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TECHNOLOGY-ENHANCED LEARNING ENVIRONMENTS: A CASE STUDY ON THE EFFECTIVENESS OF BUILD_3D FOR PC AND SMARTPHONE HARDWARE ASSEMBLY

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ABSTRACT

Teaching PC and smartphone hardware assembly faces a major challenge in educational contexts with limited access to physical laboratories or real equipment. This limitation hinders hands-on learning, which is essential for the development of technical skills in engineering and related careers. Although simulators and digital tutorials have been implemented as a solution, many of these resources fail to provide immersive experiences or foster deep understanding, due to their low interactivity or lack of immediate feedback. Therefore, for this research, a mixed reality (MR) application called Build_3D was developed and used as an educational support for learning about PC and smartphone hardware. To evaluate its effectiveness, a quasi-experimental study was conducted, including a control group that used traditional methods and an experimental group that used the application. The results indicated a significant improvement in the academic performance of the experimental group, attributed to the immersive and interactive nature of the MR experience. Furthermore, students reported high levels of satisfaction, particularly regarding the interface, clarity of information, and ease of use. These findings suggest that integrating MR into educational environments can over-come physical barriers, promote active learning, and strengthen students' technical understanding. The proposed solution not only improves academic performance but represents a viable and scalable model for modernizing hands-on teaching in higher education, especially in technological disciplines.

KEYWORDS: 3D Simulation, Active Learning, Educational Technology, Computer Hardware, Higher Education, Teaching Innovation, Mixed Reality, Meta Quest 3 Virtual Environment.

1. INTRODUCTION

Hands-on learning in technical careers, such as engineering and computer-related areas, represents an essential component for the development of professional skills (Liston et al., 2022; Vate-U-Lan, 2008). This area of knowledge involves not only identifying physical components, but also understanding their function, interactions and the correct assembly process (Faizan Hassan et al., 2024; Fasihuddin, 2023). However, one of the main challenges faced by educational institutions, particularly in developing countries or pre-budgetary constrained contexts, is the lack of access to well-equipped laboratories that allow real and repeatable practices (da Silva et al., 2023; Valenzuela-Valdés et al., 2016). This shortcoming limits students' ability to develop technical skills, which can result in poor academic performance and inadequate preparation for the professional environment (Chou & Feng, 2019; Shrestha, 2021).

The issue becomes even more relevant in the post-pandemic context, where many institutions have opted for hybrid or fully virtual learning models, and the need for technological alternatives to overcome physical limitations has become increasingly urgent (Park, 2021; Puspasari et al., 2020). In this sense, emerging technologies such as Augmented Reality (AR), Virtual Reality (VR) and, more recently, Mixed Reality (MR), have been the subject of growing interest in the educational field (Kiat et al., 2016; Moro et al., 2021; Yang et al., 2020). These technologies have the potential to offer immersive and interactive experiences that can simulate real-world scenarios, facilitate autonomous learning, and promote greater student motivation (Cai et al., 2020; Criollo-C, Guerrero-Arias, Buenaño-Fernández, et al., 2024; Faridi et al., 2020). However, despite their potential, there remains a gap between the development of these technologies and their effective implementation in real-world educational contexts (Criollo-C, Guerrero-Arias, Cerezo, et al., 2024; Criollo-C, Guerrero-Arias, et al., 2021; Sural, 2017).

MR is a fusion between real and virtual environments that enables real-time interaction with digital objects within physical space, it is positioned as one of the most promising technologies in technical education (Cabero-Almenara et al., 2025; Xia et al., 2021). Compared to VR, which completely replaces the physical environment, MR maintains a link to the student's real-world space, which can facilitate spatial orientation, precise object manipulation, and integration of theoretical knowledge with hands-on experiences (Richert et al., 2019; Shaytura et al., 2021). Furthermore, with the advancement of devices such as Meta Quest 3, which combine high-precision sensors, high-quality graphics, and portability, the creation of educational applications in MR is becoming increasingly accessible and functional (Criollo-C, Guerrero-Arias, Buenaño-Fernández, et al., 2024).

Several studies have addressed the implementation of immersive technologies in education, yielding varied results (Ali et al., 2019; Tumkor, 2018). In some cases, the use of 3D simulators and interactive platforms has demonstrated improvements in knowledge retention, engagement and understanding of abstract concepts (Martín-Gutiérrez et al., 2011; Müller et al., 2007; Putranda et al., 2023). However, many of these solutions have limitations: unintuitive interfaces, unrealistic experiences, or insufficient instructional design to adapt to the pace and needs of the learner (Vasilevski & Birt, 2020). Also, much of the existing research has focused on the perception or acceptance of these technologies, leaving aside the direct measurement of the academic impact through comparative experimental studies (Cabero-Almenara et al., 2025).

In light of this context, the present research aims to provide an empirical contribution to evaluate the impact of the use of an educational application based on MR on the learning of computer hardware and smartphones. Unlike many existing Mixed Reality educational tools, Build_3D was specifically designed for use with Meta Quest 3 devices. Its interface integrates realistic hardware assembly experiences, both from personal computers and smartphones, into a fully interactive environment with a defined pedagogical structure. While other MR applications typically focus on visualization or conceptual exploration, Build_3D combines highly accurate 3D modeling, and guided interaction, allowing students to manipulate virtual components just as they would in a physical lab. This research revealed that the students who participated in the experiment achieved an improvement of 30–35% in academic performance. In addition, a 25–27% improvement was observed in the test completion time.

The proposal seeks not only to facilitate access to practical experiences, but also to promote an active, autonomous and motivating learning environment that effectively complements the theory taught in class. To evaluate the application's effectiveness, a quasi-experimental study was designed with two groups of students: a control group that followed the traditional learning method (theoretical classes with static lectures), and an experimental group that used

Buil_3D as a complementary resource. Both groups were assessed through a test administered at the end of the instruction period, allowing comparison of the scores obtained. The results analysis focused on identifying whether there was a significant difference in academic performance attributable to the use of immersive technology.

The results obtained show a notable improvement in the experimental group, whose members achieved significantly higher scores in a shorter amount of time in the final evaluation compared to the control group. This difference is attributed to several factors: the increased level of interactivity, the possibility of safely and repeatedly experiencing the assembly of components, and the greater motivation generated by the immersive environment. In addition, it was observed that students in the experimental group reported higher satisfaction with the learning process, highlighting the ease of use and its usefulness for visualizing complex processes intuitively. This study provides relevant empirical evidence on the potential of MR as a tool for enhancing academic performance in technical fields. The implementation of this technology allows overcoming physical and economic barriers and is presented as a viable solution for institutions seeking to innovate in their teaching methods without relying exclusively on physical infrastructure. Additionally, the use of MR in standalone devices such as Meta Quest 3 offers an immersive experience without cables or additional equipment, which facilitates its adoption in diverse educational environments.

The objectives of this research were:

1. Objective 1: To analyse whether the use of the Build_3D application improves students' academic performance compared to traditional methods of hardware instruction.
2. Objective 2: To identify the challenges and limitations encountered when using an MR-based application as a support tool in education.

This section presents an overview of the use of MR technology in education. Section II presents a related work. Section III outlines the methodology used to achieve the proposed objectives. Section IV presents the findings of the study. Section V comprises the results. Section VI presents the conclusions and Section VII outlines possible avenues for future research

1. LITERATURE REVIEW

In recent years, MR has emerged as a promising educational technology that enables the integration of virtual environments with the physical world in real time, offering highly interactive immersive experiences (Pooryousef et al., 2024). Several studies have explored its application in educational contexts, highlighting its potential to enhance conceptual understanding, student motivation and accessibility to technical practices in resource-limited environments (Hughes et al., 2005; Putranda et al., 2023). Through this technology, students can interact with three-dimensional objects, allowing for better understanding (Cabero-Almenara et al., 2025). They can also interact with data sets, complex formulas, and abstract concepts that might be more difficult to understand with verbal instructions from the teacher (Ali et al., 2019; Richert et al., 2019). MR as pedagogical support offers educators new innovative possibilities to explore with students through direct experience creates an effective way to captivate struggling learners or can simply provide another opportunity to boost engagement during lessons (Criollo-C et al., 2025; Sankaran et al., 2019). Examples include:

Ali Almaas et al. (Ali et al., 2019) present a systematic mapping of the literature published between 2007 and 2017 on collaborative educational environments that integrate MR technologies. The authors identify a growing interest in these technologies, particularly with the emergence of devices such as the HoloLens and Oculus Rift. The main contribution of the study is to provide a comprehensive overview of the current state of the field, encouraging educators to design MR-based learning artifacts and to promote further research that strengthens collaborative education. The study highlights that most RM work focuses on ad hoc systems and artificial experiments, with limited validation in real or long-term educational settings. Furthermore, they emphasize that RM applications rarely integrate assessment or performance monitoring mechanisms, limiting themselves to visualization or practice. The article reveals that most RM applications in education focus on natural sciences, languages, or medicine, with very little attention paid to technical training or applied engineering.

Albeedan Meshal et al. (Albeedan et al., 2024) have conducted several studies related to MR technology The first of them propose and evaluate an MR system to train young police officers in Kuwait in crime scene investigation. Using Microsoft HoloLens 2.0, the system spatially recreates 3D scanned scenes. The goal is to offer a practical and cost-effective alternative to training in real environments, which is often expensive and complex. The results were positive in terms of usability, interaction and overall satisfaction. Experts also highlighted their educational value, despite the high cost of the devices, and recommended their future commercialization as an essential tool in forensic training. In another paper, these authors explore the intention to use MR devices among police academy students, especially for forensic investigation training. The results show that the mobility of the MR device positively influences both perceived ease of use and usefulness. It is also evident that the fit between tasks and technology is more determinant in usefulness than in ease of use. The study offers theoretical and practical implications for the adoption of MR in technical training environments (Albeedan et al., 2023).

Fidalgo Catarina et al. (Fidalgo et al., 2023) present a systematic review of 62 studies on the use of MR in distance assistance and training environments. They identify opportunities such as expanding the scenarios beyond the classical interaction between an expert and a trainee, enabling seamless transition between realities, and integrating advanced techniques such as eye or gesture tracking. MR appears as a promising solution in fields such as medicine, engineering and education.

Putranda Insan Ganang et al. (Putranda et al., 2023) investigated the use of MR to enhance piano teaching by incorporating real-time audio processing. The application was tested with 31 users and revealed that curiosity and joy were the main factors motivating its use. Although the learning effectiveness was moderate, with an improvement of 31.28%, it highlights the potential of MR to maintain motivation and enhance the musical educational experience.

Pooryousef Vahid et al. (Pooryousef et al., 2024) propose a new workflow for autopsy documentation using an MR system. The solution integrates 3D visualization, voice and hand interaction, procedure recording and real-time collaboration. Unlike previous tools, this approach aims to fully embedded into the forensic process, avoiding additional steps such as manual image extraction for reporting. Preliminary findings suggest that the system can improve data management, facilitate post-procedure review and reduce reporting times. Moreover, it is projected to be a tool of high educational value for medical and forensic training.

Shaytura Sergey et al. (Shaytura et al., 2021) explore the use of VR, AR, and MR technologies in the creation of immersive cyber-physical systems, mainly focused on virtual laboratories. Real-world experiences are described using laser scanning to generate highly accurate digital models of objects, university buildings, roads, and other physical spaces. These representations can be used in educational planning as well as in urban management or security, when integrated with real-time camera data. The combination of these technologies allows the user to be included within three-dimensional models, enhancing sensory interaction with virtual environments. The article describes how this convergence between 3D scanning, VR and solid modeling is becoming an integral part of the educational and scientific research process.

Hughes Charles et al. (Hughes et al., 2005) address the transition of MR technologies from the laboratory to real and sustainable applications, highlighting the importance of multidisciplinary collaboration to achieve this. Practical experiences are presented in the development of virtual urban environments applied to military training, situational awareness and community learning. The article highlights that for emerging MR capabilities to be fully integrated into everyday applications, it is essential to overcome technical, creative and production challenges, as well as to generate immersive experiences that are educationally, recreationally and socially meaningful.

Pascal Knierim et al. (Pascal et al., 2018) identify current challenges facing developers and educators, such as lack of relevant content, pedagogical difficulties in integrating MR into the classroom, and lack of knowledge of the real long-term benefits. Nevertheless, important opportunities are also recognized: the personalization of learning, the possibility of creating more immersive support experiences, and the democratization of access to knowledge. The text concludes with a call for further research on how to design effective MR environments that truly transform teaching and learning.

Recent literature supports the use of MR technology as an innovative strategy to enrich technical, scientific and artistic learning. However, it also underscores the need to continue generating empirical evidence that validates its impact on academic performance and skill acquisition, especially in controlled studies and real application contexts, such as the one developed in this research.

2. METHODOLOGY

2.1. Mobile Augmented Reality Application Design

2.1.1. Design Process

The project was born from the idea of building a tool focused on learning about the components and assembly of hardware, such as a computer and a smartphone, using MR technology. To achieve this goal, two challenges had to be overcome with innovation and creativity. The first challenge was the assembly process for the elements (PC and smartphone), and the second was designing an interface that provides an optimal user experience. The application enables users to take components and assemble them correctly with natural interactions, meaning minimal friction and as closely resembling real-life actions as possible. The natural approach allows users to manipulate objects, position them, release them, or rearrange them using hand gestures like “grabbing” and “releasing”. To accomplish this, customized software and code were utilized, leveraging the integrated cameras in Meta Quest 3 to detect hand silhouettes, finger positions, curvature, flexion, spacing between fingers, and opposition.

The complete application design is published in our previous publication: "Using Mixed Reality (MR) as an Emerging Technology for Improving Higher Education: Analysis of Mental Workload." (Criollo-C, Guerrero-Arias, Buenaño-Fernández, et al., 2024). Figure 1 provides a detailed visualization of the disassembly process of a PC and a smartphone. The background displayed in these figures is an example of the ability to use MR ubiquitously, this academic support can be used in the classroom or outside the classroom. Build_3D uses MR to show key internal elements such as the battery, the motherboard, the camera module or the haptic engine, among others. This detailed segmentation allows users to see each component in its physical context, facilitating interactive learning about PC and smartphone hardware. Figure 1 shows that users can interact directly with device components, simulating actions such as removing the motherboard. Figure 1A shows the components of a PC and Figure 1B shows the components of a smartphone. This suggests that the application promotes a hands-on, immersive approach, which can improve information retention and motivation in learning. Direct manipulation of components in MR space represents a significant advance over traditional teaching methods, such as textbooks or 2D simulations.

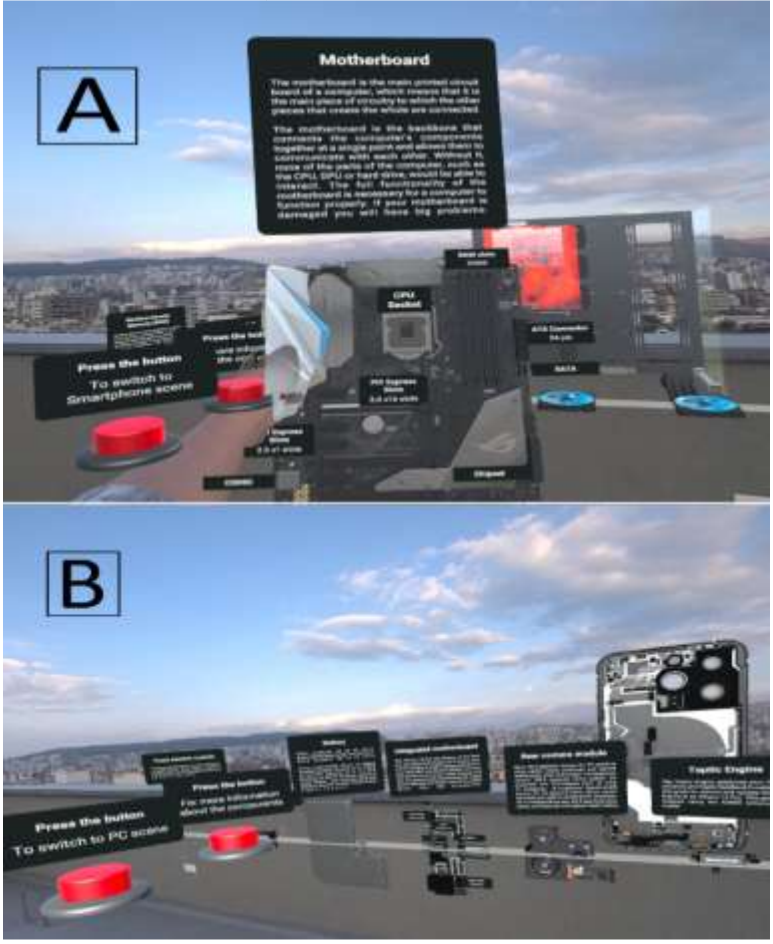

Figure 1. Handling Hardware Components In Build_3D (A: PC Components, B: Smartphone Components)

In each scene, floating information panels are used to explain the hardware com-ponents. The texts provide technical descriptions of the purpose and characteristics of each component. This accessible presentation allows students to learn at their own pace, providing a personalized educational experience. The application is scalable in terms of the types of devices that can be disassembled, suggesting that it can be extended to other hardware or electronic devices, which would provide versatility for different training areas. Additionally, as seen in Figure 1 there is a mechanism (a red button) that can be pressed to switch between the visualization of a smartphone and a PC, highlighting a key feature in the design of Build_3D, which is its ability to teach various types of hardware technology. This shows that the application can be adjusted to different levels of knowledge, covering both simple components and more complex systems like those in a PC.

2.2. *Experimental Protocol*

This research used a non-probabilistic convenience sampling and a quasi-experimental design with two control groups and two experimental groups, with the aim of evaluating the impact of MR on academic performance in subjects related to the assembly of PC hardware and smartphones. The intervention consisted of teaching the same thematic content to both groups, using two different methodologies.

The study involved 100 students enrolled in two sections of a computer hardware course. The groups were formed as follows for the experimental study.

2.2.1. *Participants*

- Section 1 is referred Group 1 (GR1): composed of 50 students (9 women and 41 men).
- Section 2 is referred Group 2 (GR2): composed of 50 students (12 women and 38 men).

All students had basic prior knowledge of the content addressed and experience in the use of digital technologies. Each participant was provided with an informed consent form for their participation and was informed that they could withdraw from the experiment at any time. Participation was voluntary and anonymous, guaranteeing compliance with ethical principles. In addition, we included the participation of 15 university teachers, experts in technological education, who were interviewed with the aim of identifying the challenges and limitations associated with the use of MR applications as support in the teaching-learning process.

2.2.2. *Control And Experimental Group Design*

Because the experiment was carried out in the same semester but at different times for each section, the groups were divided into two subgroups each (GR1: EG1, CG1; GR2: EG2, CG2) to carry out the proposed research analysis. Experimental subgroups EG1 and EG2 received PC and smartphone hardware lessons using two teaching methodologies: one traditional and one with the support of the Build_3D application. The control subgroups CG1 and CG2 only received classes using the traditional method. Each subgroup is composed of 25 students, as shown in Table 1.

2.2.3. *Teaching Scheme*

Two different teaching schemes were used in this research:

- Traditional Teaching: This type of teaching was used with the control group stu-dents CG1 and CG2. This group of students received the class through traditional classroom utilizing presentations and workshops.
- Teaching with Build_3D: This type of teaching was used with the experimental group students EG1 and EG2. This group of students received the class through a blended strategy, which included a traditional theoretical session taught by the teacher and a subsequent hands-on interaction with the Build_3D application. This combination sought to enhance learning by integrating the verbal explanation with immersive experience.

At the end of the instruction, both groups completed a questionnaire designed to measure the understanding and application of the knowledge imparted.

2.2.4. *Task*

The activities conducted in the study included the following:

- Use of Build_3D. The subgroups (EG1 and EG2) used the Build_3D application to explore and virtually manipulate elements such as CPU, RAM, GPU, power supply and motherboard.
- Learning assessment. Both groups (GR1 and GR2) completed a structured test consisting of 20 questions to compare the results obtained and the time it took them to answer the questions.
- Teacher interviews: Semi-structured interviews were conducted with 15 teachers with experience in educational technologies. The interviews addressed issues such as technical barriers, pedagogical limitations, institutional acceptance and perception of the impact of MR on learning.

These interviews complemented the quantitative data of the study, providing a qualitative perspective on the practical implementation of immersive technologies in the university environment.

2.2.5. *Knowledge Test Validation Instrument*

The assessment instrument was validated using the Kuder-Richardson test (KR20), with a result of KR20 = 0.80 for GR1 and KR20 = 0.90 for GR2 (acceptable between 0.70 and 0.90). The KR20 is used to establish the reliability of a knowledge test based on its averages and variances. For this purpose, a dichotomous scoring instrument (correct or incorrect) must be used. This formula is based on the difficulty and number of questions, the sum of their variances and the total variance of the assessment (Saupe, 1961).

2.2.6. *Definition Of Variables*

These variables define the structure of the experimental methodology illustrated in Figure 2, with the independent variables being the teaching method and the sample size, and the dependent variable being the result of the student evaluation.

- Independent variables:
- o Teaching method (TM):
- o Traditional teaching (TT)
- o Mixed reality teaching (MRT)
- Tamaño de la muestra:
- o 25 students (EG1)
- o 25 students (CG1)
- o 25 students (EG2)
- o 25 students (CG2)
- Dependent variables:
- o Evaluation results (R)

Table 1: Students' Demographic Data.

Experimental and control groups	Group 1	Group 2	Total of students
Experimental Group	25	25	50
Control Group	25	25	50

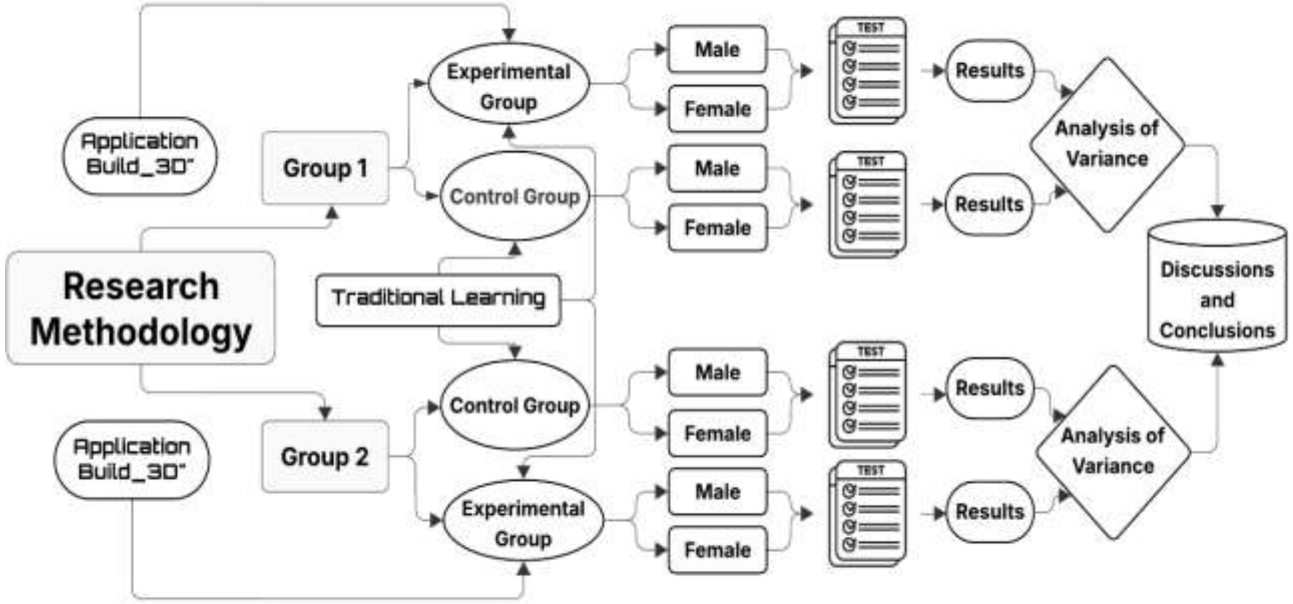

Figure 2. Research Design.

2.2.7. *Definition of Hypotheses*

To demonstrate the usefulness of the Build_3D application as a support tool in teaching PC Hardware and Smartphones, we intend to measure the results of the questionnaire and compare them between the experimental and control groups. To conduct this analysis, it is necessary to generate hypotheses to validate whether the use of Build_3D improves the results obtained by the students in the experimental group compared to the control groups. **The hypotheses were the following:**

- First Hypothesis (H1): In the average score of the test results between EG1/EG2 and CG1/CG2 there is no significant difference.
- Second Hypothesis(H2): In the average score of the test results between EG1/EG2 and CG1/CG2 a significant difference is presented.
- Third Hypothesis (H3): The score of the EG1and EG2 group does not have a significant difference due to the teaching method used.
- Fourth Hypothesis (H4): The score of EG1and EG2 group has a significative difference due to the teaching method used.

3. RESULTS

3.1. *Experimental And Control Group*

To test hypotheses H1 and H2, a Z-test was performed to evaluate the results of the questionnaire between each experimental and control group (EG1 and EG2; CG1 and CG2). The Z-test was performed with a reliability of 95% and the variances used were previously taken from a T-test assuming different variances in both groups. The variances obtained (EG1 = 2.916; CG1 = 18.166; EG2 = 1.693; CG2 = 32.25) are shown in Table 2 and Table 3. The value of the Z-test performed on groups EG1, CG1 and EG2, CG2 can be seen in Table 4 and Table 5. Based on the obtained Z values and the two-tailed critical value (example taken from EG1 and CG1; Z = 3.70 > two-tailed critical value = 1.959) the null hypothesis H1 is disproved and H2 is accepted as true. In addition, Table 6 shows the Cohen's d value, which is a statistical measure that indicates how large or significant the difference is between two groups (Yin et al., 2025). Based on these results, it is concluded that there is a significant difference between the students in the experimental group compared to the control group.

The value of the Z-test performed on groups EG1, CG1 and EG2, CG2 can be seen in Table 4 and Table 5. Based on the obtained Z values and the two-tailed critical value (example taken from EG1 and CG1; Z = 3.70 > two-tailed critical value = 1.959) the null hypothesis H1 is disproved and H2 is accepted as true. In addition, Table 4 shows the Cohen's d value, which is a statistical measure that indicates how large or significant the difference is between two groups. Based on these results, it is concluded that there is a significant difference between the students in the experimental group compared to the control group.

Table 2: Two-Sample T-Test Assuming Unequal Variances (EG1; CG1).

Variables	*EG1*	*CG1*
Mean	18.2	12.8
Variance	2.916666667	18.1666667
Observations	25	25
Hypothetical difference of means	2	
Degrees of freedom	32	
T-statistic	3.702365444	
P(T<=t) one-tailed	0.000400851	
Critical value of t (one-tailed)	1.693888748	
P(T<=t) two-tailed	0.000801701	
Critical value of t (two-tailed)	2.036933343	

Table 3: Two-Sample T-Test Assuming Unequal Variances (EG2; CG2).

Variables	*EG2*	*CG2*
Mean	17.12	11.2
Variance	1.693333333	32.25
Observations	25	25
Hypothetical difference of means	3	
Degrees of freedom	27	
T-statistic	2.505968521	
P(T<=t) one-tailed	0.009270054	
Critical value of t (one-tailed)	1.703288446	
P(T<=t) two-tailed	0.018540108	
Critical value of t (two-tailed)	2.051830516	

Table 4: Z-Test for Two-Sample Mean (EG1; CG1).

Variables	*EG1*	*CG1*
Mean	18.2	12.8
Variance (known)	2.92	18.17
Observations	25	25
Hypothetical difference of means	2	
Z	3.701780229	
P(Z<=z) one-tailed	0.000107046	
Critical value of z (one-tailed)	1.644853627	
Critical value of z (two-tailed)	0.000214092	
Critical value of z (two-tailed) Critical value of z (two-tailed)	1.959963985	

Table 5: Z-Test for Two-Sample Mean (EG2; CG2).

Variables	*EG2*	*CG2*

Mean	17.12	11.2
Variance (known)	1.39	32.25
Observations	25	25
Hypothetical difference of means	3	
Z	2.517241379	
P(Z<=z) one-tailed	0.005913888	
Critical value of z (one-tailed)	1.644853627	
Critical value of z (two-tailed)	0.011827777	
Critical value of z (two-tailed) Critical value of z (two-tailed)	1.959963985	

Table 6: Cohen´S D Value to EG And CG.

	CG1	*EG1*	*CG2*	*EG2*
Mean test results	18,20	12,80	17,12	11,2
Standar deviation (SD)	1,70782513	4,26223728	1,30128142	5,67890835
Number of participants	25	25	25	25
MCG1-MEG1	5,40		5,92	
Pooled SD	3,24679329		4,11966827	
Cohen´s d	1,66317949		1,43700891	

In this context, to identify the reason for the results with the T and Z tests, the two additional hypotheses (H3 and H4) were used together with an analysis of variance (ANOVA), considering the dependent and independent variables. ANOVA is a statistical method that allows countering a null hypothesis where the means of different populations coincide (Criollo-C, Abad-Vásquez, et al., 2021). To accept or reject the hypotheses presented (H3 and H4), an analysis with 95% reliability was performed for each group of students (independent variable). These groups were evaluated with a questionnaire of 20 pre-questions to identify whether the teaching methodology (independent variable) contributed to the result obtained (dependent variable). Table 1 shows the number of groups and students who participated in the research, Table 7 describes the sample size, the working groups, and the teaching methodology used in each case. Table 8 shows that for groups EG1 and CG1 the critical value of F (4.042) is lower than the value of F (34.577). Therefore, the null hypothesis (H3) is rejected, and the hypothesis (H4) is accepted. Table 9 shows that for groups EG2 and CG2 the critical value of F (4.042) is lower than the value of F (25.812). Therefore, the null hypothesis (H3) is rejected, and the hypothesis (H4) is accepted.

Table 7: Student Sample Size.

Variable	Teaching Method	Size
EG1	TT and MRT	25
CG1	TT	25
EG2	TT and MRT	25
CG2	TT	25

Table 8: Analysis Of Variance for EG1 And CG1.

Origin of variances	**Sum of squares**	**Degrees of freedom**	**Average of the squares**	**F**	**Probability**	**Critical value for F**
Between groups	364.5	1	364.5	34.5770751	3.8186E-07	4.04265213
Within groups	506	48	10.5416667			
Total	870.5	49				

Table 9: Analysis Of Variance for EG2 And CG2.

Origin of variances	**Sum of squares**	**Degrees of freedom**	**Average of the squares**	**F**	**Probability**	**Critical value for F**
Between groups	438.08	1	438.08	25.8124325	6.1231E-06	4.04265213
Within groups	814.64	48	16.9716667			
Total	1252.72	49				

Therefore, it is concluded that the differences between experimental and control groups are marked and consistent, suggesting that students who used the Build_3D application had a better conceptual understanding and knowledge retention. The test results for the experimental and control groups can be seen in Figure 3. The EG1 group obtained an average of 18.20 correct answers, while CG1 only achieved 12.80. In the case of EG2, the average was 17.12, compared to 11.20 for the CG2 group. These differences are substantial, indicating that the use of the application not only improved time efficiency, but also the quality of learning, as measured by test performance. In addition to the number of correct answers, the total time (in minutes) that each student took to complete all the questions was recorded. The test was administered in digital format, and an automatic recording system was used to calculate the exact time of resolution from start to delivery, which allowed us to analyse the speed and fluency of the participants' performance. Figures 4 and 5 show the time students took to complete the test.

3.2. Problems And Limitations in The Use of MR As a Support in Education

The findings derived from the interviews with teachers reveal a series of significant barriers that must be addressed to achieve effective implementation of MR in educational contexts.

- At the student level, as shown in Figure 6A, the inequality in access to MR devices outside the classroom and the learning curve associated with the initial use of the Meta Quest 3 viewer stand out.
- From the teachers' perspective, the challenges, as shown in Figure 6B, are centred on the lack of specific training, the limited time to plan immersive classes and the difficulty of linking MR experiences with curricular objectives. Added to this is the complexity of managing classrooms where students interact individually with virtual environments.
- Educational institutions, as shown in Figure 6C, face structural problems such as initial investment in equipment, limited technological infrastructure and the absence of clear policies on the use of MR.
- These factors reflect the urgent need to design institutional strategies that include training, technical support and comprehensive curricular planning. Taken together, these challenges underscore that technological innovation in education requires not only resources, but also a systemic and collaborative vision for its sustainability

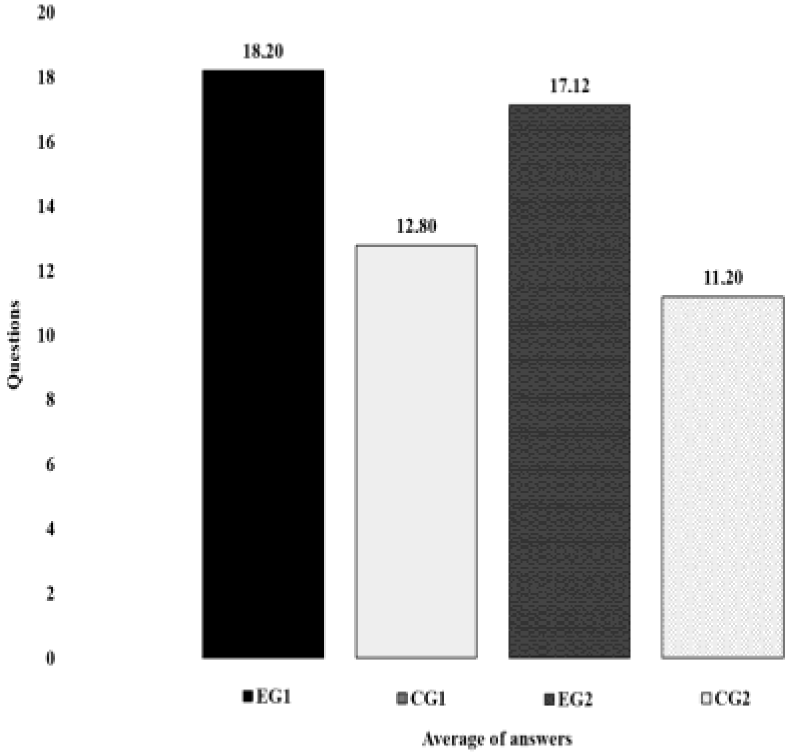

Figure 3: Average Grades in The Experimental (EG1, EG2) And Control Groups (CG1, CG2).

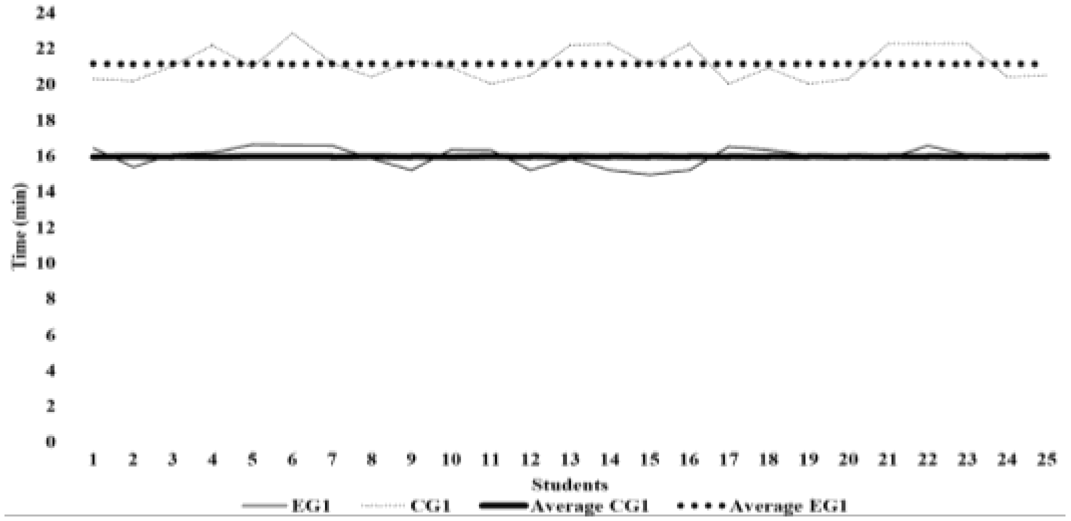

Figure 4: Resolution Time of The EG1-CG1 Test.

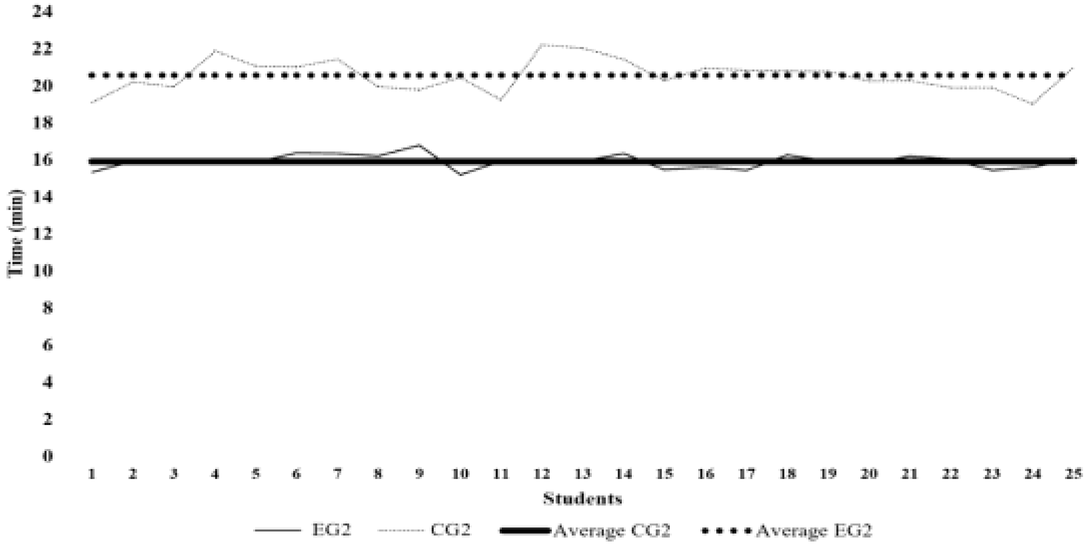

Figure 5: Resolution Time of The EG2-CG2 Test.

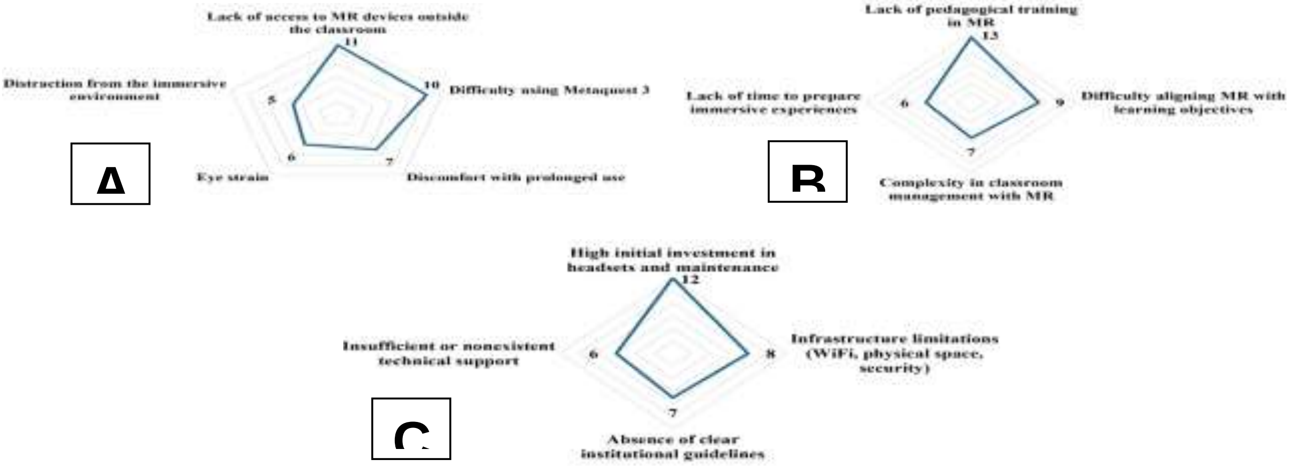

*Figure 6: Problems And Limitations of The Use of MR As Support in Education (A: Students, B: Teachers, C: Educational Institutions) * Numbers Represent.*

4. DISCUSSION

4.1. *Objective 1*

The results of this research show the significant impact of the incorporation of MR in the teaching-learning process of technical content, specifically in the assembly of personal computer hardware and smartphones. The intervention carried out using the Build_3D application, in combination with the Meta Quest 3 viewer, was able to demonstrate substantial improvements both in the academic performance of the students and in their time efficiency when solving knowledge tests. The comparison between the experimental and control groups, evaluated by robust statistical tests (T-tests, Z-tests and ANOVA), confirms that the MR-based methodology provides clear pedagogical advantages over the traditional approach.

Quantitative data reveal a statistically significant difference in academic performance between the experimental groups (EG1 and EG2) and their respective control groups (CG1 and CG2). This improvement can be attributed to the immersive and interactive nature of the 3D environment generated by the Build_3D application, which allowed the students not only to visualize the hardware components, but also to manipulate and assemble them virtually, generating a multisensory learning experience. The EG1 group obtained an average of 18.20 correct answers in the knowledge evaluation, compared to 12.80 for the CG1 group, while the EG2 group achieved an average of 17.12, significantly higher than the 11.20 of CG2. This difference, supported by the critical values of the Z and T tests, invalidates the null hypothesis (H1 and H3) and validates the alternative hypotheses (H2 and H4), confirming that the teaching method directly influences learning.

The analysis of variance (ANOVA) reinforces this conclusion by showing that the variation between groups is not due to chance, but to the differentiated pedagogical intervention. In both cases analysed (EG1-CG1 and EG2-CG2), the observed F-value far exceeded the critical value, indicating that the mean differences between groups are statistically significant. In particular, the F values (34.57 and 25.81, respectively) confirm that the MR teaching method has a direct effect on student performance, validating the effectiveness of the Build_3D tool as a didactic support in higher education contexts.

Another relevant indicator, besides academic performance, was the time taken to complete the questionnaires. Students in the experimental groups not only achieved better results, but also completed the tests in less time, as evidenced in the comparative graphs presented (Figures 4 and 5). This difference in time is indicative of a more fluid and efficient cognitive processing by the students who interacted with the Build_3D application, which may be related to a more solid understanding of the content addressed and better knowledge retention.

This finding is particularly relevant considering that MR allows students to experience autonomous, active and visual learning, which may explain both the improvement in results and the reduction in response time. The fact that students were able to manipulate the hardware components in a three-dimensional virtual environment and receive immediate feedback during practice with Build_3D seems to have facilitated the internalization of knowledge, reducing the need for extensive reflection when answering the test questions. This speed, without detriment to the quality of the answers, is a key indicator of educational efficiency.

From a pedagogical point of view, the results reinforce the principles of active learning, which postulates that students learn best when they are directly involved in the process. The combined methodology used in the experimental groups, which integrates theoretical instruction and immersive practice, is aligned with constructivist approaches that promote the construction of knowledge from experience. In contrast, the control groups, which were limited to traditional methods, relied heavily on memorization and one-way instruction, which could explain their lower performance.

Likewise, as can be observed in previous research on the use of Build_3D, the positive perception of the students in relation to the application interface, the clarity of the instructions and the ease of use, reinforces the argument that usability is a determining factor in the effectiveness of technological tools in education (Criollo-C et al., 2025). These elements, in contrast to the mental workload assessment of Build_3D, reflect not only a high satisfaction, but also a low extrinsic cognitive load, which facilitates learning and concentration on the contents (Criollo-C, Guerrero-Arias, Buenaño-Fernández, et al., 2024). Consequently, build_3D acts not only as a technical tool, but also as a facilitator of the educational process, adapting to different learning styles.

It should be noted that the results of this study have relevant practical implications for educational institutions seeking to modernize their training processes. The proposed model demonstrates that it is possible to offer quality practical experiences through virtual environments, overcoming the physical, logistical and economic limitations faced by a large part of technical education, especially in developing countries. The Build_3D application represents, in this sense, a scalable and accessible solution that can be integrated into academic programs without requiring costly infrastructure or risks associated with the use of real hardware.

Finally, it is important to note that the rapid technological evolution means that tools such as Build_3D must be kept up to date and adaptable to new versions of devices and platforms. This represents a technical and financial challenge for educational institutions, but also an opportunity to continuously innovate in the way teaching and learning takes place. The use of MR, as evidenced in this study, not only improves quantifiable learning indicators, but also motivates students, encourages their autonomy and awakens their interest in technology.

4.2. *Objective* 2

Another valuable aspect of the study was the incorporation of a qualitative perspective through semi-structured interviews with teachers who are experts in educational technology. These interviews provided a better understanding of the perceived barriers and opportunities surrounding the use of MR in the classroom. Teachers agreed that lack of infrastructure, institutional resistance and associated costs are some of the main challenges to implementing these technologies on a massive scale. However, they also pointed out that MR has great potential to transform practical teaching, especially in contexts where physical resources are scarce or non-existent. The consensus among the teachers interviewed supports the viability of the proposed model and suggests that, with proper planning, its implementation could be extended to various areas of technical and vocational education.

Among the challenges most pointed out by teachers is the lack of specialized training, both in the use of MR devices and in the design of pedagogical activities that take advantage of their potential. Most of those interviewed agreed that, although technological resources such as Meta Quest 3 are becoming increasingly accessible, lack of knowledge of how they work limits their effective incorporation into the classroom. This finding is consistent with previous studies that point out that the introduction of new educational technologies requires not only investment in equipment, but also continuous teacher training (Albeedan et al., 2023).

Another important obstacle identified was the limited technological infrastructure in many higher education institutions. Despite the interest in adopting MR tools, several professors indicated that their centres do not have the connectivity, technical support or resources needed to integrate this type of solution in a stable manner. This limits their use to pilot projects or specific subjects, making their institutional scalability difficult.

From the pedagogical point of view, some teachers expressed concern about the distraction and visual fatigue that can be generated by the prolonged use of immersive viewers, especially in students who are not accustomed to these technologies. Although the immersive experience was positively valued, the need to regulate exposure times and complement these activities with traditional or hybrid methodologies to avoid cognitive overload was also mentioned.

At the institutional level, there was evidence of resistance to change in certain educational environments, due to cultural factors, lack of innovation policies or lack of awareness of the potential of MR. Several teachers pointed out that, although there are individual initiatives on the part of some teachers, they do not always have institutional support or recognition in the teacher evaluation systems. This hinders the sustainability of technological experiences, since they are not aligned with the organizational structure or with traditional academic incentives.

A limitation in curriculum design was also identified, since many technical assignments do not explicitly contemplate the use of immersive technologies within their competencies or learning outcomes. Consequently, teachers who wish to incorporate MR must do extracurricular or by adapting content without formal guidance, which can lead to inconsistencies in evaluation and thematic coverage.

Despite these challenges, most of the teachers interviewed showed a favourable attitude towards the use of MR in education and considered that, with the right conditions, these tools could transform the way in which practical and complex concepts are taught. Particularly valued was the ability of Build_3D to provide an autonomous, safe and realistic hardware assembly experience, especially useful in contexts with limited access to physical laboratories.

The challenges identified do not focus exclusively on the technology itself, but on the institutional, educational and pedagogical ecosystems that surround it. The implementation of MR as an educational tool requires a systemic vision that combines infrastructure, teacher training, innovation policies and curriculum redesign. If these factors are addressed in a comprehensive manner, the use of applications such as Build_3D can evolve from a one-time solution to a transformative strategy in technical and higher education.

4.3. *Engagement And Motivation*

This study emerges from a strong commitment to fostering educational innovation in contexts where the practical teaching of PC and smartphone hardware is restricted by limited access to physical laboratories and real equipment. As educators and researchers, we take on the responsibility of seeking alternatives that can overcome these barriers, ensuring that students acquire the technical skills essential for their professional development. Our main motivation lies in providing immersive, interactive, and meaningful learning experiences that not only enhance academic performance but also increase student engagement and satisfaction. The implementation of Mixed Reality with the Meta Quest 3 headset represents an opportunity to transform technical education, promoting equity in access to innovative tools while modernizing hands-on teaching practices. This work reflects our commitment to the continuous improvement of educational quality in the digital age, reinforcing the importance of integrating advanced technologies into higher education.

4.4. *Practical Implications*

The findings of this study carry several practical implications for higher education institutions, instructors, and students. First, the integration of Mixed Reality (MR) into technical education provides a scalable and cost-effective alternative to traditional laboratory-based learning, especially in contexts where access to physical equipment is limited or expensive. By using MR applications such as Build_3D with the Meta Quest 3 headset, universities can significantly reduce dependency on costly hardware while still offering students authentic, hands-on learning experiences.

For instructors, MR technologies open new pedagogical opportunities. They allow educators to design immersive and interactive lessons that enhance student motivation, engagement, and conceptual understanding. The immediate feedback provided by MR systems supports active learning and helps identify misconceptions in real time, thereby improving teaching effectiveness.

From the student perspective, the use of MR fosters deeper technical comprehension, improved academic performance, and higher satisfaction with the learning process. Additionally, MR prepares learners to work with cutting-edge digital tools, aligning their training with the demands of modern industries.

Finally, at an institutional level, adopting MR can strengthen innovation strategies, enhance the quality of education, and promote equitable access to advanced learning technologies, ultimately contributing to the digital transformation of higher education.

5. CONCLUSIONS

The results consistently indicate that the experimental groups (EG1 and EG2), which used the Build_3D app, obtained better results both in terms of test resolution time (lower average time) and number of correct answers (higher academic performance). Furthermore, the validation of the instrument by means of the KR20 test, and the statistical analyses (T, Z and ANOVA), support the methodological robustness of the findings obtained. This reinforces the hypothesis that the integration of immersive technologies such as augmented reality can enhance learning processes, facilitating the understanding of abstract content, especially in subjects that benefit from three-dimensional modelling.

In this context, it has been demonstrated that the integration of MR technologies, specifically through the Build_3D application and the Meta Quest 3 viewer, significantly improves the practical teaching of PC and smartphone hardware assembly in higher education.

On the other hand, teacher interviews provided a valuable qualitative perspective, confirming the acceptance and potential of these tools, as well as pointing out institutional and technical challenges that need to be addressed for their wider adoption. Overall, the results suggest that the application of MR in educational settings is not only feasible, but also beneficial in overcoming the physical limitations of traditional laboratories, fostering active learning and strengthening the acquisition of technical skills. The proposed solution is scalable, accessible and aligned with the goals of sustainability in education by reducing dependence on physical material resources.

Regarding the limitations of the study, it is recognized that the sample was selected for convenience and that the results, although statistically significant, are based on a population limited to a single institution. Therefore, future research could replicate this study with a larger and more diverse sample, including institutions from different geographical, socioeconomic and cultural contexts, to validate the generalizability of the findings. It is also suggested to investigate the long-term impact of MR on knowledge retention and the development of practical skills, as well as to explore its application in other areas of technical and scientific training.

6. FUTURE WORK

Based on the findings of this research, several lines of future work are identified that can strengthen and expand the impact of the use of MR as a support in education, for example, it is recommended to conduct research that analyses the medium and long-term impact of the use of MR in knowledge retention and the development of practical skills. A post-course follow-up would identify whether the learning achieved through Build_3D is sustained over time and whether it influences future academic performance or professional environments.

The implemented methodology can be adapted to other areas of technological and scientific training, such as computer networks, electronics, industrial maintenance or even medicine. The development of new educational applications based on MR would make it possible to evaluate the versatility of this technology in different contexts.

To improve the generalizability of the results, it is proposed to replicate the study in different educational institutions, including universities in different regions, socio-economic levels and pedagogical models. This would make it possible to identify contextual factors that may influence the effectiveness of the MR.

The design of MR experiences should consider usability and accessibility criteria for students with different levels of technological experience or special needs. The development of adapted versions of Build_3D for different audiences is proposed as a line of work.

Future research should systematically analyze the technical hardware requirements that can influence the learning experience, such as processing power, graphics performance, available memory, and the need for proper spatial calibration. Likewise, the physical conditions of educational spaces need to be considered, as MR requires safe movement areas and stable connectivity for optimal performance.

Another essential aspect is the cost of the device and its maintenance. MR headsets, such as the MetaQuest 3, entail a considerable initial investment, as well as recurring expenses for licenses, updates, wear and tear, and technical support. These factors can represent a barrier to widespread adoption, especially in institutions with limited resources.

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REFERENCES

Albeedan, M., Kolivand, H., & Hammady, R. (2023). Evaluating the Use of Mixed Reality in CSI Training Through the Integration of the Task-Technology Fit and Technology Acceptance Model. *IEEE Access*, *11*, 114732–114752. https://doi.org/10.1109/ACCESS.2023.3323949

Albeedan, M., Kolivand, H., Hammady, R., & Saba, T. (2024). Seamless Crime Scene Reconstruction in Mixed Reality for Investigation Training: A Design and Evaluation Study. *IEEE Transactions on Learning Technologies*, *17*, 856–873. https://doi.org/10.1109/TLT.2023.3337107

Ali, A. A., Dafoulas, G. A., & Augusto, J. C. (2019). Collaborative Educational Environments Incorporating Mixed Reality Technologies: A Systematic Mapping Study. *IEEE Transactions on Learning Technologies*, *12*(3), 321–332. https://doi.org/10.1109/TLT.2019.2926727

Cabero-Almenara, J., Gallego, M. R., & Llorente-Cejudo, C. (2025). Mixed, virtual and augmented reality: technologies for learning. *Texto Livre*, *18*. https://doi.org/10.1590/1983-3652.2025.49561

Cai, S., Liu, E., Shen, Y., Liu, C., Li, S., & Shen, Y. (2020). Probability learning in mathematics using augmented reality: impact on student’s learning gains and attitudes. *Interactive Learning Environments*, *28*(5), 560–

573.

Chou, P. N., & Feng, S. T. (2019). Using a tablet computer application to advance high school students' laboratory learning experiences: A focus on electrical engineering education. *Sustainability*, *11*(2). https://doi.org/10.3390/su11020381

Criollo-C, S., Abad-Vásquez, D., Martic-Nieto, M., Velásquez-G, F. A., Pérez-Medina, J.-L., & Luján-Mora, S. (2021). Towards a new learning experience through a mobile application with augmented reality in engineering education. *Applied Sciences*, *11*(11). https://doi.org/10.3390/app11114921

Criollo-C, S., Guerrero-Arias, A., Buenaño-Fernández, D., Jaramillo-Alcazar, Á., & Luján-Mora, S. (2024). Using Mixed Reality (MR) as an Emerging Technology for Improving Higher Education: Analysis of Mental Workload. *Emerging Science Journal*, *8*(Special issue), 410–424. https://doi.org/10.28991/ESJ-2024-SIED1-024

Criollo-C, S., Guerrero-Arias, A., Cerezo, J. E., Arif, Y. M., Fortuna, A., Prasetya, F., & Lujan-Mora, S. (2024). Improving higher education with the use of mobile augmented reality (MAR): A case study. *IEEE Access*, *12*, 139003–139017. https://doi.org/10.1109/ACCESS.2024.3465833

Criollo-C, S., Guerrero-Arias, A., Jaramillo-Alcázar, A., & Luján-Mora, S. (2021). Mobile learning technologies for education: Benefits and pending issues. *Applied Sciences (Switzerland)*, *11*(9). https://doi.org/10.3390/app11094111

Criollo-C, S., Guerrero-Arias, A., Samala, A. D., Arif, Y. M., & Lujan-Mora, S. (2025). Enhancing the educational model using mixed reality technologies with Meta Quest 3: A usability analysis using IBM-CSUQ. *IEEE Access*, *13*, 56930–56945. https://doi.org/10.1109/ACCESS.2025.3555930

da Silva, I., García-Zubía, J., Hernández-Jayo, U., & Da Motas Alves, J. B. (2023). Extended Remote Laboratories: A Systematic Review of the Literature From 2000 to 2022. *IEEE Access*, *11*, 94780–94804. https://doi.org/10.1109/ACCESS.2023.3271524

Faizan Hassan, M., Mehmood, U., Samad Danish, A., Khan, Z., Muhammad Yar Khan, A., & Muneeb Asad, R. (2024). Harnessing Augmented Reality for Enhanced Computer Hardware Visualization for Learning. *Journal of Xi'an Shiyou University, Natural Science Edition*, *20*(02), 601–610.

Faridi, H., Tuli, N., & Mantri, A. (2020). Experience Fleming's rule in electromagnetism using augmented reality: Analyzing impact on students learning. *Procedia Computer Science*, *172*, 660–668. https://doi.org/10.1016/j.procs.2020.05.086

Fasihuddin, H. (2023). Virtual Reality Technology in Teaching Computer Hardware: A Prototype and Assessment from User Perspectives. *TEM Journal*, *12*(2), 899–907. https://doi.org/10.18421/TEM122-36

Fidalgo, C. G., Yan, Y., Cho, H., Sousa, M., Lindlbauer, D., & Jorge, J. (2023). A Survey on Remote Assistance and Training in Mixed Reality Environments. *IEEE Transactions on Visualization and Computer Graphics*, *29*(5), 2291–2303. https://doi.org/10.1109/TVCG.2023.3247081

Hughes, C. E., Stapleton, C. B., Hughes, D. E., & Smith, E. M. (2005). Mixed reality in education, entertainment, and training. *IEEE Computer Graphics and Applications*, *25*(6), 24–30. https://doi.org/10.1109/MCG.2005.139

Kiat, L. B., Dayana Abd Halim, N., Ali, M. B., & Binti Ibrahim, H. (2016). Augmented Reality, Virtual Learning Environment and Mobile Learning in education: a comparison. *IEEE Conference on E-Learning, e-Management and e-Services*, 23–28.

Liston, M., Morrin, A. M., Furlong, T., & Griffin, L. (2022). Integrating Data Science and the Internet of Things Into Science, Technology, Engineering, Arts, and Mathematics Education Through the Use of New and Emerging Technologies. *Frontiers in Education*, *7*. https://doi.org/10.3389/feduc.2022.757866

Martín-Gutiérrez, J., Navarro, R. E., & González, M. A. (2011). Mixed reality for development of spatial skills of first-year engineering students. *Frontiers in Education Conference*, T2D-1-T2D-6. https://doi.org/10.1109/FIE.2011.6142707

Moro, C., Smith, J., & Finch, E. (2021). Improving stroke education with augmented reality: A randomized control trial. *Computers and Education Open*, *2*, 100032. https://doi.org/10.1016/j.caeo.2021.100032

Müller, D., Bruns, F. W., Erbe, H.-H., Robben, B., & Yoo, Y.-H. (2007). Mixed reality learning spaces for collaborative experimentation: A challenge for engineering education and training. *International Journal of Online Engineering*, *3*(4). https://doi.org/10.3991/ijoe.v3i4.454

Park, J. J. (2021). The Future of Flexible Learning and Emerging Technology in Medical Education: Reflections from the COVID- 19 Pandemic. *Korean Medical Education Review*, *23*(3), 147–153.

Pascal, K., Thoas, K., Matthias, H., & Albrecht, S. (2018). Challenges and Opportunities of Mixed Reality Systems in Education. *Virtual and Augmented Reality in Everyday Context*. https://doi.org/10.18420/muc2018-ws07-0471

Pooryousef, V., Cordeil, M., Besançon, L., Bassed, R., & Dwyer, T. (2024). Collaborative Forensic Autopsy Documentation and Supervised Report Generation using a Hybrid Mixed-Reality Environment and Generative AI. *IEEE Transactions on Visualization and Computer Graphics*, 1–11. https://doi.org/10.1109/TVCG.2024.3456212

Puspasari, S., Suhandi, N., & Iman, J. N. (2020). Augmented Reality Development for Supporting Cultural Education Role in SMB II Museum During Covid-19 Pandemic. *International Conference on Informatics and Computing*, 1–6.

Putranda, I. G., Yumna, A. M., Rosmansyah, Y., & Sukmana, Y. (2023). Exploring Audio Processing in Mixed Reality to Boost Motivation in Piano Learning. *IEEE Access*, *11*, 71194–71200. https://doi.org/10.1109/ACCESS.2023.3293250

Richert, A., Mai, V., Mengen, H., & Wolf, S. (2019). Mixed Reality Games in Engineering Education. *Experiment International Conference*, 365–370. https://doi.org/10.1109/EXPAT.2019.8876572

Sankaran, N. K., Nisar, H. J., Zhang, J., Formella, K., Amos, J., Barker, L. T., Vozenilek, J. A., LaValle, S. M., & Kesavadas, T. (2019). Efficacy Study on Interactive Mixed Reality (IMR) Software with Sepsis Prevention Medical Education. *Conference on Virtual Reality and 3D User Interfaces*, 664–670. https://doi.org/10.1109/VR.2019.8798089

Saupe, J. L. (1961). Some Useful Estimates of the Kuder-Richardson Formula Number 20 Reliability coefficient. *Educational and Psichological Measurement*, *XXI*(1), 63–71. https://doi.org/https://doi.org/10.1177/001316446102100105

Shaytura, S., Olenev, L., Nedelkin, A., Ordov, K., Minitaeva, A., & Guzhina, G. (2021). Mixed Reality in Education and Science. *International Conference on Control Systems, Mathematical Modeling, Automation and Energy Efficiency*, 667–673. https://doi.org/10.1109/SUMMA53307.2021.9632140

Shrestha, M. (2021, July 26). Augmented Reality Mobile Tool for Engineering Education. *Augmented Reality Mobile Tool for Engineering Education*. https://doi.org/10.18260/1-2--36731

Sural, I. (2017). Mobile augmented reality applications in education. In H. Altinpulluk & G. Kurubacak (Eds.), *Mobile Technologies and Augmented Reality in Open Education* (pp. 200–214). IGI Global Scientific Publishing. https://doi.org/https://doi.org/10.4018/978-1-5225-2110-5.ch010

Tumkor, S. (2018). Personalization of engineering education with the mixed reality mobile applications. *Computer Applications in Engineering Education*, *26*(5), 1734–1741. https://doi.org/https://doi.org/10.1002/cae.21942

Valenzuela-Valdés, J. F., Pardo, P. J., Padilla, P., & Lozano-Guerrero, A. J. (2016). Low-Cost Ubiquitous Context-Aware Wireless Communications Laboratory for Undergraduate Students. *IEEE Transactions on Learning Technologies*, *9*(1), 31–36. https://doi.org/10.1109/TLT.2015.2438864

Vasilevski, N., & Birt, J. (2020). Analysing construction student experiences of mobile mixed reality enhanced learning in virtual and augmented reality environments. *Research in Learning Technology*, *28*(January). https://doi.org/10.25304/rlt.v28.2329

Vate-U-Lan, P. (2008). Mobile learning: Major challenges for engineering education. *Proceedings - Frontiers in Education Conference, FIE*, 11–16. https://doi.org/10.1109/FIE.2008.4720385

Xia, S., Chu, L., Pei, L., Zhang, Z., Yu, W., & Qiu, R. C. (2021). Learning Disentangled Representation for Mixed-Reality Human Activity Recognition With a Single IMU Sensor. *IEEE Transactions on Instrumentation and Measurement*, *70*, 1–14. https://doi.org/10.1109/TIM.2021.3111996

Yang, C.-H., Liu, S.-F., Lin, C.-Y., & Liu, C.-F. (2020). Immersive Virtual Reality-Based Cardiopulmonary Resuscitation Interactive Learning Support System. *IEEE Access*, *8*, 120870–120880. https://doi.org/10.1109/ACCESS.2020.3006280