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PAPER

Mobile Application with Augmented Reality as a Support Tool for Learning Human Anatomy

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ABSTRACT

Learning the anatomy of the human skeletal system presents several challenges in understanding the complexity of the human body. One of the most common issues is the absence of effective and accessible learning methods that enable students to gain comprehensive knowledge. Therefore, the use of technologies such as augmented reality (AR) aims to address this issue and facilitate its resolution by enabling students to engage with three-dimensional anatomical models, fostering hands-on, visualization-based learning. The aim of this study is to enhance the learning of human skeletal anatomy through the use of AR technology. The study employed a quantitative approach and a pre-experimental design, in which the experiment was conducted according to the research plan and involved 60 students. Mobile-D was used to develop the mobile application. The findings revealed that 93.3% of participants agreed that the use of augmented reality is a valuable for learning human anatomy, as it enables interactive visualization of various parts of the human body. The study also indicated that 28.3% of the students scored "Outstanding," while 68.3% scored "Predicted." In addition, 65% of students expressed interest in using augmented reality technology to learn anatomy.

KEYWORDS

augmented reality, human anatomy, learning

1 INTRODUCTION

Over the past four years, the teaching-learning (TL) method has been impacted by the COVID-19 pandemic [1], leading to an increased demand for adaptability in the use of non-contact interaction technologies by learners [2]. The pandemic has accelerated the adoption of innovative learning formats that offer greater flexibility and adaptability to learners and their needs [3]. Digital technologies offer several advantages that can be utilized to capture learners' attention, covering topics from the basic to the more complex. They can be employed in various settings to visualize objectives and facilitate interactive teaching [4].

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The TL of human anatomy presents significant challenges because of its highly visual and hands-on nature. Understanding anatomy requires direct interaction with anatomical models, performing dissections, and witnessing real-time demonstrations [4]. Moreover, the field encounters the challenge of delivering effective instruction without sufficient resources and space [5]. To be more specific, a research paper [6] identifies three primary challenges in the study of human anatomy: the scarcity of suitable cadavers for medical education, the differing behavior of living tissue compared to dead tissue, and ethical and cultural concerns related to real dissections. These challenges highlight the potential advantages of using augmented reality (AR) technology [7].

There has been a significant increase in research on AR technology, primarily due to its potential for learning [8] and its significant advantages for promoting basic science education [9]. AR, or augmented reality, is a technology that uses AR, mobile devices, or computers to overlay virtual objects onto the real world [10]. This creates 3D models that enable access to additional information through interaction between AR-generated objects and real-world objects [11]. Consequently, AR integrates virtual elements such as videos, images, and texts into the real world [12]. With this feature, the learner can inspect objects thoroughly, enhancing their understanding and cognitive development [13]. In addition, studies mention other benefits of using this technology in the educational process, such as enhancing perception, reducing cognitive load, increasing motivation and interest in learning, and promoting creative and critical thinking [14]. Thus, AR has become a promising tool in education for enhancing learning. This tool is used in various fields of study and education, including physics, mathematics, and chemistry [15], [16]. Given the varying levels of difficulty and complexity in different areas of learning and education, it is essential to devise an effective learning strategy to attain a thorough understanding [17], [18].

A crucial factor for the feasibility of mobile application development for this research is the growing availability of mobile devices in recent years. These types of devices are primarily used for such solutions because of their practicality [19], [20].

The primary goal of this research is to develop a mobile application that utilizes AR to improve the learning of the human skeletal system. Three indicators were established for this study: students' perception of learning time, students' average grades, and their interest in learning human skeletal anatomy.

2 BIBLIOGRAPHIC REVIEW

In this research, we have reviewed studies related to the use of AR for learning as well as other contributions that enhance the value of this work.

In the body of the reviewed work, several causes or arguments for the development of applications for learning through AR were identified. For example, in [21], it is mentioned that the use of AR facilitates the transmission and acquisition of knowledge, thereby enhancing the skills and abilities that students need to develop during their training phase. This is more specific in the fields of science and human anatomy. Similarly, a study [22] highlights the current shortage of materials for in-depth learning and understanding of human anatomy. To address this, a mobile application with AR was developed to facilitate the study of the anatomy of the human foot and knee. The application involved the creation of 3D objects based on 2D medical images. They achieved a 64% acceptance rate from students who found that the AR application made it easier for them to learn human anatomy. Furthermore, in reference [23], an application called "AR Biology" was developed using the software prototyping approach.

They developed learning objects and used them with a sample of 223 students. As a result, they obtained 77.01% of responses, indicating that interaction and learning with 3D models are more effective than with plain text. Furthermore, 94% of the students reported that the AR models helped them reinforce their learning. However, it is important to assess the compatibility of the application, as 52.47% of the students encountered difficulties when downloading and installing the application. In reference [24], a complex skeletal structure was developed using 3D models based on existing images. The application was tested with 30 pupils aged 10–11 years, and the result was a 16% increase in average grades. Furthermore, 83% of the students believed that educational gaming apps enhanced their interest in learning. In conclusion, there is significant potential for utilizing AR-enabled smart devices to improve the learning experience of human anatomy. Similarly, in reference [25], a mobile application was developed utilizing AR for learning human bone anatomy. Open-source tools and free licenses for 3D object modeling were utilized in the development of the application. The authors emphasized the significance of utilizing SDKs to improve efficiency and time management in app development. The researchers concluded that AR technology has the potential to enhance interactive education. There are complex projects that utilize this technology to enhance learning, such as the one described in [26], where a sophisticated virtual biological laboratory system was developed for experimentation and testing by students at a specific university. The aim was to pique curiosity, generate interest, and reduce the cognitive burden on the students. The researchers concluded that students have a more positive attitude toward learning when using AR technology and that they master biological experiments more effectively.

In other research studies, alternative approaches that consider the learning factor have been explored. For example, in [27], a virtual environment system was developed for learning, and the collaboration factor was incorporated to enhance the comprehension and information exchange within a specific group of students. The system had 16 users, including medical students. In terms of their mental effort, they obtained a low result in learning but a very positive result in the system's importance and usefulness indicator. In [28], an AR application was developed to create 3D models of human anatomy. The models were developed using images collected from various websites. An evaluation and survey were conducted to assess the acceptance and benefits of the application. The results showed a high level of acceptance and significantly better retention of information compared to traditional learning methods.

3 METHODOLOGY

This section presents the research methodology and the development of the AR mobile application. The study is applied in nature, employing a quantitative approach and a pre-experimental design, with the experiment conducted in accordance with the research plan. The pre- and post-test designs are represented by equation (1).

$$\boldsymbol{GE}\colon O_1 \times O_2 \tag{1}$$

Where:

GE: Experimental group
O_1: Pre-Test
O_2: Post-Test
X: Variable manipulation

In this study, a purposive sampling of 60 primary school students enrolled in the "Human Anatomy" course was utilized. Subsequently, the data underwent statistical analysis to test the hypothesis and draw conclusions from the results. To assess the validity of the instruments, expert judgment and the Cronbach's alpha coefficient were used to measure reliability.

For the development of the mobile application, we utilized the Mobile-D software development methodology. This methodology provides a structured and systematic approach to developing mobile applications. It emphasizes user participation and continuous testing to ensure the efficiency and quality of the process [29]. Another reason for utilizing this methodology is that it fosters collaborative work, and application development can be accomplished with a team of fewer than 10 people [30]. In the context of learning human bone anatomy through AR, the decision was made to utilize the Mobile-D methodology to ensure a successful implementation. The selection of this methodology is based on the necessity to follow a systematic planning process, starting with the initial requirements exploration and progressing through phases such as initialization, production, stabilization, and testing, culminating in the final implementation [31].

The activities and results of each phase of the Mobile-D methodology are detailed below.

3.1 Exploration

During the initial phase, research, definition, and identification activities were conducted. The project identified individuals and stakeholders. A sponsor, an educational institution, has also been identified to provide support for the development and realization of this work. The required resources and materials were then defined, along with the scope and timeline of the project. After defining the project scope, materials, and schedule, the functional and non-functional requirements were categorized by different modules of the application to provide a better structure and understanding of the deliverables to be developed, as shown in Table 1.

Table 1. Functional requirements

Code	Description
FR01	When starting the application, the loading screen with the logo will be displayed.
FR02	Show the start button below the logo.
FR03	The buttons with the labels of the functions performed by the application will be displayed on the screen: information, instructions, visualization, and quiz.
FR04	The main objective of the application and the reasons why it was developed will be displayed on the screen.
FR05	The function of each option in the main menu is detailed and how the AR visualization works, as well as how the quiz works.
FR06	A menu is displayed with the buttons of the 2 parts into which the human skeleton is divided and one with the complete human skeleton.
FR07	The buttons with the parts into which the section of the selected skeleton is divided are shown.
FR08	Pressing one of the options will turn on the camera, waiting to scan a target.

(Continued)

Table 1. Functional requirements *(Continued)*

Code	Description
FR09	When focusing the camera towards the target, the previously selected 3D model will be displayed with the respective information.
FR10	More than one model can be displayed per selected option.
FR11	A questionnaire of 10 questions will be displayed, which will be displayed in random order with 4 options for each question.
FR12	Pressing the "Submit" button will display the score obtained.

3.2 Exploration

During the initialization phase, careful planning, preparation of the environment, and analysis of the requirements and objectives of the human bone anatomy augmented reality learning application development project are carried out. The environment was prepared for developing the application. As part of this process, technical resources such as code editors and software for designing 3D objects were made available. On the other hand, a training plan was developed to enhance technical skills and knowledge, along with a communication and material exchange plan to facilitate this research work. During this phase, the project's architecture is designed. Figure 1 depicts the architecture designed for the mobile application. In this design, the device's camera captures the scene, and the Vuforia SDK is responsible for creating frames of the captured scene by converting the projected image to a variable resolution to ensure proper processing of the tracker.

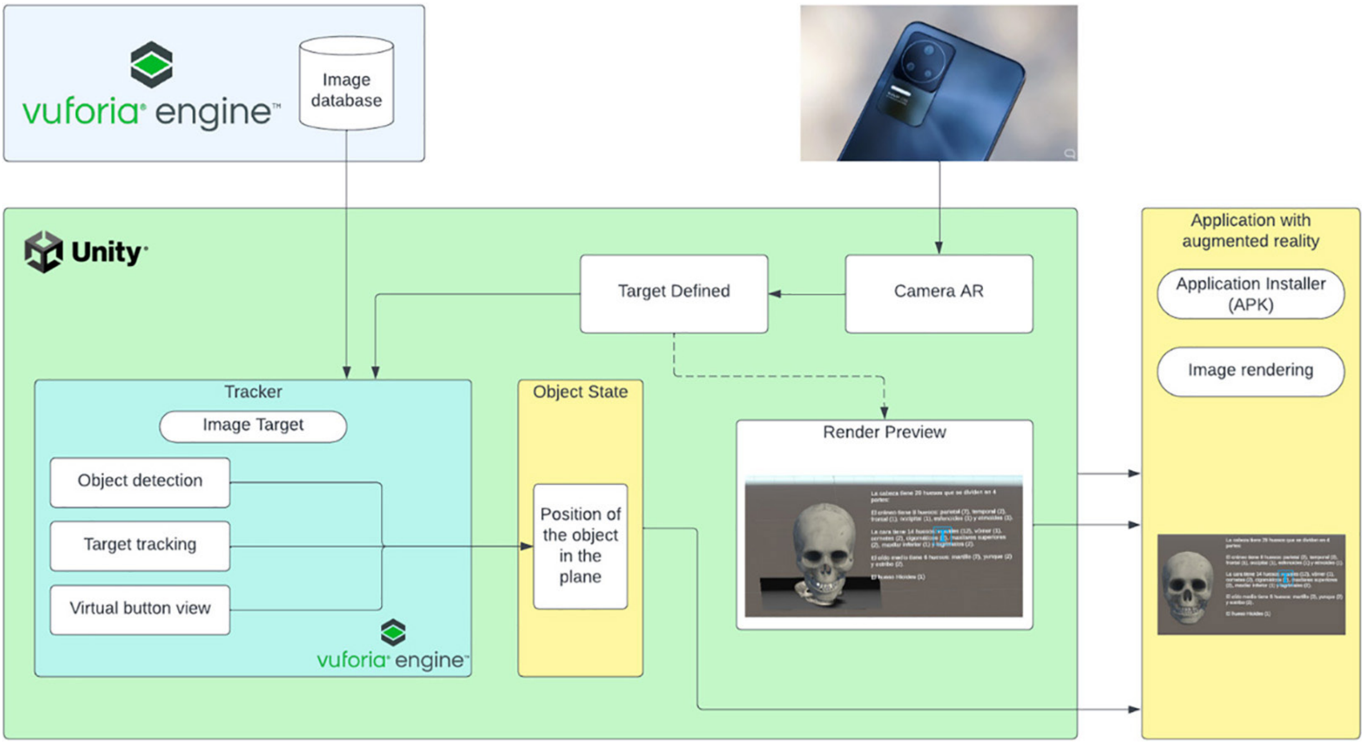

Fig. 1. Mobile application architecture

Finally, a thorough analysis of the previously defined requirements was conducted to fulfill the user stories. To define the user stories, the relationship between the functional requirements was identified by analyzing their characteristics, dependencies, and how they integrate and communicate with each other. Subsequently, the prototypes shown in Figure 2 were designed based on the defined user stories.

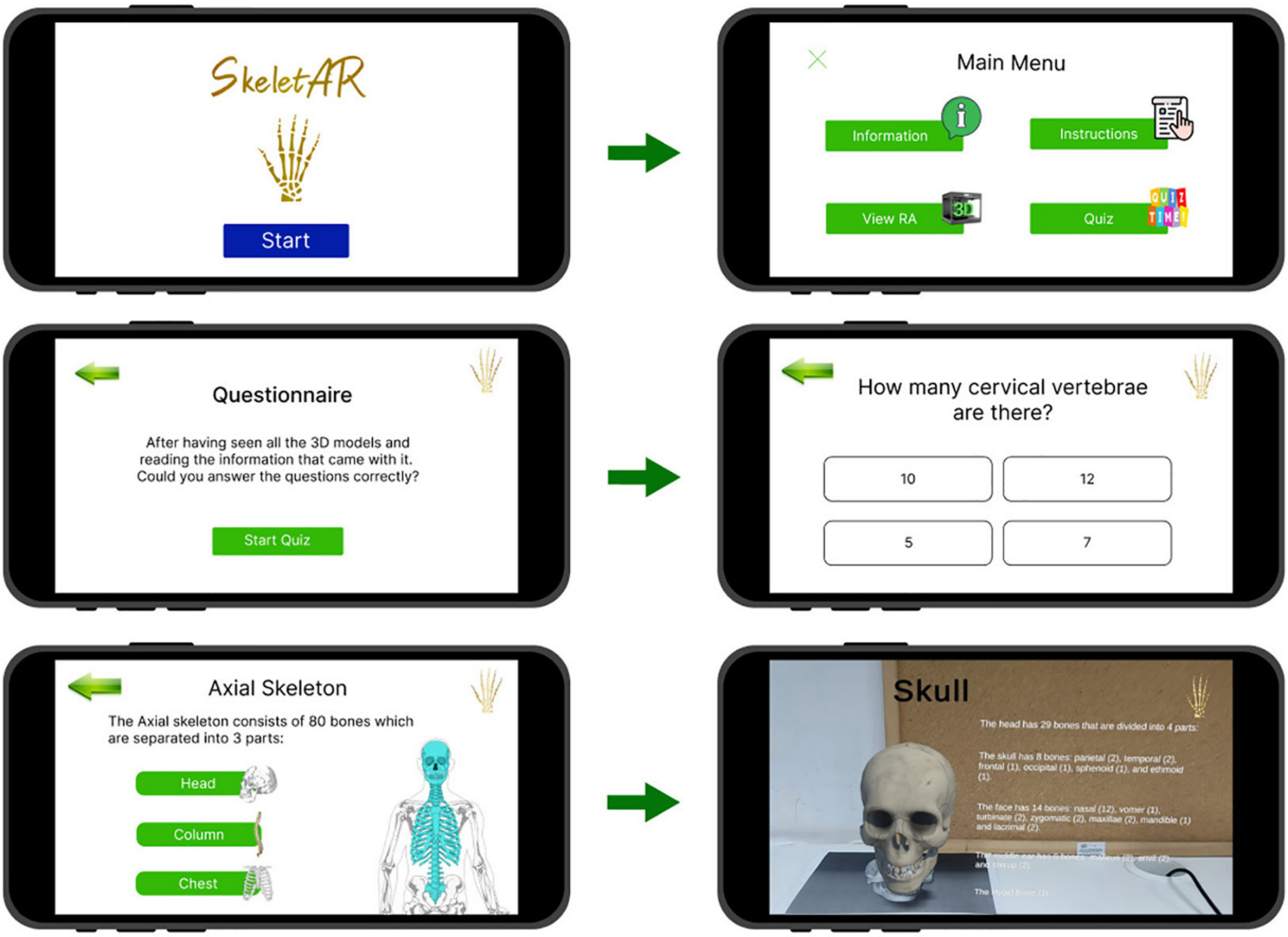

Fig. 2. Sequence of the main screens of the application

Figure 2 sequentially displays the main screens of the application. On the main menu screen, the user can access information about the application, instructions, and the AR visualization function. Furthermore, the learner has the option to take a quiz to assess their understanding of the human skeletal system.

3.3 Production

During this phase of the methodology, a comprehensive analysis of the user stories was conducted to assess their level of complexity and to allocate them a suitable rating and priority for subsequent development. Various factors were taken into account, including the complexity of the required functions and the strategic significance of each user story within the application. Table 2 displays the specified sequence of user stories for development.

Table 2. User history

ID	Name	Difficulty	Priority
HU01	Home Screen Module	Easy	Low
HU02	Main Menu Module	Moderate	Half
HU03	Application Information Module	Easy	Low
HU04	Instructions Module	Easy	Low
HU05	AR View Module	Moderate	Half
HU06	Skeleton Parts Module	Moderate	Half
HU07	3D Models Module	Difficult	Half
HU08	Quiz module	Difficult	Half

In addition to analyzing the user stories, meetings were held with stakeholders involved in the development of the application. A literature review on the development of educational applications was also conducted to gain relevant knowledge about best practices, current trends, and potential challenges.

3.4 Stabilization

Once the user stories were developed based on prioritization, the integration of these stories or deliverables was carried out in this phase of the methodology. The user interfaces were configured and programmed in sequential order, as shown in Figure 2. Subsequently, a general test was conducted to identify and resolve errors, validating the application as a whole.

3.5 Tests

Before implementing the developed mobile application, test cases were designed to evaluate its performance, functionality, and usability. These tests made it possible to evaluate whether the application met the objectives, requirements, and user stories defined in previous phases. As an example, Table 3 illustrates a test case.

Table 3. Test case CP01: 3D model information

No Test Case	CP01
Name	**Information of 3D Models**
Initialization	Enter the SkeletAR application, on the first screen press the start button, then press the RA Menu button, then press one of the options with labels of the parts into which the human skeleton is divided and then one of the sections.
Expected output	**Correct** View the respective information of each 3D model on its right side.
Purpose	Validate if pressing the option of the section of a part of the skeleton shows the information of the 3D model scanned with the phone's camera.
Test procedure	Press the "Start" option. Select the "AR Menu" option. Select the option "Axial Skeleton." Select the "Head" option.
Output obtained	**Correct** The 3D model information is displayed on the right side.

3.6 Implementation

The developed application will be implemented in educational institutions, which are the primary stakeholders in this research. For the implementation, you will need the APK of the application and an Android mobile device. The application was installed on 60 devices.

4 RESULTS

Three types of surveys were conducted with 60 students, each corresponding to a key performance indicator (KPI) of the present research. For the first key performance indicator (KPI), a survey using a Likert scale was conducted, while for the second KPI, a survey using a Vigesimal scale was conducted. Finally, for the third KPI, a survey using a dichotomous scale was conducted. The summary of the results is presented in Table 4.

Table 4. Overall result of the pre- and post-tests

No	Scale Type	Indicators	Results	
1	Likert scale	KPI 1: Perception of learning time	2.0	2.0
2	Vigesimal scale	KPI 2: Note for evaluation	11.2	14.9
3	Dichotomous scale (positive answer)	KPI 3: Interest level	3	14

From the table above, there is no change in the "perception of learning time" indicator. However, in the "marks per assessment" indicator, there has been a significant improvement of 3.7 points on the vigesimal scale. Finally, there is a significant difference in the indicator of "level of interest." This indicates that the application increased the students' interest in learning human bone anatomy.

4.1 Comparison of pre- and post-tests results

As illustrated in Figure 3 above, there is no difference between the results of the pre-test and post-test of KPI 1, according to the Likert scale. This indicates that there is still disagreement on the perception of learning time. The lack of change in this indicator suggests that the tested students do not encounter difficulties with learning the timing of human bone anatomy. This could be attributed to the methodology employed, the materials utilized, the students' prior knowledge, and other factors that have a positive impact on students' learning outcomes.

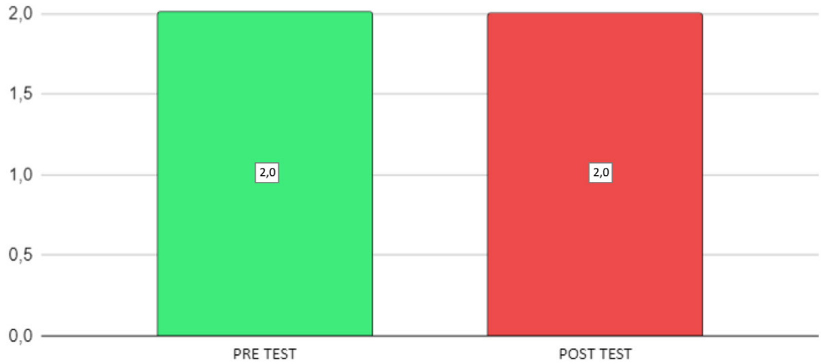

Fig. 3. KPI 1: Comparison of pre- and post-tests

In Figure 4, it is evident that there is a significant difference between the pre- and post-test results. The average of the post-test responses for KPI 2 differs by 3.7 points on the Vigesimal scale. This significant improvement indicates that the content of the application is enriching and understandable for the students. This is because the majority of the students who were tested demonstrated an improvement in their understanding and knowledge of human bone anatomy.

Fig. 4. KPI 2: Comparison of pre- and post-tests

As depicted in Figure 5, there has been a notable increase in the number of students interested in learning about human bone anatomy after the implementation of RA. Before the implementation of this technology, students had limited exposure to the subject matter and were less engaged in the learning process. With the introduction of the AR application, students can now interact with 3D images of human bones, enabling them to better understand the complexities of the human skeletal system.

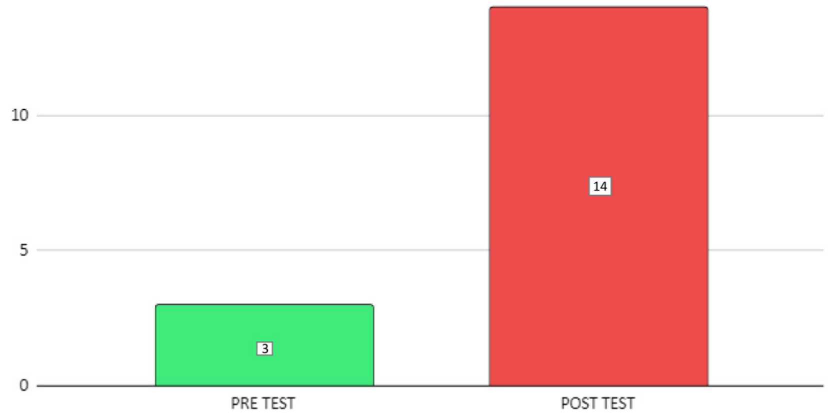

Fig. 5. KPI 3: Comparison of pre- and post-tests

4.2 Results of KPI 1

Table 5 presents the detailed results of the surveys conducted in relation to KPI 1. It is evident that most of the responses disagree with the perceived learning time indicator. This suggests that students do not feel the need for additional time to learn and understand human bone anatomy, which explains the positive response. The results indicate that 3.3% of the students neither agree nor disagree, while 93.3%

disagree and 3.3% strongly disagree with the perception of learning time for human bone anatomy.

Table 5. Results of KPI-1

POST: TEST: KPI 1	Frequency	Percentage	Valid Percentage	Accumulated Percentage
Strongly disagree	2	3.3	3.3	3.3
In disagreement	56	93.3	93.3	96.7
Neither agree nor disagree	2	3.3	3.3	100.0

4.3 Results of KPI 2

Figure 6 displays the results for KPI 2, indicating that 41 students achieved an average of 14.9 points on the 20-point scale. The average result falls within the 'expected' category, marking an improvement from the 'initial' category. However, a small group remains in the "initial" category, indicating the need for sufficient reinforcement of knowledge to achieve a corresponding improvement. The results show the following statistics: 3.3% have a below-average score, 68.3% have an average score, and 28.3% have an above-average score based on their knowledge of human bone anatomy.

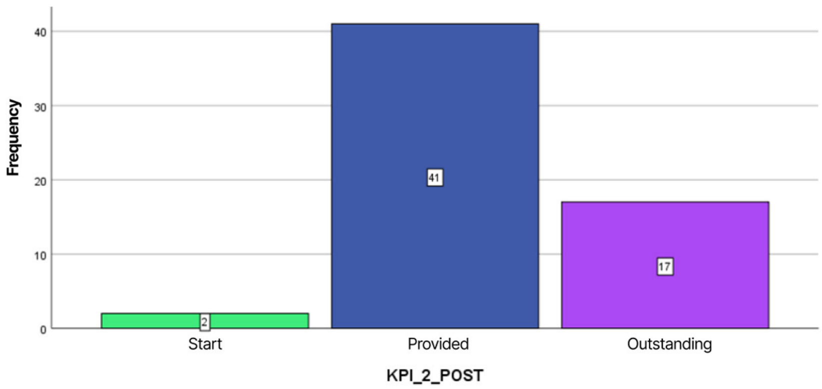

Fig. 6. KPI 2: Post-test bar chart

4.4 Results of KPI 3

Table 6 presents the detailed results of the surveys conducted for KPI 3. It is evident that the majority of students have responded positively regarding their interest in learning human bone anatomy. This suggests that the interactions, visual resources, and content provided by the developed application are highly engaging for the students being evaluated. The results indicate that 65% of the students expressed interest, while 35% indicated disinterest in the lesson on the human skeletal system.

Table 6. Results of KPI-2

POST: TEST: KPI 3	Frequency	Percentage	Valid Percentage	Accumulated Percentage
Yes	39	65.0	65.0	65.0
No	21	35.0	35.0	100.0

5 DISCUSSIONS

The results obtained in this research work have enabled us to validate the main objective defined. However, it is prudent to compare these results with previous research on learning human anatomy with AR to demonstrate its relevance. After reviewing several studies, we referenced [23], which also created an AR-based system for learning human anatomy. However, unlike our study, they assessed a cohort of 53 students ranging in age from 16 to 23 years old. On the other hand, there is a similarity with the "grade per assessment" indicator in this research, as observed in [24], where an increase in the grades of 78% of the students was noted. This demonstrates that the use of AR applications has an exceedingly positive impact on students' understanding of human anatomy. As for the interest level indicator, it was found that the work [25] resulted in a 95% increase in the level of interest in learning human anatomy. In terms of research methodology, [26] employed a similar approach to the present study by using questionnaires and a pre- and post-test design. The evaluation results of the research showed a 92.2% accuracy rate in a sample of 51 students. Other studies have also explored this issue using different methodologies. For example, [27] utilized a qualitative approach to gather and analyze data from students, incorporating observations and interviews to gain insights into their experience with the developed application. While it is true that AR has a positive impact on the learning of human anatomy, a study [28] found no significant difference in the impact of using AR, unlike the present research and those mentioned above. However, there is widespread acceptance of this technology due to the interactivity it offers.

6 CONCLUSIONS

This article presents the design, development, implementation, and testing of a mobile application with augmented reality for learning human bone anatomy, using the mobile-D methodology. The dimensions or indicators of this study were determined to be the perception of learning time, average grades, and level of interest in the human bone anatomy class. A sample of 60 students was used, and it was observed that 93.3% of the respondents disagreed with the statement that learning human bone anatomy required a lot of time. Regarding the grade distribution, 28.3% of the students achieved an "outstanding" average, while 68.3% achieved an "expected" average. In the third indicator, it was observed that 65% of the students are interested in human bone anatomy due to the implementation of the augmented reality learning application.

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