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RESEARCH ARTICLE

Improving Higher Education With the Use of Mobile Augmented Reality (MAR): A Case Study

SANTIAGO CRIOLLO-C[1], (Member, IEEE), ANDREA GUERRERO-ARIAS[2], JOSÉ ENRIQUE CEREZO UZCÁTEGUI[1], YUNIFA MIFTACHUL ARIF[3], (Member, IEEE), APRILLA FORTUNA[4], FEBRI PRASETYA[5], AND SERGIO LUJÁN-MORA[6]

[1]Carrera de Ingeniería en Ciberseguridad, Facultad de Ingeniería y Ciencias Aplicadas, Universidad de Las Américas, Quito 170125, Ecuador
[2]Jezreel International Christian Academy, Quito 170520, Ecuador
[3]Department of Informatics Engineering, Universitas Islam Negeri Maulana Malik Ibrahim Malang, Malang 65144, Indonesia
[4]Department of Mechanical Engineering, Universitas Negeri Padang, Padang 25132, Indonesia
[5]Faculty of Engineering, Universitas Negeri Padang, Air Tawar Padang, Padang, West Sumatra 25132, Indonesia
[6]Departmyent of Software and Computing Systems, University of Alicante, 03690 Alicante, Spain

Corresponding author: Santiago Criollo-C (luis.criollo@udla.edu.ec)

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ABSTRACT Currently, students face difficulties in understanding and assembling desktop computer hardware. Traditional teaching, which relies on theoretical classes and manuals, does not provide sufficient interactive or practical experience, hindering the comprehension and retention of knowledge. Understanding hardware is fundamental for computer science and related fields students, as it is the basis for building and maintaining computer systems. The lack of practical knowledge in this area can result in inadequate training, limiting students' abilities to apply theoretical concepts in real-world situations, which can affect their academic performance and job market readiness. There have been initiatives that included the use of printed manuals, video tutorials, and software simulations to teach hardware. However, these methods failed to engage students sufficiently or provide a practical and realistic learning experience. These methods can become boring and disconnected from the practical experience necessary for properly assembling computer hardware. The proposed solution is the use of an augmented reality (AR) mobile application to create an interactive and practical learning experience. The application called Build_PC was designed, and it allows students to visualize and manipulate hardware components in a virtual environment superimposed on the real world, allowing practical learning of computer assembly and operation. The main results of the research, which used volunteer students associated with control and experimental groups, show that the use of Build_PC significantly improved the understanding and retention of knowledge about computer hardware. Students who used the application demonstrated a greater ability to understand the operation of hardware components compared to those who used traditional methods. In addition, students reported greater motivation and satisfaction with the learning process. Implementing a AR-powered application in hardware education has several important implications. Firstly, it provides an effective tool to enhance understanding and knowledge retention, which can lead to better academic and professional preparation for students. Furthermore, it can serve as a model for integrating emerging technologies in other educational areas, enhancing practical teaching and interactive learning. It also highlights the need to invest in innovative educational technologies to keep up with job market demands and student expectations.

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INDEX TERMS Augmented reality, mobile augmented reality, active learning, MAR application, mobile learning, authentic learning.

I. INTRODUCTION

Educational institutions have increasingly encountered challenges in the teaching process across all educational levels, attributed to factors such as a lack of motivation, commitment, concentration, interest, attention, and confidence, along with emerging economic, social, political, and cultural barriers [1], [2]. These issues significantly impact students' personal, academic, and professional development, potentially leading to problems such as educational inequality, poor adaptation to the labor market, and difficulties in problem-solving [3], [4], [5]. As such, it is crucial for educational models to evolve in response to the changing needs and expectations of students and society [6]. In this context, digital technologies have emerged as vital tools in enhancing, transforming, and innovating educational models. They offer equitable access to high-quality educational resources, enable personalized learning, foster collaboration, and support interactive and motivational learning experiences while developing essential 21st-century skills [7]. Mobile Augmented Reality (MAR) has gained particular attention in various domains, including higher education [7], [8], [9]. This cutting-edge technology merges physical and digital worlds to present novel and enhanced methods of teaching and learning [5]. By creating immersive experiences, MAR allows students to interact with knowledge in ways that facilitate a deeper understanding of complex and abstract concepts [10], [11], [12]. MAR leverages a mobile device's camera and sensors to detect the environment and track the device's position and orientation in real time [13]. overlaying graphics, images, or digital information on the device's screen to create a seamless blend of real and virtual worlds [14]. Notable applications of MAR include educational games [15], navigation aids for urban exploration or tourism [16]. and various interactive learning experiences. For instance, students can engage with 3D models of biological, geographical, or physical objects within their real environment [17], [18], [19], [20]. Furthermore, MAR has been effectively utilized in fields such as medicine [21], [22], mathematics [23], languages [24], music [25], art [26], architecture [27], telecommunications [28].

This research investigates the impact of MAR on higher education, specifically evaluating whether its use can enhance students' assessment scores and academic performance. The study analyzed MAR through a mobile application named Build_PC as a support tool in engineering education. Participants, comprising volunteer students from a private university, were divided into experimental and control groups. Results indicated that the experimental group, using MAR, achieved higher scores in a shorter time compared to the control group, demonstrating the potential of MAR technology to positively influence engineering education outcomes.

The following sections of this paper are organized as follows: Section II reviews the application of MAR technology in education. Section III details the research methodology employed. Section IV presents the research findings. Section V discusses these results in depth. Section VI outlines the study's conclusions, and Section VII suggests directions for future research.

II. MOBILE AUGMENTED REALITY

Nowadays, with the development of digital technologies, especially with the development of MAR, it is possible to observe and interact with virtual objects that are visible in a real-world environment [29], [30]. MAR-based applications have been developed for multiple areas such as medicine, electronics, tourism, telecommunications, interior design, entertainment, education, among others [30], [31], [32], [33]. MAR can be used to visualize the interior design of a physical space with an overlay of virtual elements, helping to visualize and personalize a space before making significant changes or purchases [34].

MAR-based applications are usually classified by how they display augmented content on mobile device screens. These are:

- Marker-based AR: This type of AR uses specific patterns or images that the device's camera recognizes to overlay virtual content on the real environment. Markers are usually QR codes or geometric patterns that the application can easily identify [35].
- Markerless AR: This AR does not require specific patterns to function. It uses sensors like GPS, compasses, accelerometers, and gyroscopes to determine the device's location and orientation, allowing virtual content to be overlaid on the real environment anywhere. A common example is location-based AR, such as that used in applications like Pokémon GO [35].
- Geographic AR: This is an extension of markerless AR, also known as location-based augmented reality. It is a type of technology that uses the user's geographical position to overlay digital information onto the real environment. This type of AR does not require physical markers but employs sensors and technologies such as GPS, compasses, accelerometers, and gyroscopes to determine the location and orientation of the mobile device. This technology is used in travel guide applications and maps [35].

Mobile Augmented Reality in Education: In recent years, information technologies have complemented the traditional educational model, offering new learning opportunities through educational games and interactive visualizations [36]. For this reason, with the help of MAR-based applications, the educational model can be improved and offer new dynamic and interactive approaches to teaching and learning [37]. MAR has the potential to transform education by offering immersive and contextualized learning experiences [26]. This technology allows the visualization of abstract concepts, facilitating their understanding by visualizing them interactively and **3D** [38]. It also enables educational experiences by visualizing experiments through the overlay of virtual elements in a physical environment [39]. MAR allows personalized learning and can improve students' understanding, motivation, and performance by making it more interesting and entertaining [37], [40].

This technology is increasingly used in education at all levels, from early childhood education to undergraduate studies [17], [41]. In early childhood education, MAR is used to introduce basic concepts interactively and funnily [42]. For example, MAR applications can show 3D animations of letters, numbers, shapes, and colors, helping children learn visually and manipulatively [43], [44]. In primary education, AR can be used to bring abstract concepts to life. For example, a lesson on the solar system can include an AR experience where students can see and manipulate 3D models of the planets in the classroom [45], [46]. In secondary education, AR can be used to explore more complex topics visually and practically. For example, in a biology class, students could use an AR application to see 3D models of cells and microscopic organisms [18].

In higher education, MAR is used in various ways to enrich the educational experience and improve student learning. Here are some examples:

- In the medical field, MAR facilitates the interactive study of human anatomy, neuroanatomy, neurosurgery, biology, the nervous system, physiotherapy, among others, allowing practical and visual learning safely [18], [21], [22], [47].
- In exact sciences, MAR is used for the practical teaching of abstract phenomena such as electromagnetism, waves, fission, particle structure, among others [20], [21], [28]. Additionally, educational applications with MAR have been developed, which are used to visualize 3D geometric objects and calculate area, volume, lengths, etc. [17].
- In social sciences, MAR has been used to improve the language learning environment as a second language, encouraging students to better connect with others, express opinions, share ideas, and construct meanings [48], [49]. Furthermore, this technology has facilitated the teaching of liberal arts like music and cultural competence in controlled study environments outside the traditional classroom with positive results [25], [26].

For computer science, hardware and software, programming languages, among others, initiatives have used virtual reality (VR) instead of MAR technology. Immersive technology is used due to better visualization and interaction with 3D objects [50], [51], [52], [53]. Although immersive technology has been explored for teaching computer science, software, and programming languages, the use of MAR for hands-on learning of computer hardware has not been extensively documented. This research fills this gap, providing an innovative educational solution that uses MAR to allow students to virtually interact with hardware components, which is safer and more cost-effective than using actual physical hardware in the initial stages of learning. Build_PC introduces new forms of interaction that have not been widely explored in previous studies. For example, it allows students to virtually disassemble and assemble hardware components and perform diagnostic and troubleshooting practices. This level of interactivity is a novelty in computer hardware teaching and provides a more immersive and hands-on learning experience. In addition, a detailed analysis of the impact of using Build_PC on student learning is included, showing significant improvements in understanding of hardware concepts, and practical skills. These results highlight the effectiveness of this solution compared to traditional teaching methods and other educational technologies.

III. METODOLOGY

Unlike other similar initiatives in the current literature, this research did not focus solely on the application's design and usability aspects but also on evaluating the results of using Build_PC in a case study. This research aims to identify whether using a MAR technology application can influence students' academic performance. Statistical techniques measuring variances obtained in an evaluation instrument (knowledge test) applied to an experimental group and a control group were used. The research results will provide data that will lead to new knowledge about the influence of digital technologies on personalized learning.

The research design is represented in Figure 1. Here you can see the different stages of the analysis of the use of MAR in the different groups of students. This chart shows a clear structure of the experimental methodology used to evaluate the impact of mobile augmented reality on PC hardware education, ensuring a balanced comparison between teaching methods and considering gender variables.

A. MOBILE AUGMENTED REALITY APPLICATION DESIGN

1) DESIGN PROCESS

- Identification. Initially, the main components of a desktop computer and their respective functions were identified. Subsequently, the capabilities of mobile devices with the Android Operating System (OS) were investigated to determine the tools and Software Development Kits (SDKs) suitable for developing the educational application. Finally, frameworks and libraries used in Unity for developing mobile AR applications were classified. These libraries needed to facilitate the tracking of a 2D physical model and map the desktop computer model to the real world through the mobile device's camera. The chosen framework was Vuforia, a licensed system that provides AR capabilities without consuming excessive resources.

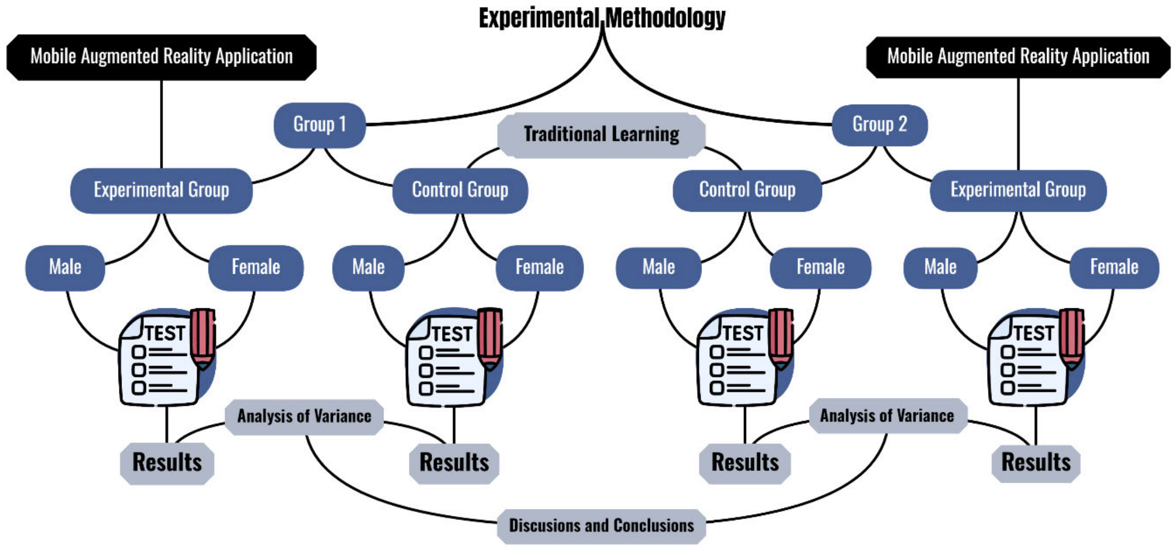

FIGURE 1. Structure of experimental methodology.

TABLE 1. Development platforms used.

Development platforms	Features
Unity	Unity is a video game development platform that has different versions of long-term support (LTS). Also, it can be defined as a game engine that provides a complete environment for the development of 2D and 3D video games, as well as mixed reality (XR). The developed games can be exported for use in different devices such as, desktop computer, laptop, console, smartphone, tablet, Oculus, among others.
Visual Studio 2022	Visual Studio is an integrated development environment (IDE) produced by Microsoft. This software is used to write, debug, and compile programming code. It includes a package that can be installed to connect to Unity and debug code while running the application.

- Optimization. For the computer model, a free asset downloaded from the internet was used, which was later optimized for seamless use on mobile devices. The open-source tool Blender was utilized for this purpose.
- Interface Design. The number of interfaces to be displayed to users was defined, including the settings menu and the information window for the desktop computer components. Subsequently, the positioning and style of elements in each interface were designed, including text placement, color, size, and font type.
- User Interaction Design. Several interaction possibilities were defined, such as using cursors, interacting through the camera with hand gestures, among others. Ultimately, a raycasting system was chosen to allow users to tap on a component on the screen, with the application responsible for mapping that point and component to the exact location within the computer case.

2) DESIGN ELEMENTS

The development of the marker-based AR application called Build_PC was carried out using Unity 2022.3.17f1 LTS together with Visual Studio 2022 Community Edition. These are commonly used tools in the development of augmented reality video games. The features of these platforms are explained in Table 1. The following libraries were used for the application development:

- Unity: UnityEngine / UnityEngine.UI: for connecting and using Unity engine's internal functions.
- UnityEngine.InputSystem: for user interaction with the application and UI.
- Vuforia: to use the phone's camera and have a model to track the PC.

In the development of an application, which is going to be used as support in education, it is essential to clearly and precisely establish the requirements and needs that are intended to be addressed [54], [55]. These elements will guide the creative process, ensuring that the application is effective in meeting its educational objectives [54]. Likewise, the design must ensure that the application motivates users and encourages them to use it [56], [57]. Therefore, it should have a user-friendly interface, be simple, coherent, and intuitive, avoiding redundancy and offering interactive navigation [54], [55], [58], [59]. In this case, the requirements were identified in a previous study [60], [61], and are listed in Table 2.

TABLE 2. General requirements for the design of MAR applications [60], [61].

Requirements	Features
Simple and easy to use	Provide ease in the game, the user should not get caught in the links of the different sections
Consistent interfaces	Use known functionalities that resemble computer menus
Nice design	Generate satisfaction, enthusiasm, and fun by using the different controls in the activities carried out by the application
Feedback	Provide an understanding of mistakes made to improve task interpretation
Multimedia content	Generate use intent by creating multimedia interfaces that attract the user's attention
Intuition	Avoid user disorientation due to total number of interactions
Motivation	Motivate the user with kind messages while progressing through the game
Navigability	Follow the user interface design principles established by the platform on which the mobile application was developed
Lightweight	The application must allow its execution on devices with limited processing and storage capacity, although this results in loss of performance
Allow extensibility	The sensors of a device are different depending on the hardware used by the manufacturers. With the wide variety of methods for obtaining information, the designed application must be open to new ways of accessing the sensors.
Ease of testing and maintenance	Consistency in components should facilitate the development of unit tests and maintenance of the application.

TABLE 3. Iterations required for the construction of the MAR application.

Iteration number	Definition	Priority (1 -10)	Iteration duration (WEEK)
1	Create components.	10	1
2	Create interaction.	10	1
3	Optimize models.	6	2
4	Create tracking model.	9	1
5	Create UI elements.	8	1
6	Create block order verification.	6	1
7	Create option not to use tracking.	9	2
8	Add component information.	9	1
9	Create saving system.	7	2
10	Create object thumbnails for the information screen	5	1
Total duration of mobile application development		**13 weeks**	

Additionally, due to the specific design and usability, Build_PC has the following functionalities:

- Component Interaction: The user should be able to interact with the PC components and interface freely, easily, and intuitively.
- Component Information: The user should be able to obtain information about each component and its function.
- Component Order Verification: The user should receive feedback when making an error.
- Visualization: The user should be able to see the PC components clearly and without confusion both inside and outside the case.
- Friendly Environment: The user should perceive an environment where they can work and complete the proposed exercises without problems.

The configuration of these activities was carried out within a set timeframe defined in Table 3. If problems arose, the team would briefly meet to resolve doubts and continue with the project. The priority of each cycle was determined by the project's final objectives. At the end of each cycle, the work done was reviewed, demonstrated, and adapted in a team meeting to finalize Build_PC development. The following are images of the designed application's use. Figure 2 shows how Build_PC places PC elements 3D on the mobile device. Figure 3 shows a student using the Build_PC application.

FIGURE 2. Build_PC environment.

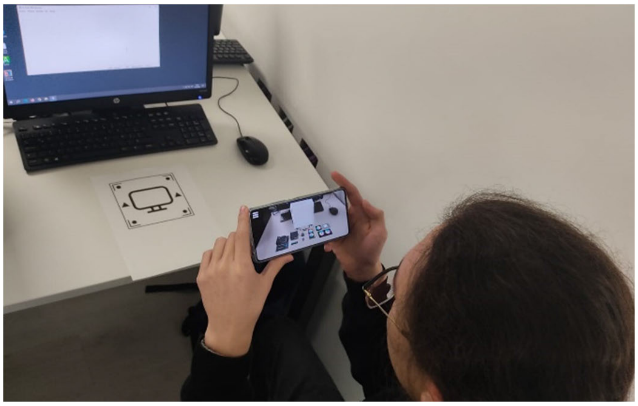

FIGURE 3. Student using Build_PC.

These two figures illustrate how the Build_PC application displays computer parts in a 3D format and how users can interact with it.

3) BUILD_PC CONFIGURATIONS AND OPERATION

Figure 4 presents two flowcharts: the first outlines the configurable options available within the mobile application, and the second details the application's functionality and user interaction processes. Build_PC is designed to be user-friendly and intuitive, reflecting the design principles detailed in Table 2. This emphasis on simplicity and intuitiveness not only enhances the user experience and operational efficiency but also promotes user adoption and has a positive effect on the application's intended use.

Additionally, the Build_PC design incorporates a language-switching feature. Users can choose to view interface information in Spanish, English, Indonesian, or Arabic. This multilingual capability enables Build_PC to cater to a diverse audience, accommodating various linguistic preferences. By supporting multiple languages, the application enhances accessibility and inclusion, thereby broadening its educational reach and impact. This feature ensures that users from different linguistic backgrounds can effectively engage with the application, further supporting its goal of providing a comprehensive and user-centric educational tool.

Moreover, the inclusion of a language change option demonstrates a commitment to global usability and user satisfaction, contributing to a more inclusive educational experience. The design approach not only addresses immediate user needs but also anticipates future demands for expanded language support, thus aligning with best practices in educational technology development.

B. PARTICIPANTS

A non-probability convenience sampling of 80 students from a private university was used in this research. Each student accepted an informed consent provided through a web form. The students were classified into two groups (1 and 2), and each group was further divided into control and experimental groups corresponding to the level of acquired knowledge. Group 1 has basic knowledge about PC hardware, and Group 2 has advanced knowledge about PC hardware. Each group of participants received an explanation of using Build_PC and could ask questions after using the application. Once their doubts were clarified, and they felt confident in mastering the application, they performed the requested tasks. The experimentation lasted approximately 20 minutes; after completing the tasks, they were asked to choose a predefined word that best described their perception of using Build_PC.

C. DEMOGRAPHIC INFORMATION

The total number of students was divided into two groups, GR1 with 40 third-semester students and GR2 with 40 fifth-semester students. Both groups, GR1 and GR2, are further divided into two subgroups, one experimental and the other control, as follows: GR1 (CG1 and EG1), and GR2 (CG2 and EG2). Of the total students (80), 24 were women (30%) and 56 men (70%). The participants' age ranged between 18 and 20 years. Additionally, 70 of them had an Android OS mobile device (90%), and the remaining 10% had an iOS device. The students indicated that 55 of them, representing 68%, had not previously used educational applications with MAR technology, while 25 students, representing 32%, had. The students with iOS devices used the BUILD_PC application with Android OS mobile devices provided by the teacher. Figure 5 shows the gender distribution, which is similar in both groups, with an important male majority in both groups. The average age is shown in Figure 6, which is very close in both groups, with only a one-year difference. Figure 7 shows a notable preference for Android in both groups, especially in GR2. Additionally, most participants in both groups had not previously used an educational application, as shown in Figure 8, although GR2 has a slightly higher number of previous users.

D. EXPERIMENTAL PROTOCOL

1) KNOWLEDGE TEST VALIDATION INSTRUMENT

The evaluation instrument was validated using the Kuder-Richardson test (KR20) with a result of KR20 = 0.70 (acceptable between 0.70 and 0.90). Additionally, the time

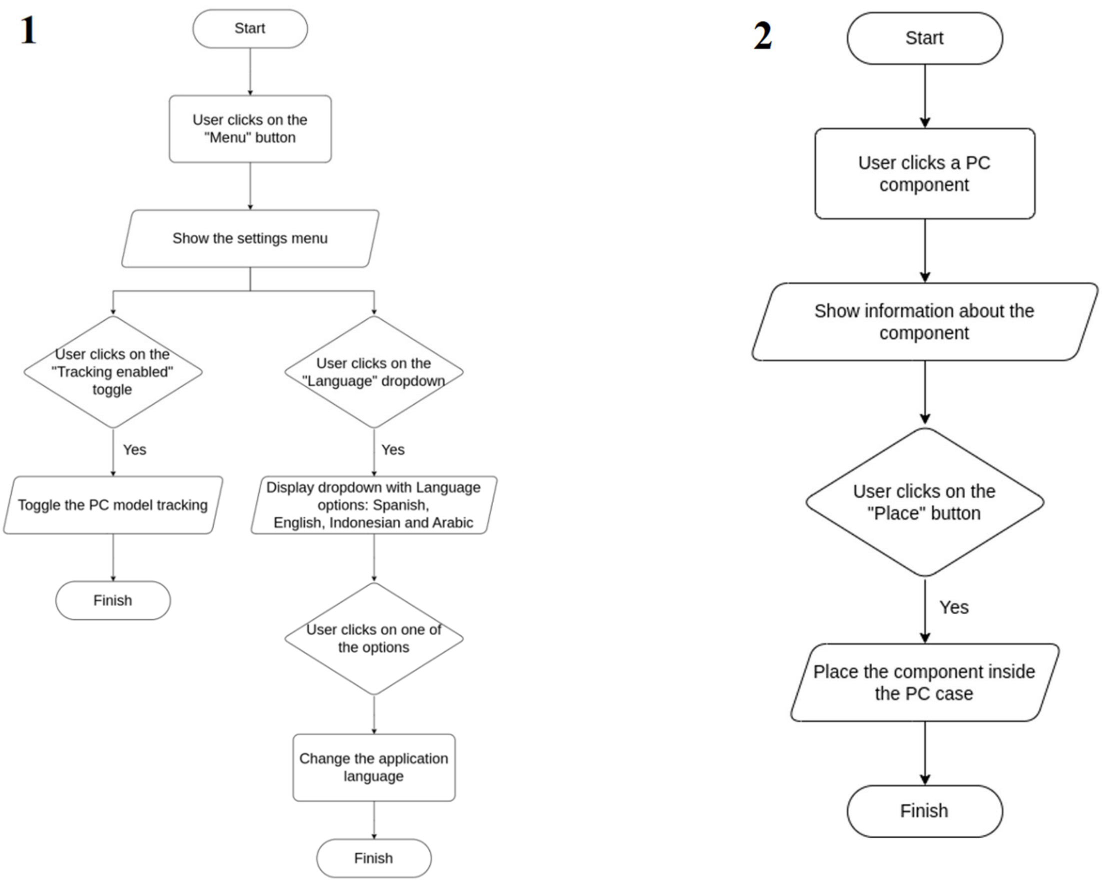

FIGURE 4. Build_PC settings and operation.

FIGURE 5. Participants by gender.

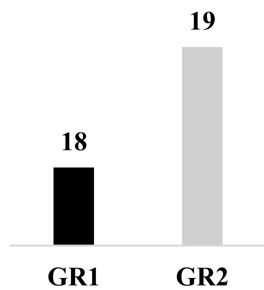

FIGURE 6. Average age of participants.

taken for each student to complete the knowledge test was measured. The Kuder-Richardson (KR20) formula is used to establish the reliability of a knowledge test based on its averages and variances. For this, 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 evaluation variance [62].

2) TASK

To conduct the experimental procedure in the research, students performed the following tasks:

- First: They must use a mobile device with Android OS version 9.0 or higher, which can be a smartphone or tablet.
- Second: They must install the Build_PC application on their mobile devices; the teacher provided the installer file to each student.
- Third: They must print the marker to use it with the camera and visualize the content on the mobile device screen, as shown in Figures 1 and 2.
- Fourth: They must take the knowledge test after the class, both CG and EG.

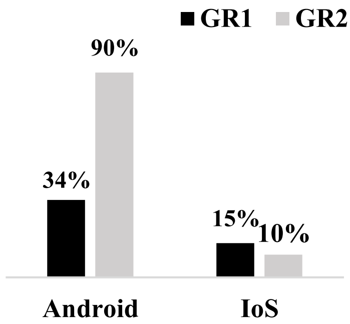

FIGURE 7. Operating systems that participants use.

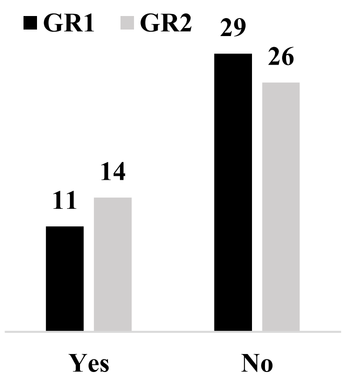

FIGURE 8. Use of previous educational applications.

- Fifth: They must choose a word that describes the Build_PC application.

3) CONTROL AND EXPERIMENTAL GROUP DESIGN

The two groups (GR1 and GR2) were divided into two subgroups each to carry out the proposed research analysis. The experimental subgroups EG1 and EG2 received PC hardware classes using two teaching methodologies, one traditional and the other using the Build_PC application. The control subgroups CG1 and CG2 only received the traditional method. Each subgroup comprises 20 students, as shown in Table 4.

TABLE 4. Number of students in each subgroup.

Groups	GR1	GR 2	Total of students
Experimental Group	20	20	40
Control Group	20	20	40

4) TEACHING SCHEME

Two different teaching schemes were used in this research:

Traditional Teaching: This type of teaching was used with the control group students CG1 and CG2. The teacher used a traditional methodology through presentations, readings, and knowledge tests, resulting in a method known to the students.

Teaching With Build_PC: This type of teaching was used with the experimental group students EG1 and EG2. The teacher used a mixed teaching methodology, traditional and using the Build_PC application to reinforce PC hardware knowledge.

5) DEFINITION OF VARIABLES

These variables define the structure of the experimental methodology illustrated in the Figure 1, with the independent variables being the teaching method and the knowledge level, and the dependent variable being the evaluation results of the students.

Independent Variables:

1. Teaching Method (TM):
   - Traditional Teaching (TT)
   - Mobile Teaching (MT)
2. Knowledge Level (KL)
   - Initial Level (GR1)
   - Intermediate Level (GR2)

Dependent Variables:

- Evaluation Results (R)

IV. RESULTS

A. USE OF BUILD_PC

Students in the experimental groups were asked to describe the application using six predefined words, shown in Figure 9. The results provide an interesting insight into students' perceptions of Build_PC. The "Easy to use" characteristic is the most notable in both groups, especially in GR2, where it reaches nearly 8. It is followed by "motivating," another strong characteristic, especially in GR2, with approximately 5 mentions. The "Friendly" characteristic is also significantly higher in GR2 compared to GR1. Finally, the characteristics "Entertaining," "Useful," and "Intuitive"

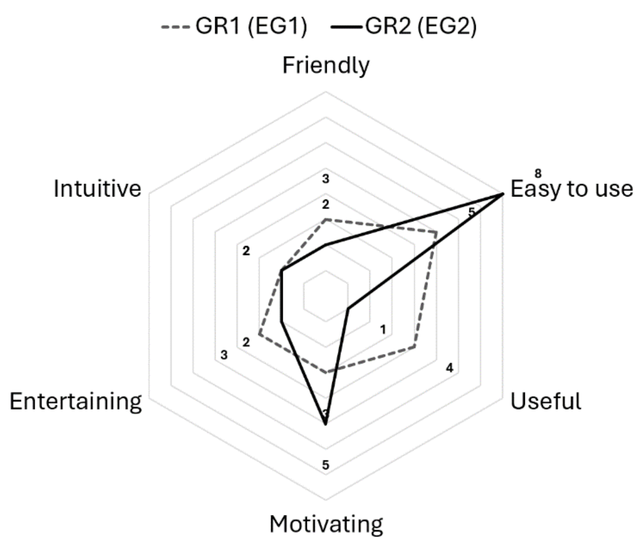

FIGURE 9. Description of Build_PC.

have lower values in both groups, being slightly higher in GR2.

B. EXPERIMENTAL AND CONTROL GROUPS

The two groups, EG and CG, completed a knowledge test after the class, with their responses shown in Table 5. These data will help identify whether using a MAR technology application can improve academic performance. To measure BUILD_PC's utility, hypotheses were generated to validate the application's effectiveness in the experimental group compared to the control group. The hypotheses are as follows:

TABLE 5. Average score in the knowledge test of the subgroups.

EG1	CG1	EG2	CG2
10	6	9	5
10	7	10	3
9	8	9	6
9	9	9	8
10	9	9	5
9	8	9	7
10	4	10	4
10	4	9	7
9	7	10	7
9	5	10	7
9	7	9	4
9	6	10	7
10	4	10	5
10	8	9	6
10	7	10	4
10	10	8	6
9	5	9	6
10	5	9	4
10	7	10	4
10	5	10	7

Hypothesis A (HA): There is no significant difference in the average knowledge test score between the EG and CG.

Hypothesis B (HB): There is a significant difference in the average knowledge test score between the EG and CG.

To test Hypotheses A and B, a Z-test was conducted to evaluate the learning performance and Build_PC interface of both the experimental and control groups. The test was performed with a 95% confidence level, and the variances used were previously taken from a T-test assuming different variances in both groups. The obtained variances (EG = 0.307; CG = 2.789) can be seen in Table 6. The Z-test value for the EG and CG groups is shown in Table 7. Based on the obtained Z values and the critical two-tailed value ($Z = 12.310 > \text{critical two-tailed value} = 1.959$), HA is rejected, and HB is accepted as true. It is concluded that using a mobile application was determinant for the EG students to achieve a higher average score compared to the CG students.

To further validate the results obtained with the T and Z tests, an analysis of dependent (R) and independent variables (TM and KL) was conducted, and new hypotheses were proposed:

TABLE 6. T-test for two samples assuming unequal variances.

T-Test	EG	CG
Mean	9.5	6.075
Variance	0.307	2.789
Observations	40	40
Hypothesized mean Difference	0	
Degrees of Freedom	48	
P(T<=t) Two-Tailed	1.846E-16	
Critical T-Value (Two-Tailed)	2.010	

TABLE 7. Z-test for the mean.

Z-Test	EG	CG
Media	9.5	6.075
Known Variance	0.307	2.789
Observations	40	40
Hypothesized Mean Difference	0	
Z-Value	12.310	
P(Z<=z) One-Tailed	0	
Critical Z-Value (One-Tailed)	1.644	
Critical Z-Value (Two-Tailed)	0	
Mean	1.959	

Hypothesis C (HC): There is a significant difference in the scores of the four groups due to the teaching method used.

Hypothesis D (HD): There is no significant difference in the scores of the four groups due to the teaching method used.

For this, an analysis of variance (ANOVA) was used, a statistical method that allows testing a null hypothesis where the means of different populations coincide [63]. To accept or reject the presented hypotheses (HC and HD), an analysis with a 95% confidence level was performed for the four groups (independent variable). These groups were evaluated with a knowledge test to identify if the teaching methodology (independent variable) contributed to the obtained result (dependent variable). Tables 8 and 9 describe the sample size and working groups.

TABLE 8. Dependent and independent variables and sample size.

Variable	Sample Size
Independent Variables	TM & KL
Dependent Variable	R
Sample Size	80

Table 10 shows the ANOVA of dependent and independent variables with the groups defined in Table 9. It can be observed that the probability of the four groups is $p = 5.7762E\text{-}20$; this value is lower than the confidence level with which this test was conducted $\sigma = 0.05$. Additionally, the F-value = 55.52 is higher than the critical F-value = 2.724. Therefore, HC is rejected, and HD is accepted.

These results show a statistically significant difference in the groups due to the teaching method used and that using

TABLE 9. Independent variables.

Variable	Teaching Method	Size
EG1	TT & MT	20
CG1	TT	20
EG2	TT & MT	20
CG2	TT	20

TABLE 10. Analysis of variance (ANOVA).

Source of Variations	Between Groups	Within Groups	Total
Sum of Squares	244.037	111.35	355.387
Degrees of Freedom	3	76	79
F	55.521179		
Probability	4.12E-19		
Critical F-Value	2.72494392		

Build_PC had a directly proportional impact on the knowledge test results in the experimental groups.

Figure 10 shows the average knowledge test scores of the control and experimental groups of GR1 and GR2. It can be observed that the experimental groups had a better average score in their respective knowledge test, which could be due to using the Build_PC application as support in regular education. Figures 11 and 12 show the results of GR1 and GR2 evaluated by gender. The results are divided by control and experimental groups. Figure 11 corresponds to the control group, no significant differences are observed between men and women in GR2, but in GR1, women have a higher score than men. In Figure 12, it can be observed that both men and women in the experimental group improved their scores.

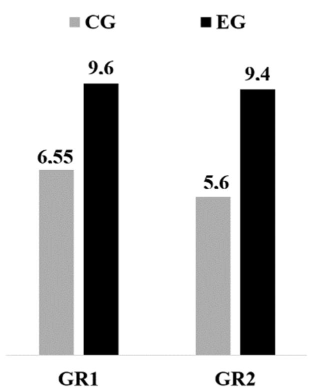

FIGURE 10. Average scores of the GR1 and GR2 knowledge test.

It can be concluded that these results are due to using different teaching methodologies and using Build_PC as a complement to education. Regarding the relationship between gender and average, it cannot be concluded that one gender is better than the other. The results respond to the low number of participants in this research, especially the low

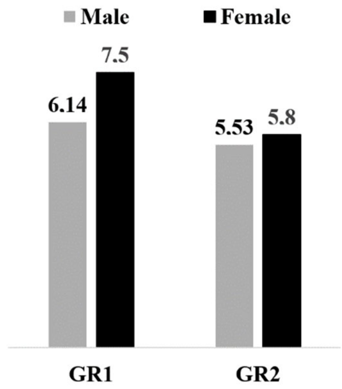

FIGURE 11. Average scores of the CG knowledge test.

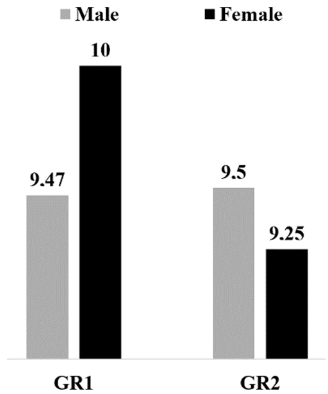

FIGURE 12. Average scores of the EG knowledge test.

number of women in an engineering career. The number of women in this research can affect the interpretation of the results because if a few of them have a low score, it can significantly impact the overall average. In Figure 13, the time taken by GR1 students to answer the proposed knowledge test is shown. The average time was significantly lower in the experimental group (13.08 minutes) compared to the control group (14.98 minutes).

The variability (standard deviation) of the times is similar between both groups (EG = 0.532; CG = 0.579). This indicates a significant difference between the groups. These results suggest that the intervention in the experimental group using Build_PC, along with a teaching methodology, positively affected the speed with which students could complete the knowledge test compared to the control group.

In Figure 14, the time taken by GR2 students to answer the proposed knowledge test is shown. The average time was significantly lower in the experimental group (12.87 minutes) compared to the control group (14.88 minutes). The variability (standard deviation) of the times was (EG = 0.792; CG = 0.872). This indicates that the experimental group's times are more consistent and tend to be lower than the control groups. These results suggest that the intervention in the experimental group using Build_PC, along with a teaching methodology,

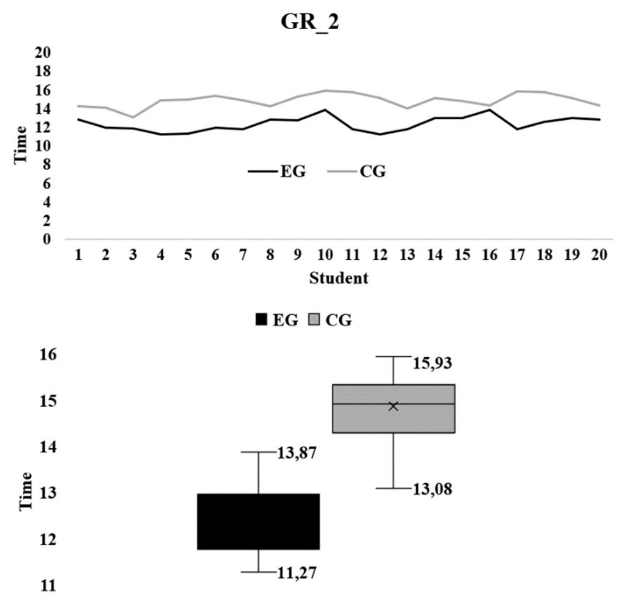

FIGURE 13. GR1 knowledge test resolution time.

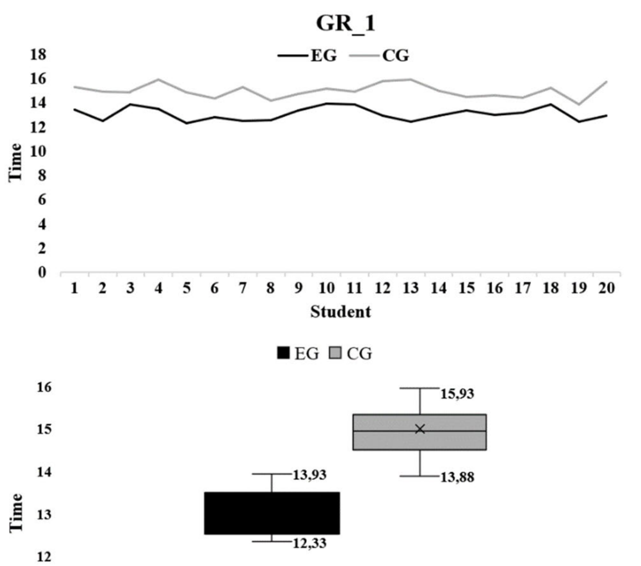

FIGURE 14. GR2 knowledge test resolution time.

positively affected the speed with which students could complete the knowledge test compared to the control group.

V. DISCUSSION

A. PARTICIPANTS PERCEPTIONS

The analysis of student feedback provides valuable insights into their demographics and how these may influence the study's results concerning the educational application.

Most students found Build_PC to be user-friendly, a critical factor for the acceptance of any educational tool. However, a discrepancy between the two groups was observed: in EG1, only 5 students considered the application easy to use, whereas in EG2, 8 students had a similar perception. This variation may suggest that individual or contextual factors, such as prior familiarity with similar technologies, impact how students perceive the application's ease of use.

The term "Motivating" was the second most frequently mentioned (8 times) by students, indicating that the application not only facilitates ease of use but also enhances student engagement with their learning. Terms like "Useful," "Entertaining," and "Friendly" were each mentioned 5 times, reflecting that students view the app as a beneficial learning tool with an appealing and engaging interface. Nonetheless, perceptions of the application's usefulness varied significantly between groups. In EG1, 4 students found the application useful, while in EG2, only 1 student shared this view. This disparity is concerning as perceived usefulness is a major determinant of technological acceptance and usage intention. The lower perceived usefulness in EG2 suggests that the app may not align with the expectations or needs of these students.

The term "Intuitive" was mentioned 4 times, underscoring that the app is generally perceived as user-friendly in terms of usability and accessibility. However, both groups did not find the application intuitive, which points to an area for improvement. An application lacking intuitiveness can discourage new users and hinder the effectiveness of achieving their goals within the app.

Gender distribution between the groups was similar, indicating that gender does not significantly affect perceptions or responses. The preference for the Android OS was notably higher in EG2, potentially affecting familiarity and comfort with the platform. The average age of participants was comparable between groups, controlling for variables related to age and technological experience. Most participants had no prior experience with educational applications, which is significant when considering the learning curve and perceived usability of the new application.

B. ANALYSIS OF THE EXPERIMENTAL AND CONTROL GROUP

In recent years, education has grappled with maintaining student interest and motivation in a rapidly digitizing world. Mobile Augmented Reality (MAR) technology presents a promising solution by offering immersive and interactive educational experiences. This technology has the potential to transform student interaction with educational content, thereby enhancing engagement and motivation.

The study aimed to evaluate the effectiveness of a MAR application in teaching PC hardware by comparing an experimental group (EG) that used the app with a control group (CG) that employed traditional teaching methods. Statistical tests, including the Z-test and Analysis of Variance (ANOVA), were utilized to assess the impact of the teaching method on student performance.

The Z-test revealed that the EG, which used the mobile AR application, outperformed the CG significantly, indicating that AR can be a potent tool for teaching PC hardware. The interactive and 3D visualization features of AR likely facilitated better comprehension and retention of the material for EG students.

ANOVA results further supported that the use of Build_PC contributed to higher scores in the EG compared to the CG. The traditional teaching methods used in the CG lacked the interactive and visual advantages provided by Build_PC. Conventional teaching methods tend to be less dynamic and more dependent on memorization and theoretical understanding, which can result in lower retention and comprehension. Additionally, the absence of immediate and personalized feedback can adversely affect learning accuracy.

In addition to evaluating the effectiveness of MAR technology in teaching PC hardware, the research assessed the time taken by EG and CG students to complete a knowledge test. The results indicated that EG students completed the test significantly faster than CG students. This finding highlights not only the application's effectiveness but also its impact on learning efficiency. The data demonstrated that EG students using the mobile AR application were quicker in completing the knowledge test compared to CG students using traditional methods. This result suggests that AR enhances both understanding and retention of the material, while also improving task completion efficiency.

VI. CONCLUSION

In this study, two groups were compared: an experimental group (EG) that used the Build_PC application to learn about computer hardware, and a control group (CG) that studied the same topic through traditional methods without the application. Both groups undertook a test designed to evaluate their understanding of PC hardware, which included questions on both theoretical concepts and practical knowledge.

The results revealed that the EG, which utilized the Build_PC application, achieved a significantly higher average score compared to the CG. Additionally, the EG completed the test in a shorter average time. While the CG also demonstrated a competent grasp of the topics, their average score and the time taken to complete the test were notably lower than those of the EG. This suggests that the Build_PC application not only enhanced the understanding of the material but also improved the efficiency with which students completed their assessments.

Through a survey, it was validated that the Build_PC application is perceived positively in terms of ease of use and motivation, although there are critical areas like perceived utility and intuition that need improvement. MAR technology has proven effective not only for improving academic performance but also for increasing learning efficiency. The research highlights the importance of adapting technological tools to the needs and expectations of students to maximize their effectiveness and acceptance.

In the research, it was observed that using Build_PC as support for traditional education methods positively influenced academic performance and understanding of one or more topics, demonstrating that MAR technology is a potential tool for education. These results show that this technology can be used to innovate traditional educational methodologies and transform current education.

When designing an educational mobile application, the customization of the design becomes a crucial component for offering a truly personalized learning experience. The construction of Build_PC seeks to adapt the content, interface, and functionalities of the application to the individual needs, skills, interests, and preferences of the students. Personalized design for personalized learning not only enhances educational effectiveness but also makes the learning process more engaging and meaningful for students. It is important to consider the factors that motivate the use of digital technologies among new-generation students. Today's students are immersed in a digital environment and have high expectations for interaction and immediacy of educational resources. Mobile applications that incorporate gamification elements, interactive learning, and real-time feedback can better capture the interest and motivation of these students, making learning more engaging and effective.

Using an agile methodology in the design of Build_PC allowed for more efficient, collaborative, and user-centered development. Constant iteration, continuous communication, and adaptability ensured that the application not only met the project requirements but also precisely adjusted to the students' needs. This flexibility and quality focus allowed Build_PC to be robust, functional, and satisfactory for use as educational support.

Students with fewer economic possibilities will have older mobile devices with lower performance, which may limit their ability to use MAR technology applications requiring higher performance. This disparity can lead to a less effective learning experience for these students, as they may face technical difficulties, longer loading times, and a lower capacity to interact with multimedia content or advanced features of educational applications. It is important to work to mitigate this gap through developing mobile applications that perform well on a wide range of devices, including older or lower-performance mobile equipment. Additionally, collaboration or equipment loan programs could be implemented in educational institutions to ensure all students have access to the necessary technology for their learning.

VII. FUTURE WORK

Since intuition and ease-of-use perception present areas for improvement, future work could focus on redesigning the Build_PC application's interface to make it more intuitive and accessible. This could include additional usability testing, implementing user feedback-based design, and using user-centered design techniques. Additionally, longitudinal studies should be conducted to evaluate the long-term impact of using the application on academic performance, knowledge retention, and student motivation. This could provide a more comprehensive view of the application's educational value. Furthermore, the application's efficiency and acceptance on different operating systems should be investigated to ensure an optimal user experience across all platforms.

Despite the positive results, the combination of AR applications with other traditional and digital teaching methods should be explored to develop a hybrid learning approach. This could help maximize the benefits of each method and provide a more comprehensive learning experience.

These future work areas could not only improve the Build_PC application but also contribute to the overall knowledge about using technologies in education, providing valuable guidelines for other researchers, teachers, and educational institutions.

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SANTIAGO CRIOLLO-C (Member, IEEE) was born in Quito, Ecuador, in 1984. He received the B.S. degree in electronics and information networks engineering from the National Polytechnic School, Quito, in 2010, the M.S. degree in communication networks from Pontificia Universidad Católica del Ecuador, and the Ph.D. degree in computer science with the University of Alicante, Alicante, Spain, in 2021, where he has oriented his research to the use of mobile devices as support in higher education. Since 2013, he has been a Professor of information technology with Universidad de Las Américas, Quito.

ANDREA GUERRERO-ARIAS was born in Quito, Ecuador, in 1985. She received the B.S. degree in visual communication from Universidad Autónoma de Quito, in 2012, the B.S. degree in linguistics applied to the English language from the Army Polytechnic School, in 2019, and B.S. degree in teaching English as a foreign language from the University of La Rioja, Spain, in 2022, is interested in researching the use of mobile devices in educational enhancement. She has been a Professor of EFL with the Jezreel International Christian Academy, Quito, Ecuador.

JOSÉ ENRIQUE CEREZO UZCÁTEGUI was born in Mérida, Venezuela, in 2004. Currently, he is pursuing the degree in software engineering with the Universidad de Las Américas, Quito, Ecuador, where he is in his fifth semester. He is a Young Researcher. From a young age, he showed a special interest in programming, finding it easy to learn and use. His passion for technology and his innate ability for programming have led him to excel in his academic career and research projects related to software development. His meticulous approach and ability to tackle complex problems have made him a valuable collaborator in the field of technology research.

YUNIFA MIFTACHUL ARIF (Member, IEEE) received the Diploma degree from the Department of Electronics Engineering, Politeknik Elektronika Negeri Surabaya, Indonesia, in 2007, and the master's and Ph.D. degrees from the Department of Electrical Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia, in 2010 and 2022, respectively. He was an Assistant Professor with the Department of Informatics Engineering, Universitas Islam Negeri Maulana Malik Ibrahim, Malang. His research interests include game technology, learning technology, metaverse, recommender systems, blockchain technology, and the Internet of Things. He is a member of IAENG. He is also active in managing international journals as an editor or a reviewer.

APRILLA FORTUNA received the bachelor's degree in mechanical engineering vocational education from Universitas Negeri Padang. He has been a Bachelor's Assistant Lecturer with Universitas Negeri Padang for two academic terms and has become a candidate for the master's degree of the top ten QS World University Rankings. He has contributed to the scientific community through his extensive publication record, with more than 12 published scientific papers, including notable contributions to Scopus-indexed journals. His research interests include educational technology, emerging technologies in education, vocational education and training, engineering education, assessment, virtual reality, augmented reality, mobile learning, and future trends in metaverse technologies. He serves as an Editorial Board Member of the journals: *Journal of Engineering Researcher and Lecturer*, *Journal of Computer-Based Instructional Media*, and *PAKAR Pendidikan*.

FEBRI PRASETYA is currently a Senior Lecturer and the Head of the CNC/CAD/CAM Laboratory, Department of Mechanical Engineering, Faculty of Engineering, Universitas Negeri Padang. His research interests include instructional media, education technology, emerging technologies in education, vocational education and training, augmented reality, mobile learning, virtual reality, and future trends in metaverse technologies. He serves as the Editorial Board Member of the journals: *Journal of Vokasi Mekanika* and *PAKAR Pendidikan*.

SERGIO LUJÁN-MORA was born in Alicante, Spain, in 1974. He received the Computer Science and Engineering degree from the University of Alicante, in 1998, and the Ph.D. degree in computer engineering from the Department of Software and Computing Systems, University of Alicante, Alicante, in 2005. He is currently a Senior Lecturer with the Department of Software and Computing Systems, University of Alicante. In recent years, he has focused on e-learning, massive open online courses (MOOCs), open educational resources (OERs), and the accessibility of video games. He is the author of several books and many published articles in various conferences (ER, UML, DOLAP) and high-impact journals (DKE, JCIS, JDBM, JECR, JIS, JWE, IJEE, and UAIS). His main research interests include web applications, web development, and web accessibility and usability.