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Impact of an Augmented Reality Application on the Development of Science and Technology Skills in Regular Basic Education Students

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***Abstract*— This research addresses the challenges of teaching abstract scientific concepts in Basic Regular Education, where limited laboratory infrastructure often hinders student comprehension. The investigation utilized a quantitative quasi-experimental design featuring a pre- and post-assessment structure, involving 67 fourth-grade secondary students. The main aim was to assess the influence of a mobile Augmented Reality (AR) application on the practical acquisition of science and technology competencies. Subjects were assigned to a control condition, using conventional printed guides, and an experimental group that interacted with a customized mobile application developed with Unity and Vuforia engines to visualize topics such as cell biology, anatomy, and astronomy. Statistical analysis showed that, although both groups had homogeneous levels of knowledge before the intervention, the experimental group subsequently showed a statistically significant improvement ($p < 0.05$), corresponding to a substantial effect size (Cohen's d = 0.98). In contrast, the control group showed a negligible improvement. It is concluded that mobile AR significantly enhances academic performance by serving as a cost-effective "pocket laboratory," democratizing access to high-quality scientific experimentation and serving as a superior alternative to traditional two-dimensional methods in resource-constrained contexts.**

***Keywords*—Augmented Reality, Science Education, Educational Technology, Mobile Learning, Practical Learning, Secondary Education, Interactive Simulation.**

I. Introduction

Science and technology education is a key and cross-cutting support for the development of academic and professional competencies in this century [1]. The educational landscape has undergone a transformation in recent times, a shift that confirms Augmented Reality (AR) is no longer simply a novelty, but a vital tool for cultivating higher-order abilities such as spatial reasoning and critical analysis [2], [3]. Likewise, AR acts as a powerful pedagogical support by allowing the observation of rarely seen phenomena [4].

Observing the progress in the development of practical learning within Basic Regular Education reveals a slow assimilation and understanding of abstract concepts. There is an underlying problem in the difficulty of observing phenomena that do not occur naturally in the classroom or that require expensive and sophisticated professional equipment for visualization. This barrier prevents students from connecting theory with practice, thus limiting their ability to internalize fundamental scientific concepts.

Recent studies integrating innovative technologies into the development of educational competencies frequently mention their potential to promote active learning, enrich theoretical knowledge, and foster a more sustainable and digitalized culture. They also emphasize the crucial role of educational institutions, not only as transmitters of information but also as transformative agents for the development of higher-order cognitive skills [5], [6]. In this context, technology ceases to be an accessory and becomes a necessary mediator between the student and complex knowledge. Augmented Reality (AR) is currently acquiring strategic importance, emerging as a viable solution for presenting content in an observable and manipulable format. Its unique ability to transform educational environments through the superimposition of virtual elements upon the physical surroundings is a technological advantage that should be explored further [7]. Unlike virtual reality, which isolates the user, AR allows for maintaining a connection with the physical environment, enriching it with layers of information that facilitate contextualized learning.

In the educational field, the implementation of augmented reality is presented not only as something novel, but as a substantial improvement in learning strategies. It is used as an interactive tool that provides crucial visual support in the simulation of abstract objects, allowing for the understanding of complex topics, such as environments or physical structures, that are traditionally difficult to observe or imagine without external help [8], [9].

This technology presents itself as a competitive advantage in learning compared to traditional methods. On the other hand, its counterpart, printed or 2D materials, are limited to offering poor and static interaction with the content, forcing students to exert excessive cognitive effort to imagine three-dimensional processes. By combining AR technology and its spatial visualization advantages, an innovative category of educational software is introduced, along with a more engaging and motivating teaching method. This allows us to identify this technology as a direct pedagogical benefit, delving into its methodological implications for the modernization of the school curriculum [10], [11].

This study uses augmented reality as a framework to present intuitive material. The goal is to facilitate the understanding of concepts and serve as an effective means of exploring abstract topics that cannot be grasped naturally in a traditional classroom. The proposal aims to democratize access to scientific experimentation through accessible digital tools.

The specific problem addressed focuses on students in

Basic Regular Education. The diagnosis reveals that abstract topics are not explored in depth due to a lack of appropriate tools; likewise, laboratory infrastructure and innovative technology are resources that are acquired slowly or, in many cases, are simply unavailable to institutions. This situation of material scarcity requires urgent improvement to guarantee students' practical learning, where Augmented Reality (AR) emerges as a cost-effective and logistically efficient solution. Consequently, the primary aim of this research is to assess the effect of a mobile AR tool on the enhancement of practical skills in science and technology, measured through the competencies established in the National Curriculum Design (DCN) of Peru. To achieve this, the research adopted a quantitative framework based on a quasi-experimental model, utilizing a pre- and post-evaluation format. This methodology allows for a comparison of the performance of a control group (subjected to the traditional teaching method) with an experimental group (which used the AR application), thus ensuring the validity of the findings. The specific objectives of the research are detailed below:

- To investigate whether there is a statistically significant improvement in practical learning among students who use AR as a support tool.
- Analyze the differences in academic performance between the control and experimental groups after the educational intervention.
- Examine the effect size of AR intervention on students' acquisition of practical learning skills.

These objectives contribute integrally to the research aimed at observing and quantifying the impact of an augmented reality application based on the content of Basic Regular Education. The ultimate goal is to validate strategies that facilitate the understanding of abstract topics by combining active teaching methodologies with scalable technological solutions.

II. Literature Review

While Augmented Reality (AR) is situated under the umbrella of Extended Reality (XR), a collective designation for immersive technologies like Virtual Reality (VR), AR, and Mixed Reality (MR), its application in real-world environments differs significantly in terms of accessibility. Unlike virtual reality, which encloses the user in an environment, mobile AR enables collaboration within the physical classroom [12].

Similarly, high-fidelity VR or Mixed Reality experiences require robust and expensive equipment to support these technologies. Other recent studies, based on a literature review, have identified advanced hardware such as HoloLens and Magic Leap headsets, which demonstrate high immersive potential [13]. However, the literature also indicates that the use of sophisticated computer equipment to develop virtual reality platforms or complete spaces [14] presents logistical challenges, and the discomfort of the specific equipment (dizziness, weight of the headsets) and its high cost are frequently cited as barriers to its widespread educational adoption.

Conversely, current literature recognizes Augmented Reality as an advantageous and scalable technology, positioning it as a superior alternative for content presentation in resource-limited contexts. This technology has intrinsic appeal for students, as it increases their motivation to learn by transforming a passive classroom into an interactive environment [8]. However, it presents a disadvantage: there are critical factors that must be considered for its successful implementation. Crucial aspects involve adequate preparation for instructors and learners regarding the application of such technologies, alongside determining the ideal intervention length to prevent cognitive saturation [15], [16]. Following the concepts that underpin this research, the following categories are described:

A. Theoretical foundations

The concept of Augmented Reality was fundamentally established by Azuma in 1997, characterized by the integration of physical and digital elements, real-time user interaction, and three-dimensional registration [17]. It is now true that AR provides learning experiences. Considering learning theories, two stand out: situated learning and constructivist learning. Situated learning theory states that learning takes place in a specific location or space, its main characteristic being the specific context, resulting in interactions related to the culture, place, objects, processes, and people within that context [18], [19].

On the other hand, constructivist learning states that knowledge is actively constructed from one's own ideas, its characteristics being inquiry, reflective analysis, and knowledge reconstruction [20]. Taking these two theories into account, when situated in a specific context where students interact, they generate a learning environment that enriches inquiry through questioning. Students reflect and generate knowledge based on their experiences in the environment. Likewise, the Piagetian approach should be considered, mentioning the progressive construction from concrete actions toward abstract thought. Although associated with age, these can also be understood as cognitive levels when a person faces new learning [21]. Furthermore, AR possesses a unique potential for teaching complex and abstract phenomena [12].

B. Augmented reality

Augmented reality (AR) is defined as an immersive technology that presents virtual objects superimposed on the real world in real time. This technology is commonly used to facilitate the understanding of abstract topics, maintaining a clear and visual explanation. In the field of biology and anatomy, recent meta-analyses have shown that AR significantly improves learning outcomes compared to traditional methods, particularly highlighting its effectiveness in visualizing complex spatial structures, such as the human heart or cell organelles, which are difficult to understand from 2D textbook diagrams.

The pedagogical value of AR lies in its ability to "make the invisible visible," allowing users to see and interact with phenomena beyond the reach of the human eye, such as the dynamics of the Solar System, the microscopic structure of the cell, and the internal systems of the human body [11], [22], [23]. Beyond visualization, AR integrates virtual information into a person's physical environment, enabling students to contextualize the subject matter without losing touch with their immediate reality. Studies encompassing Augmented Reality mention that complex topics are presented in a more suitable format that seeks to foster student interaction [24], [25].

C. *Mobile Augmented Reality*

AR remains relevant in various applications, but one of the most widely used due to its ubiquity is mobile devices (smartphones and tablets). Especially through the use of these devices' cameras, mobile AR offers an easy and inexpensive way to present abstract objects [26], [27], [28].

Using the mobile phone camera, it is possible to overlay virtual objects by tracking the environment and capturing images of the real world. The 3D virtual objects are geometrically superimposed on the real world, becoming visible to the human eye through the device screen, acting as a magical window into educational content [29].

While AR technology offers a clear advantage for displaying abstract content, rigorous measures must be taken for its effective adoption. Technical factors play a crucial role; software and device hardware (processor, camera quality, and gyroscope) are at different stages of development in the context of public education. Variability in the range of mobile devices can affect the stability of 3D models and the smoothness of the experience. Therefore, these technical and infrastructure factors must be considered to improve implementation and ensure a consistent and frustration-free student experience [13].

III. MATERIALS AND METHODS

A. *Research design and method*

This research employs a quasi-experimental design with a quantitative approach. This design is necessary due to the impossibility of fully randomizing the subjects, as the study involved intact groups (pre-existing classes) within the educational institution. This method allows for establishing a direct causal link connecting the technological intervention (use of the AR application) with the observed educational outcome (level of practical learning in Science and Technology).

The design comprises three strict time phases: pretest, intervention, and posttest. This structure is advantageous for the study, as it allows for isolating the effect of the technological intervention by comparing the performance of the experimental group with the baseline performance of the control group.

To define the study population, all students enrolled in the corresponding grade were considered, totaling 80 students. To determine the representative sample, the statistical formula for finite populations was applied, establishing a 95% confidence level and allowing a maximum margin of error of 5%. The calculation yielded a target sample of 67 students. Exclusion criteria were applied to students with recurring absences exceeding 30% of the sessions.

Finally, the distribution consisted of two natural sections: the Control Group (CG) with 35 students and the Experimental Group (EG) with 32 participants. Furthermore, the study design is based on current evidence suggesting that educational technology is more effective when used as reinforcement [30].

The diagnostic assessment (pretest) consisted of administering a validated assessment instrument to measure prior knowledge and practical skills in both groups before any manipulation, ensuring baseline homogeneity. During the experimental intervention, differentiated learning sessions were conducted. The control group (CG) used printed laboratory guides, static physical models, and standard textbooks. The experimental group (EG) used mobile devices with the augmented reality (AR) application installed. The posttest was administered after the session, using the same measurement instrument to quantify learning achievements and perform a comparative statistical analysis.

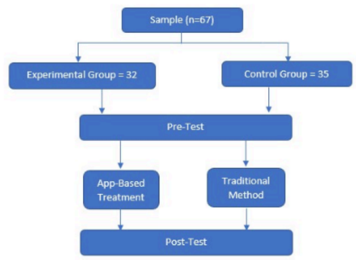

Fig. 1. Study Process map

B. *Ethical Approval and informed consent*

The study focused primarily on secondary school students, specifically those in the 4th grade of Regular Basic Education (EBR) at an educational institution in the city of Piura. The final sample of 67 students ranged in age from 14 to 16. Following ethical research protocols, participation was authorized through informed consent signed by the student's tutor and assent from the students. The study secured formal authorization from the Ethics Committee of Cesar Vallejo University (Protocol No. 00068-2025/CEI-EIS). Furthermore, all subjects were guaranteed that their personal information would remain confidential and be utilized exclusively for scientific inquiry. The groups remained in their usual classrooms to avoid disrupting the natural learning environment.

C. *AR application development*

For the technological intervention, a mobile application was developed specifically for the Science and Technology curriculum. The application's core software was built using the Unity 3D graphics engine, leveraging its real-time rendering capabilities. For the Augmented Reality logic, the Vuforia Engine SDK was integrated, utilizing its Image Targets technology for object anchoring and tracking. For modeling and resources, the three-dimensional models (eukaryotic cell, reproductive system, cardiac anatomy, solar system) were processed and optimized in Blender to ensure lightweight geometry compatible with mid-range mobile devices, common in the school environment.

On the other hand, the application's architecture consists of three functional modules. One is the AR visualization module, which uses the device's rear camera to recognize printed marker cards. Upon detecting the pattern, it is overlaid on the corresponding 3D model, allowing the student to orbit around the physical object. The second module, descriptive information, displays information panels with theoretical data when interacting with specific parts of the virtual model, facilitating self-guided learning. Finally, the assessment module (AR Quiz) consists of a system of interactive questions projected alongside the 3D model, where the student must identify the structural components to validate their immediate learning.

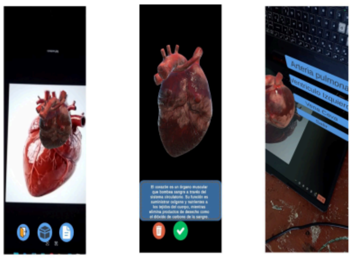

Fig. 2. Mobile application developed

D. *Procedure and Implementation*

The field phase lasted a total of eight weeks, corresponding to eight 45-minute learning sessions. Prior to this, a technical training session was conducted for the course instructor and the students in the experimental group. This introduction covered the use of the user interface, interaction gestures (rotation, scaling, and movement of virtual objects), and troubleshooting basic camera focus issues. The structure of each experimental session followed this pedagogical sequence: motivation (5 minutes), a brief theoretical introduction by the instructor, and experimentation (30 minutes). In the control group, students worked in teams analyzing 2D diagrams in books.

Fig. 3. Students who used the application

In the experimental group, students used an AR application. By pointing their mobile devices at the work guides (which functioned as markers), they visualized the organs and systems in 3D. They were asked to examine structures (the cell, the solar system, and the organs of the human body) that are impossible to see in printed materials. To conclude the session, a 10-minute discussion and feedback session was held, during which questions were answered and the topic was reinforced. The topics covered included cell biology, human anatomy (with an emphasis on the reproductive system), and basic astronomy, all strictly aligned with the National Curriculum Design (DCN).

IV. Result and Discussion

To ensure the validity of the findings, a rigorous statistical analysis was conducted, dividing the process into: verification of assumptions, comparative analysis of groups, and measurement of effect size. The data were processed using standard statistical software, considering a 95% confidence level ($\alpha = 0.05$).

A. *Verification of statistical Assumptions*

As a preliminary step to hypothesis testing, the distribution of data collected in the practical learning assessments was evaluated. Since the sample size is less than 50 participants per subgroup, the Shapiro-Wilk test was chosen, as it offers greater statistical power for this type of sample.

Table 1. Normality Test

Group	Normality Test (Shapiro-Wilk)		
	Statistical	df	Sig
Control Pre-test	.862	32	0.001
Experimental Pre-test	.905	32	0.008

As illustrated in Table 1, p-values for the pre-control and pre-experimental groups were 0.001 and 0.008, respectively, indicating statistical significance ($p < 0.05$). Since the data does not adhere to a normal distribution, the null hypothesis is discarded. This statistical reality justifies selecting non-parametric tests (e.g., Wilcoxon) to rigorously analyze the differences between the groups.

Subsequently, the homogeneity of variances (homoscedasticity) between the groups was analyzed using Levene's test, which is essential to ensure that both groups are comparable at the start of the study.

Table 2. Test of Homogeneity of Variances

Group	Levene Test			
	Levene Statistic	Sig.	df	Sig (2-tailed)
Pre-Test	.295	.589	65	.7088
			64,999	.787
Post-Test	87.124	.000	65	.001
			43,276	.001

Analysis of Table 2 highlights a key aspect of internal validity. In the pre-test phase, the significance level is 0.788 ($p > 0.05$), proving that group variances were homogeneous. Consequently, it can be affirmed that the experimental and control sections started with balanced prior understanding and similar academic abilities.

Conversely, in the post-test, the significance value of 0.001 ($p < 0.05$) indicates that, after the intervention, the variances were no longer equal. This structural change in the data distribution suggests that the augmented reality intervention not only altered the averages but also modified the dispersion of learning, generating a different performance pattern than that of the control group.

B. *Analysis of Improvement in Learning*

To answer the first specific objective regarding the existence of improvement in practical learning, the Wilcoxon signed-rank test for related samples was applied, comparing before and after within the experimental group.

Table 3. Wilcoxon Test

Group	Wilcoxon	
	Z	*p*
Experimental	-4.099	.001

The results in Table 3 show a statistically significant difference. The Z-value of -4.099, associated with an asymptotic significance (two-tailed) of p=0.000, strongly confirms that the use of the Augmented Reality application had a positive impact on academic performance.

This result validates the effectiveness of the application for visualizing abstract objects (cells, anatomical systems, and the Solar System). Compared to previous literature, this reinforces the premise that direct interaction with 3D models and the ability to manipulate them virtually facilitate the assimilation of concepts traditionally difficult to understand [31]. This finding validates the effectiveness of the application. The results are consistent with the recent meta-analysis that found that AR interventions typically produce a medium to large effect size in science education due to increased student engagement [32].

Students showed greater acceptance of this technology, with interactivity being a key factor reflected in this statistical increase [33]. The technologies used in the study were implemented with cards detected by the Vuforia SDK, a technology used for reference study applications [34].

C. *Comparison of Effectiveness*

It is necessary to analyze whether this improvement was solely due to the use of technology or simply to the passage of time (maturation). To this end, the behavior of the Control Group was analyzed using the same Wilcoxon test.

Table 4. Wilcoxon Signed Ranks Test

Group	Wilcoxon test	
	Z	*p*
Control	-1.732	.083
Experimental	-4.099	.001

The contrast shown in Table 4 is evident. In contrast to the Experimental Group, which demonstrated statistically significant progress ($p < 0.001$), the Control Group—relying on conventional teaching—yielded a Z-statistic of -1.732 with a corresponding p-value of 0.083.

Since $0.083 > 0.05$, the null hypothesis for the control group is not rejected. This means that the students who used 2D slides and conventional texts did not show a statistically significant improvement in their practical skills during the same period. This finding underscores the limitations of printed materials for teaching dynamic and abstract topics [11], [15], and isolates the study's success specifically to the technological variable introduced. Likewise, the results show acceptance by the students, indicating that Augmented Reality is an inclusive and cross-curricular technology attractive for regular basic education [35].

D. *Magnitude of the Intervention Effect*

Beyond statistical significance (the "yes" or "no"), "practical significance" was calculated using effect size, with Cohen's d and Pearson's correlation coefficient (r). This allows us to determine how much better the proposed method is.

Table 5. Effect Size Analysis (Pearson's r & Cohen's d)

Group	Effect Size		
	N	R Pearson	Cohen's d
Control	35	0.29	0.31
Experimental	32	0.72	0.98

The magnitude analysis presented in Table 5 is conclusive, according to conventional statistical standards. The Control Group showed a Cohen's d of 0.31, which is categorized as a small effect. This is consistent with traditional teaching: it produces learning, but in a limited way. The Experimental Group reached a Cohen's d of 0.98. A value greater than 0.80 is considered a large effect.

This indicates that the intervention was not only effective but also had a transformative impact on student learning. Furthermore, the Pearson correlation ($r = 0.72$) in the experimental group denotes a strong relationship between the use of the application and the improvement in grades. These quantitative metrics demonstrate the robustness of the proposal, aligning with research that positions AR as a superior technology for the development of scientific competencies compared to traditional methodology [5]. Unlike studies utilizing expensive hardware such as HoloLens or Magic Mirrors [35], this research demonstrates that similar educational benefits can be achieved using accessible mobile devices, democratization access to high-quality science education.

V. CONCLUSION

This research successfully determined and quantified the impact of Augmented Reality (AR) on the practical learning of Science and Technology in secondary school students. The findings provide robust empirical evidence confirming that the integration of immersive tools in the classroom significantly outperforms traditional lecture-based methodologies. It is crucial to highlight that, through statistical analysis of the pre-tests, it was demonstrated that both study groups began the process under conditions of cognitive homogeneity; this methodological rigor allows us to assert that the discrepancies observed in the final results are directly attributable to the technological intervention and not to external variables or disparate prior knowledge.

The results obtained reveal a transformation in the learning dynamic. The experimental group, assisted by the mobile application developed with Unity and Vuforia, showed a substantial improvement in the understanding of abstract phenomena (cell biology, anatomy, and astronomy) compared to their counterpart, the control group, which was limited to the use of textbooks and static two-dimensional images. This difference validates the premise that hands-on learning requires spatial visualization and active manipulation. AR acted as a cognitive scaffold that reduced the mental load necessary to imagine complex processes, allowing students to interact directly with the educational material, rotate it, and explore it, which generated a higher level of retention and comprehension.

The effect size analysis yielded a magnitude considered "large" according to statistical standards. This has profound implications for the educational reality of basic education institutions, especially in contexts where physical infrastructure is limited. The study suggests that mobile AR technology can democratize access to high-quality science education, functioning as a "pocket laboratory" that compensates for the lack of expensive physical models or sophisticated laboratory equipment.

In light of these results, it is strongly recommended that educational institutions and bodies responsible for curriculum policies consider the systematic integration of Augmented Reality into their teaching strategies. However, technology alone does not guarantee success; it is imperative to accompany this implementation with comprehensive teacher training programs in digital skills. Teachers must transition from being transmitters of information to facilitators of technological experiences, thereby closing the generational technological gap and promoting seamless interaction between educators and learners through these new interactive media.

Finally, while these results demonstrate a statistically significant and promising effect, it is crucial to recognize the constraints of the current investigation to inform upcoming scholarly work. The sample was limited to 67 students from two classrooms within a single educational institution, which warrants caution in generalizing the findings. Future work should replicate this intervention in longitudinal and larger-scale studies, encompassing a diversity of demographic contexts (rural vs. urban areas) and expanding the scope to other subjects within the National Curriculum. Furthermore, it would be valuable to investigate long-term knowledge retention (months after the intervention) to verify whether learning acquired through AR lasts longer than traditional rote learning.

Conflict of Interest

The author declares no conflict of interest.

Author Contributions

Jean J. Namuche was in charge of developing the mobile application; he also collected and analyzed the data and wrote the article. Antony P. Tavara, the supervisor, provided guidance throughout the study process.

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