enable direct interaction with solutions, promoting risk-free experimentation and more meaningful learning.

Immersive environments facilitated the understanding of complex concepts and the visualization of 3D models, highlighting VR and AR as key tools. One participant remarked:

"The immersive experience allowed me to visualize how an engine works in 3D, something I had only seen in flat diagrams before."

4) Category B: development of problem-solving skills

Immersive technologies have improved the ability to evaluate technological options and quickly prototype solutions. Participants noted that these tools foster informed decision-making, iterative solution adjustments, and the identification of innovative alternatives for practical problems.

Immersive technologies helped students evaluate technological options and rapidly prototype solutions. As one student commented:

"Using VR simulators allowed me to adjust my design several times before physically building it, saving resources and time."

5) Category C: impact on creativity and innovative thinking

Immersive environments stimulate creativity by enabling unconventional approaches and the generation of original ideas. Participants emphasized that these environments provide constant feedback, facilitating the development and refinement of innovative solutions in a safe and experimental setting.

Immersive environments stimulated unconventional approaches and the generation of original ideas. A participant noted:

"In the virtual environment, I could experiment with ideas that seemed impossible in reality, which led me to more innovative solutions."

6) Category D: testing and validation of technological solutions

The ability to perform early prototype validations and receive real-time feedback was one of the main benefits mentioned. Immersive environments allow the identification of technical errors, functionality optimization, and solution adjustments before final implementation.

Students emphasized the ability to validate prototypes and receive real-time feedback. An illustrative response was:

"I detected errors in the prototype thanks to the VR simulation before testing it physically, which reduced risks."

7) Category E: collaboration and teamwork in virtual environments

Participants indicated that immersive technologies enhance communication and collaboration among teams. The integration of ideas in real-time and the use of shared virtual spaces facilitate more efficient and enriching collaborative work.

Immersive technologies improved collaboration, enabling teams to work more efficiently. One student mentioned:

"Using shared virtual spaces helped us integrate our ideas and adjust the design in real-time."

Immersive environments positively impact various dimensions of learning and professional development. They provide profound and effective experiences for acquiring competencies related to the design and implementation of technological solutions. The results highlight the transformative potential of these technologies in fostering meaningful learning, innovation, and collaborative work in educational and professional contexts.

The content analysis in this research identified key patterns and categories related to the perception and development of technological competencies through immersive learning. By cross-referencing these findings with quantitative data, a significant convergence was observed between qualitative perceptions and numerical results. For instance, the interviews highlighted that students perceive immersive technologies as tools that foster creativity and innovation, a finding that aligns with the high average scores on items related to creativity and originality in technological solutions (4.49 on the Likert scale). Furthermore, students reported specific improvements in the identification and design of technological solutions, which coincide with the notable scores in the dimensions of "determining a technological solution" and "designing a technological solution." This data triangulation reinforces the validity of the results, demonstrating how immersive experiences positively impact both participants' subjective perceptions and the objective measurements of their competencies.

D. Functions of VR/AR Software for the Improvement of Problem-Solving Skills

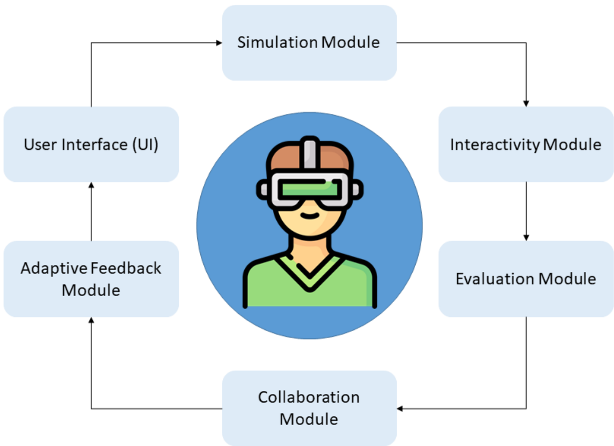

Fig. 5. Functions of VR/AR software for the improvement of problem-solving skills. Source: Own elaboration.

The Fig. 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 detailed below:

1) User Interface (UI)

Function: Provides users (students and teachers) with an intuitive platform to interact with the VR/AR software. It includes navigation menus, start buttons, and gesture or touch controls that allow users to select scenarios, interact with virtual objects, and access educational tools and resources.

2) Simulation module

Function: This module generates realistic virtual environments or augmented settings where students can immerse themselves. It uses 3D graphics engines to create interactive scenarios, such as virtual laboratories, engineering workshops, or anatomical explorations, where students can experiment and manipulate different variables in a safe environment.

3) Interactivity module

Function: Facilitates the direct manipulation of virtual objects and allows students to interact with elements within the simulated scenarios. This module provides real-time feedback on user actions, enhancing practical learning and problem-solving through experimentation.

4) Evaluation module

Function: Analyzes student performance in VR/AR activities. It provides statistics on their progress, identifies errors, and generates evaluation reports. This module helps identify areas for improvement, ensuring that students understand key concepts and techniques.

5) Collaboration module

Function: Enables real-time interaction between multiple users within the same virtual environment. It facilitates collaborative problem-solving, where students can work together, share ideas, and find joint solutions in a common virtual space.

6) Adaptive feedback module

Function: Dynamically adjusts the difficulty and content of activities based on student performance. This module uses artificial intelligence algorithms to provide a personalized learning experience, ensuring that each student receives challenges appropriate to their skill level and learning needs.

This diagram provides a clear view of how VR and AR functions combine to enhance students' problem-solving skills, integrating multiple modules to create an immersive, interactive, and adaptable learning environment.

While it is true that current data highlights significant improvements in skills such as problem-solving and creativity, it is essential to remember that achieving these competencies contributes to the overall attainment of technological competence. This involves not only assessing isolated advances in specific skills but also considering their combined impact on students' ability to design, implement, and validate technological solutions effectively. A comprehensive approach allows for a better understanding of how these interconnected competencies strengthen students' technological development and their readiness to face challenges in real-world contexts, aligning with the educational and technological goals set.

VI. Discussion

Our research aligns with prior studies by reaffirming the positive impact of immersive learning technologies, particularly AR and VR, on the development of critical competencies in educational contexts. For instance, studies like [13, 24] emphasized the potential of AR to enhance creativity and critical thinking in learners, findings that parallel the improvement in innovation and creativity observed in our research. Similarly, the role of immersive technologies in fostering active engagement and enabling students to visualize and solve complex problems, as highlighted by references [15, 19, 21], resonates with our findings that immersive environments significantly support the design and validation of technological solutions.

In medical and professional education, studies like [14, 18, 36] illustrated how immersive technologies improve learning outcomes through realistic simulations and practical training. This complements our results, which demonstrate that immersive learning enhances students' abilities to implement and validate technological solutions effectively. Furthermore, the interdisciplinary collaboration and hands-on experiences noted by references [14, 37] were echoed in our study, as students reported greater collaboration and practical skill development in immersive settings.

The findings of references [37, 38], which stressed the importance of motivational factors and the interaction between digital tools and pedagogical methodologies, also find support in our research. Students in our study highlighted the authenticity and relevance of immersive learning experiences, fostering engagement and enhancing their ability to evaluate and design effective solutions. Moreover, the technical challenges identified in references [15, 34, 37], such as the need for accessible resources and teacher training, were reflected in our research, where some participants noted variability in access to necessary tools and guidance.

Although reference [35] highlighted potential drawbacks such as cognitive overload, our results did not identify this as a significant barrier. Instead, students consistently perceived immersive technologies as intuitive and beneficial for their learning processes. This difference may suggest that appropriate instructional design, as noted by reference [38], mitigates these challenges and enhances the effectiveness of immersive tools.

Overall, our study contributes to the growing evidence supporting the integration of AR and VR in education, reaffirming their transformative potential across multiple dimensions of learning. However, like previous studies, it underscores the need for structured implementation, adequate resources, and continuous training for educators to maximize these technologies' benefits. These findings offer practical insights for enhancing educational practices and policies, bridging the gap between theoretical knowledge and real-world applications through immersive learning.

The study faced several limitations that could affect the generalizability of its findings. A small sample size may limit the breadth of conclusions, and varying levels of participant familiarity with immersive technologies may have influenced both perceptions and performance, introducing biases. The availability and quality of technological resources also varied across institutions, potentially affecting outcomes. Additionally, the short duration of exposure to the technologies constrained the ability to assess their long-term impact on learning and creativity. Future research should expand the sample size, include diverse participants, and offer prior training to minimize bias. Longitudinal studies are recommended to explore the sustained effects of immersive technologies, and interdisciplinary integration should be explored for broader applicability. Collaborative research across multiple institutions could provide valuable insights into logistical and pedagogical challenges. To address these issues, a plan is proposed that includes mandatory initial training, partnerships for access to technology, teacher workshops, and investments in infrastructure, aiming to ensure the equitable and effective adoption of immersive technologies in education.

VII. Conclusions

The research confirmed that immersive technologies, such as AR and VR, have a transformative and positive impact on the learning process. These tools not only enhance academic performance but also foster creativity and originality in addressing technological challenges. Students actively engaged with these technologies and perceived the experiences as authentic and highly relevant, reinforcing the importance of their integration into educational environments.

The findings demonstrated that immersive technologies significantly improve students' ability to design and implement complex and viable technological solutions. Participants reported increased effectiveness in creating detailed plans and successfully translating them into practical applications. Additionally, the use of immersive tools led to a notable improvement in the quantity and quality of proposed solutions, further emphasizing their value in educational contexts.

The study also highlighted the role of immersive technologies in refining the validation and testing processes for technological solutions. Students were better equipped to identify problems, conduct thorough evaluations, and develop more robust and efficient solutions. This capability underscores the essential role of immersive technologies in bridging the gap between theory and practical application.

Moreover, immersive tools were shown to be instrumental in fostering innovation and creativity. Students reported significant growth in their creative capacities when engaging with these technologies, underscoring their critical role in nurturing innovative skills that are indispensable in modern education.

In conclusion, the research validated that immersive technologies are powerful and versatile tools for advancing learning, design, implementation, and innovation in education. While the results were overwhelmingly positive, challenges such as teacher training and equitable access to technology remain and must be addressed to fully harness the potential of these tools in the future.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

BMQ has developed the background review; VHRI has designed the methodology; LCZ has collected the data; MATS has processed the data; CTC has analyzed the data; SBTG has interpreted the data; GFY has developed the discussion; ACML has elaborated the conclusions and STTT has checked the spelling and grammar of the writing; all authors have approved the final version.

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