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[Exploring the Impact of Augmented Reality on Medical Students' Intrinsic Motivation: A Three-Dimensional Analysis]

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ABSTRACT

Augmented reality (AR) is an innovative technology that has numerous uses in medical education. One prospective application that could be highly advantageous is to improve medical student's motivation. The main goal of this study was to examine how augmented reality-enabled learning resources affect the academic performance of students, particularly in medical education. 153 medical students from 3 public and 4 private medical schools in Pakistan contributed to this study. With the help of a learning application created to project the learning materials and content from one of the curriculum books, students were able to experience augmented reality. The participants filled out post-test questionnaires for both text-based and AR-based learning, which adapted a pre-validated intrinsic motivation inventory (IMI). We selected three dimensions: interest and enjoyment, effort, and pressure and tension from the survey for this study. The statistical t-test was used to arrive at the results. P = 0.000 for all statistical models. The combined mean difference in all dimensions between augmented reality learning and text-based learning is 3.2. Applications for augmented reality offer promising prospects to inspire and motivate students to learn more actively and effectively, which in turn would improve the outcomes instead of text-based learning.

Keywords: User Interaction, Augmented Reality, Interest, enjoyment, Immersive Technologies, Intrinsic Motivation

Introduction

The technology and the ways in which people interact with one another and their surroundings have undergone a rapid transition in the twenty-first century. Not only do these technologies make our lives easier, but they also help improve how future products are created and developed. The way individuals communicate has also changed because of modern technology, like augmented reality. Augmented reality (AR) refers to a technological innovation that enables the overlay of virtual elements onto the user's perception of their environment. Augmented reality (AR) is an interactive experience that combines the real world and computer-generated 3D content, spanning multiple sensory modalities, including visual, auditory, haptic, somatosensory, and olfactory. [1], [2], [3]

AR can be understood as a system containing three basic characteristics, i.e., a combination of real and virtual worlds, real-time interaction, and precise 3D registration of virtual and real. [4]. The most important feature is the addition of data and information to the user's perception of the real world rather than the complete combination of real and virtual worlds. It can be accomplished by overlaying computer-generated visual information, such as pictures, text, or 3D models, on the real surrounding environment. Additionally, AR experiences may also include auditory, haptic, and many other types of feedback [5].

The experience with 3D models is shown in Figure1.

Figure 1: Experiencing 3D model through AR

The technology works by capturing the real world through the device's camera, and the digital world is then projected onto that view. The device also contains sensors like GPS, accelerometers, and gyroscopes. These sensors help in tracking the user's position and orientation, ensuring that the virtual object is placed and aligned correctly within the real-world scene [6]. However, the above is not the case in this phenomenon, as virtual reality places a user in a fully digital world that closely mimics the real world but is not a physical object. Therefore, AR places digital content in the real world and enables the user to interact with virtual and real objects at the same time. Additionally, the above differences concentrate on outlining the AR-VR specific difference that was combined of the two integrated and enhanced a real-world opposed to creating a separate world [2], [7].

Background And Significance Of AR In Medical Studies

The technology of augmented reality has found practical application in medical education relatively recently, although it has its origins in conceptual roots dating back to the 1960s. Its growth in the medical field is due to the advent and subsequent technological growth of the power of computer technology, display technology, and mobile device design. This is achieved by the growing performance of such technologies [8].

Although the first few applications of AR in medicine included computer-assisted anatomy programs in the early 1990s and the use of stereo displays to improve 3D visualization, mass consumer releases of virtual reality, such as Oculus Rift and Google Glass in the late 2000s, allowed a more immersive user experience, thereby ensuring its growth due to the reduction of costs and the creation of more opportunities [9], [10].

AR offers several advantages in medical education, such as enhancing spatial understanding and visualization of complex anatomical structures and procedures, providing interactive and immersive learning experiences that can potentially improve knowledge retention and skill acquisition, enabling remote and self-paced learning (which became particularly important during the COVID-19 pandemic), allowing for the simulation of rare or high-risk scenarios without putting patients at risk, and facilitating collaboration and knowledge sharing among students and instructors [11]

AR has been applied in various aspects of medical education, including anatomy education, where applications overlay 3D anatomical models onto real-world objects or cadavers, allowing students to explore and interact with the models in a more intuitive way. During surgical learning, AR simulations guide students through the steps of the surgical procedure to enable them to develop their skills through practice in a safe setting [12], [13]. AR as a patient education has been used to explain confusing medical illnesses or treatments to patients and their families to make it simpler for them to grasp and feel more comfortable. AR situations are replicas of actual clinical settings that students can utilize to simulate making decisions and communicating in conditions that exist but devoid of risks [14].

The material experience of medical learning is shown in Figure 2.

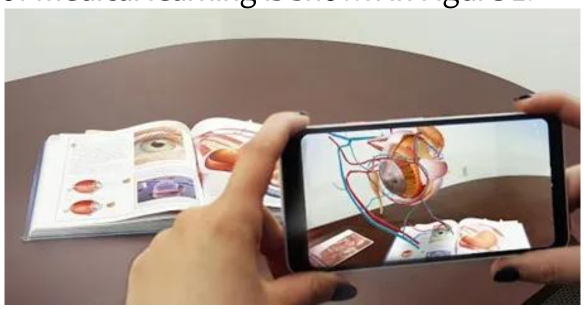

Figure 2: Medical Learning Material in AR

For example, AR applications used in medical education are the AccuVein system for seeing accessible veins, the SurgicalAR platform for planning operations, and the IRIS 1.0 System for building a picture during the operation and its guidance. Although AR in medical education does exist, it cannot be considered developed. It has great prospects for improving the validity of medical education since it makes it possible to create more interactive education [15], [16].

Augmented reality technology is a novel, modern force in the realm of medical education, and it has many benefits that can truly build up a holistic way of training future healthcare professionals. The primary concern with the above-mentioned technology is that it significantly helps to improve spatial understanding and visuals of different and intricate types of anatomical structures, different types of surgeries, and other types of clinics [17], [18]. Through the effective overlay of three-dimensional models, different types of animations, as well as virtual elements, existing in real-time, AR provides a significant understanding of spatial relationships and structures. In this regard, students can effectively understand different types of anatomies, medical surgeries, and clinical techniques [16], [19]. Augmented reality enables the creation of interactive and immersive learning environments, which seem to exhibit better knowledge retention, skill acquisition, and overall learning outcomes compared to traditional methods. Interaction with virtual objects in a realistic setting helps to engage learners' attention and make the studying experience more effective, which in turn helps to develop a profound level of understanding and retention [20]. Simulation allows practicing rare or high-risk medical scenarios without impacting patients' health, which is especially important for medical education [11]. One of the primary goals of augmented reality-based learning is to provide a better understanding of the learning materials through the usage of various practices in a safer environment [21].

The potential objectives of augmented reality-based learning are depicted in Figure 3.

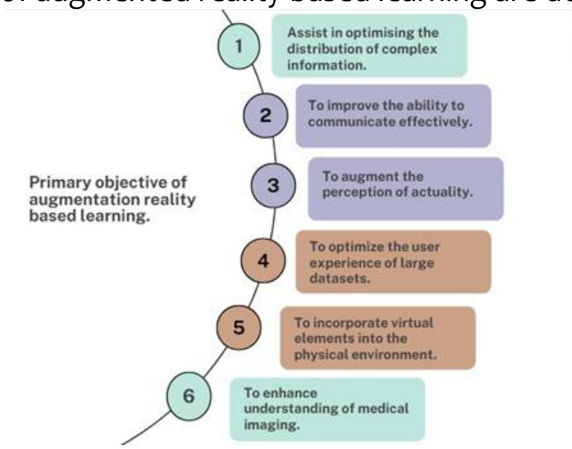

Figure 3: Primary objectives of augmented reality-based learning.

The application of augmented reality technology in the educational sphere is aimed at solving several definitive purposes that are likely to reshape the learning experience. First and foremost, the technology is used to improve spatial understanding of and visual apprehension of intricate concepts, and anatomical structures [22]. The overlay of three-dimensional visual models, animations, or virtual objects on the operative environment serves as the basis for creating interactive and immersive environments, allowing students to explore and visualise abstract or complicated topics. Therefore, this approach implies a higher level of engagement and improved knowledge retention; at the same time, the possibility to manipulate and interact with virtual models allows students to understand topics on a deeper level [23].

The primary function of AR-based learning is the possibility of simulating rare or high-risk scenarios. One of its important applications is in the field of medicine, as trainees can develop their aptitudes without putting the health of patients or subjects at risk. At the same time, the simulations allow for an interactive type of learning, imparting hands-on experience often necessary in different areas of work [24].

In addition, a distinctive element of AR-based learning is the capacity for remote, asynchronous learning, which became crucial in the situation created by the COVID-19 pandemic. Supporting students' ability to learn at their pace from any location, AR supports the concept that education is not confined to spaces and times and can be achieved through a flexible approach that takes different learners' conditions into account. Finally, one of the alacrities of AR is its connectedness, allowing learners to interact with the physical or logical objects in the simulations, which prompts them to perform virtual experiments and develop inferences about the structure or connections between elements of AR objects [25], [26].

Hypothesis

In this regard, three hypotheses will be set to test the potential of augmented reality to influence medical students' interest, effort, and perceived pressure and tension. Those hypotheses would be tested during a series of experiments so that the validity and importance of the current study's outcomes were defined.

H1: Participants will exhibit greater interest and enjoyment when utilising AR-enabled learning resources compared to traditional text-based learning materials.
H2: Participants will demonstrate increased effort and engagement when employing AR-enabled learning tools in contrast to traditional text-based learning approaches.
H3: Participants engaged in AR-enabled learning experiences will report high levels of perceived pressure and tension compared to those engaged in traditional text-based learning environments.

These hypotheses are based on the theoretical framework that AR technology can generate immersive, interactive, and enjoyable learning opportunities so that students' motivations, efforts, and wellbeing would be enhanced in the learning process. These hypotheses will be tested with reliable experimental methods. This paper seeks to complement the growing body of literature on the effectiveness and impact of AR in medical education by providing hard evidence on these hypotheses.

Proposed Methodology

4.1 Experimental setup. The study protocol was subjected to a robust ethical review process and approved by the Institutional Review Board with the reference number IPS/PIN/P22030123, hence, the research adhered to the established ethical standards. The duration of the research investigation was extensive, spanning about six months. The sample of the study was carefully selected and could be viewed as being relatively representative of the population. The participants originated from seven renowned health facilities in the region, among the participants included four private and three public. The names of the institutions are King Edward University, University of Lahore, Sharif Medical \& Dental College, Fatima Memorial College of Medicine \& Dentistry, Faisalabad Medical University, Allama Iqbal Medical College, and Lahore Medical \& Dental College. The environment of these institutions could be varied, further implying that the nature of students across these institutions varies as well. The demographic information regarding the research participants is depicted in Figure 4 & 5.

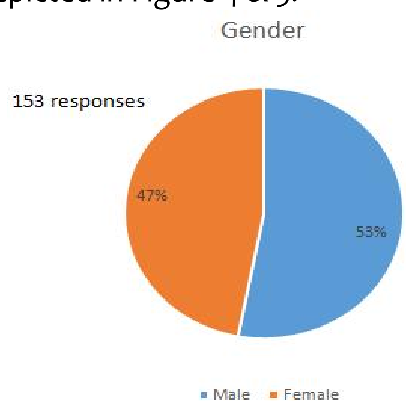

Figure 5: Participant Demographics (Gender)

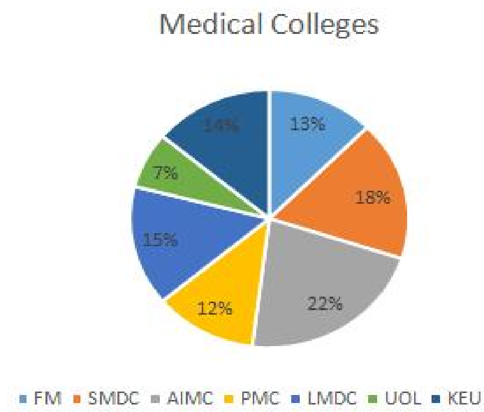

Figure 6: Participant Demographics (Medical Colleges)

To ensure consistent communication and comprehension among the participants, English was employed as the primary language for instructional materials and participant directives throughout the investigation. This strategic decision facilitated a standardised approach to the dissemination of information and the collection of data, minimising potential linguistic barriers and ensuring the reliability and validity of the research findings. The use of a common language also enabled effective collaboration and knowledge-sharing among the research team members, further enhancing the quality and rigor of the study.

The proposed system method diagram is illustrated in figure 7.

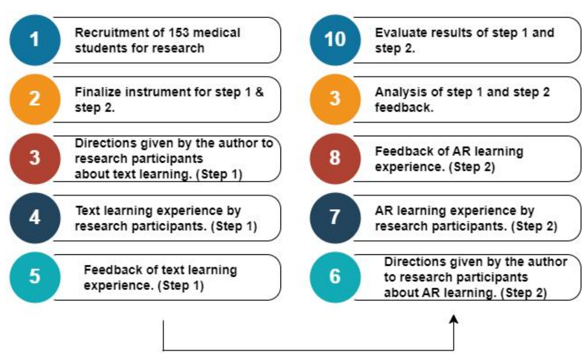

Figure 7: Proposed system method diagram

The research investigation employed a convenience sampling approach, enlisting 153 volunteer participants from the seven aforementioned medical institutions. The sample consisted of 81 male and 72 female participants. While convenience sampling offers practical advantages in terms of accessibility and ease of recruitment, it is important to acknowledge the potential limitations associated with this non-probability sampling method. The sample may not be representative of the broader population, which could impact the generalizability of the findings. However, the inclusion of participants from multiple institutions and the balanced representation of both genders in the sample may mitigate some of these concerns to a certain extent. The researchers should exercise caution in interpreting and extrapolating the results, considering the inherent limitations of convenience sampling.

Pseudo code of the study. This step-by-step approach breaks down the pseudo-code into smaller, more manageable parts, making it easier to understand and implement. Each step focuses on a specific task, such as recruiting volunteers, instructing participants, engaging in learning experiences, collecting feedback, analyzing data, and evaluating the research hypothesis. The main procedure, "Evaluate Augmented Reality Learning Experience," implements the step-by-step procedure by calling other functions and procedures in the appropriate order. It begins by recruiting the volunteers and then proceeds with iterating through the array of volunteers. For each volunteer, it instructs him/her and then enables both text-based and AR-based learning experiences, along with gathering the volunteers' feedback. In the end, it analyses all received data and evaluates the research hypothesis based on the results of the analysis. The pseudocode of the study is given below.

Step 1: Recruit Volunteers Function RecruitVolunteers(InstitutionCount): Volunteers # Initialize volunteers For i ← 1 to InstitutionCount: Volunteers ← Volunteers U RecruitFromInstitution(Institution[i]) Return Volunteers

Step 2: Instruct Participants
Procedure InstructParticipant(LearningExperience)
Provide instructions to the participant about the specified learning.

Step 3: Engage in Learning Experience 6: Procedure EngageInLearningExperience(LearningMode)
If LearningMode = TextBasedLearning: 8: Participants engage in the text-based learning experience. Else If LearningMode = ARBasedLearning
Participants engage in the AR-based learning experience.

Step 4: Collect Feedback 11: Procedure CollectFeedback(FeedbackInstrument)
If FeedbackInstrument = IMIInstrument
Participants provide feedback using the Intrinsic Motivation Inventory (IMI) instrument.

Step 5: Analyze Data 15: Procedure AnalyzeData(TextBasedFeedback, ARBasedFeedback)
Perform statistical analysis on the collected feedback data from both learning experiences.

Step 6: Evaluate Research Hypothesis Procedure EvaluateResearchHypothesis(AnalysisResults): Evaluate the research hypothesis based on the analysis results.

Step 7: Main Procedure
Procedure EvaluateAugmentedRealityLearningExperience
InstitutionCount gets GetInstitutionCount() Volunteers gets
RecruitVolunteers(InstitutionCount)
For Each Participant in Volunteers InstructParticipant(TextBasedLearning)
EngageInLearningExperience(TextBasedLearning)
CollectFeedback(IMIInstrument) TextBasedFeedback gets GetFeedback()
InstructParticipant(ARBasedLearning) EngageInLearningExperience(ARBasedLearning)
CollectFeedback(IMIInstrument) ARBasedFeedback gets GetFeedback()
AnalyzeData(TextBasedFeedback, ARBasedFeedback)
AnalysisResults gets GetAnalysisResults() EvaluateResearchHypothesis(AnalysisResults)

Step 1. The initial phase of the experiment involved a meticulous revaluation of the theoretical framework, drawing upon a comprehensive review of relevant scholarly literature and notes. The participants' responses were evaluated using the authoritative and widely acclaimed text "Davidson's Essentials of Medicine" as a reference, ensuring the validity and reliability of the assessment criteria.

Following the acquisition of informed consent and adhering to ethical guidelines and protocols, participants were instructed to engage with a designated excerpt from the chapter entitled "Cardiovascular Diseases." After their engagement with the assigned reading material, participants were invited to participate in a post-engagement survey instrument, designed to capture their responses and perceptions, as illustrated in Figure 8.

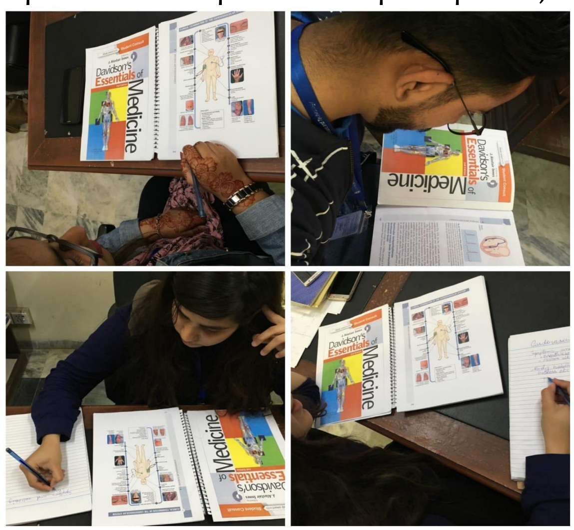

Figure 8: Medical Students In 4th Year Doing Text-Based Learning.

The survey instrument employed a series of carefully crafted baseline measures to assess participants' pre-existing knowledge structures and their subjective evaluations of the learning outcomes upon the conclusion of the assigned reading. These measures were expertly crafted to assess the participants' perceptions and comprehension of the material before and after the intervention, contributing to a more detailed analysis of the latter's effects. Beforehand, the required average time of severe engagement with the allocated reading material was about 2.4 minutes. Afterward, the completion of the survey instrument reportedly took the participants about 2 minutes, which means that the measures gave a clear indication of how long the intervention and the data collection process should take. Therefore, these time estimates will allow other researchers to replicate the study or comprehend the time scale required for similar projects.

The rigorous methodology employed, including the use of a widely acclaimed reference text, adherence to ethical protocols, and the implementation of carefully designed measures, ensured the validity and reliability of the findings. As a result, the research allowed the authors to make a valuable contribution to the advancement of knowledge in the field of medical education and augmented reality interventions.

Step 2. Following the initial phase of the study, the primary investigator provided a comprehensive explanation of the subsequent stage, which involved using an augmented reality (AR)- enhanced textbook. Participants were instructed to engage with identical reading material from the chapter "Cardiovascular Diseases," but this time presented within the context of an AR-enhanced learning environment.

The augmented reality features were realized via a specialized mobile program, which the respondents used to extract information related to the textbook pages. Some resources, including videos on different cardiovascular diseases, audio comments, and 3D models of human anatomy, supplemented the learning process.

The deployment of AR technology has provided an opportunity for participants to engage with the topic in a more interactive and immersive manner, meaning that people could acquire a multisensory way of learning. To put it another way, using 3d AR models was an original way to present the topics, as it allowed people to visualize and experience them. Overall, it could slightly improve spatial thinking. At the same time, there is no exact information on how to measure it properly. Students involved in the AR learning experience can be seen in Figure 9.

Figure 9: Medical Students In 4th Year Doing Ar-Based Learning

Upon completing the AR-enriched learning experience, participants were invited to complete a post-intervention questionnaire. This questionnaire was meticulously designed to capture participants' overall impressions, perceptions, and feedback regarding the AR-enabled instructional approach to learning. The average time of the AR-based learning experience was approximately 3.2 minutes, reflecting the concise and focused nature of the instrument. On average, respondents took 1.3 minutes to complete the post-experiment survey. This approach not only allowed for the assessment of overall impressions but also provided valuable insights into the potential benefits, challenges, and areas for improvement in the implementation of AR technology in medical education.

Unity models for augmented reality development environment. Unity 6 is used for the development of augmented reality applications, and the mathematical model of AR development through Unity can represent the various components and their relationships using set theory and linear algebra concepts. We can explain with the following sets.
$\mathcal{P}$ = Set of all planes detected in the real-world environment.
$\mathcal{F}$ = Set of all faces detected in the camera view
$\mathcal{I}$ = Set of all images detected in the camera view
$\mathcal{O}$ = Set of all objects detected in the camera view
$\mathcal{A}$ = Set of all anchors created in the AR session
$\mathcal{R}$ = Set of all raycasts performed against real-world geometry
We can represent the AR session as a tuple.

$$\mathcal{S} = (\mathcal{C}, \mathcal{P}, \mathcal{F}, \mathcal{I}, \mathcal{O}, \mathcal{A}, \mathcal{R}) \qquad (1)$$

Where $\mathcal{C}$ is the camera feed from the device's camera sensor, as shown in equation 1.
The AR Camera component can be represented as a projection matrix $\mathcal{P}$, which maps 3D points in the real-world coordinate system to 2D points in the camera's image plane as given by:

$$P: \mathbb{R}^3 \to \mathbb{R}^2$$

The AR Plane Manager component can be modeled as a function that maps the camera feed to the set of detected planes:

$$f\mathcal{P}: \mathcal{C} \to \mathcal{P}$$

The AR Face Manager, AR Image Manager, and AR Object Manager components can be represented as functions that map the camera feed to their respective sets of detected entities as follows:

$$f\mathcal{F}: \mathcal{C} \to \mathcal{F}$$
$$f\mathcal{I}: \mathcal{C} \to \mathcal{I}$$
$$f\mathcal{O}: \mathcal{C} \to \mathcal{O}$$

The AR Raycast Manager component can be modeled as a function that takes a raycast origin and direction and returns the set of intersections with real-world geometry:

$$f\mathcal{R}: \mathbb{R}^3 \times \mathbb{R}^3 \to \mathcal{R}$$

The AR Anchor Manager component can be represented as a function that maps a real-world position and orientation to an anchor:

$$f\mathcal{A}: \mathbb{R}^3 \times \mathbb{R}^3 \to \mathcal{A}$$

The AR Environment Probe component can be modeled as a function that captures environment textures and lighting information from the real-world scene:

$$f\mathcal{E}: \mathcal{C} \to (\mathcal{T}, \mathcal{L})$$

where is the set of environment textures, and $\mathcal{L}$ is the set of lighting information.
The AR Session Origin component can be represented as a 4x4 transformation matrix $\mathcal{T}$, which defines the origin and orientation of the AR session relative to the real-world environment.
Using these mathematical representations, developers can model and reason about the various components and their interactions within the Unity AR development framework.

Experimental Findings

The research utilised a holistic method to measure intrinsic motivation in the form of the Intrinsic Motivation Inventory. The established IMI survey is a multidimensional reaction to the task during which participants work. The IMI was designed to measure three dimensions of intrinsic motivation, interest/enjoyment, effort/importance, and pressure/tension.

The elements extracted from the IMI survey allowed the authors to conduct a competitive assessment of three major distinctive factors of the participant's learning process:

1. The extent to which the participant is interested in and enjoying the process of learning. This subscale of the IMI tests feelings of interest and enjoyment of tasks presented, which is referred to as a self-report measure of intrinsic motivation.
2. How much effort did the student put into the learning activities. This subscale measures the amount of effort, importance, and persistence of participants and is supposed to be a positive predictor of intrinsic motivation.
3. The amount of pressure or tension the participant felt in the process of learning. This subscale measures the amount of perceived pressure and tension of the learning activity, which might decrease intrinsic motivation.

The use of the IMI was appropriate and effective because it helped measure students' intrinsic motivation through the valence, choice, and importance dimensions. Because student motivation is a multifaceted and complex concept, the inclusion of these three elements in the instrument allowed researchers to obtain a more complete picture of participants' motivational needs and preferences. At the same time, these instrumental characteristics made the questionnaire well-validated and widely developed; as a result, the data could be considered highly reliable and valid.

On the other hand, the multidimensional nature of IMI allowed the researchers to examine how perceived competence, autonomy, and relatedness interacted with each quality of intrinsic motivation, such as interest, enjoyment, and effort expenditure. As a result, the research quantified the intrinsic motivation levels and revealed the psychology of students' motivation and learning. The outcomes of text-based learning are illustrated in Figure 10.

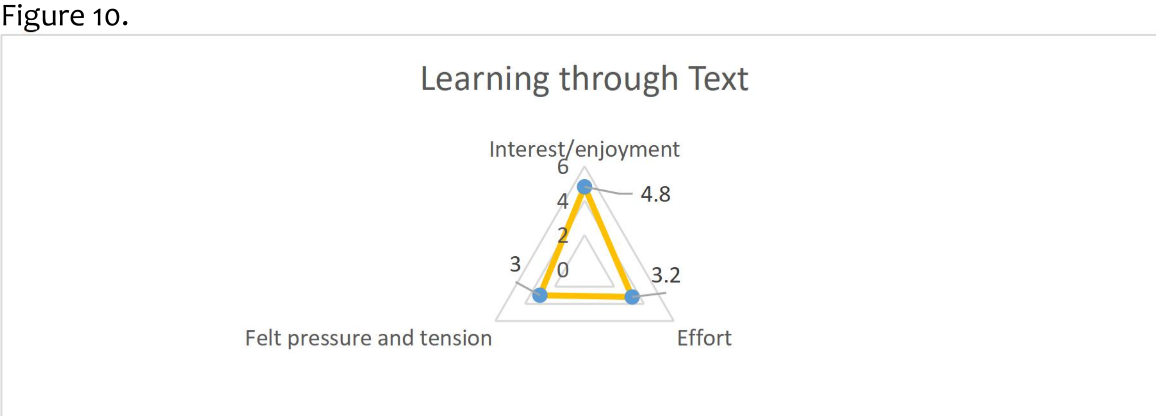

Figure 10: Outcomes Of Learning Through Text

A specially designed survey instrument was utilised to thoroughly evaluate the attributes. For each attribute under investigation, it consisted of six or seven concise questions that directly applied to the trait. The respondents were requested to respond to the extent to which they concur with each of them on a Likert scale that varies from 1 for strongly disagree to 7 for strongly agree.

The survey instrument was administered to participants under controlled conditions, ensuring standardization and minimising potential biases. Clear instructions were provided to guide participants through the process, emphasising the importance of honest and thoughtful responses.

The survey instrument presented in this stage has been highly effective in the context of collecting the necessary data concerning specific traits or aspects. Precisely, the data that was gathered via the survey tool will serve as the foundation for conducting statistics and arriving at the results. In addition, the use of psychometric principles in the development of the identified survey tool has increased the credibility and reliability of the data that was obtained. Thus, with the help of the survey tool in question, researchers have learned more about the essence and impact of the chosen attributes.

Figure 11 illustrates the results of learning using augmented reality. The contribution demonstrates a robust and thorough approach to analyzing the multi-dimensional implications of the attributes in question.

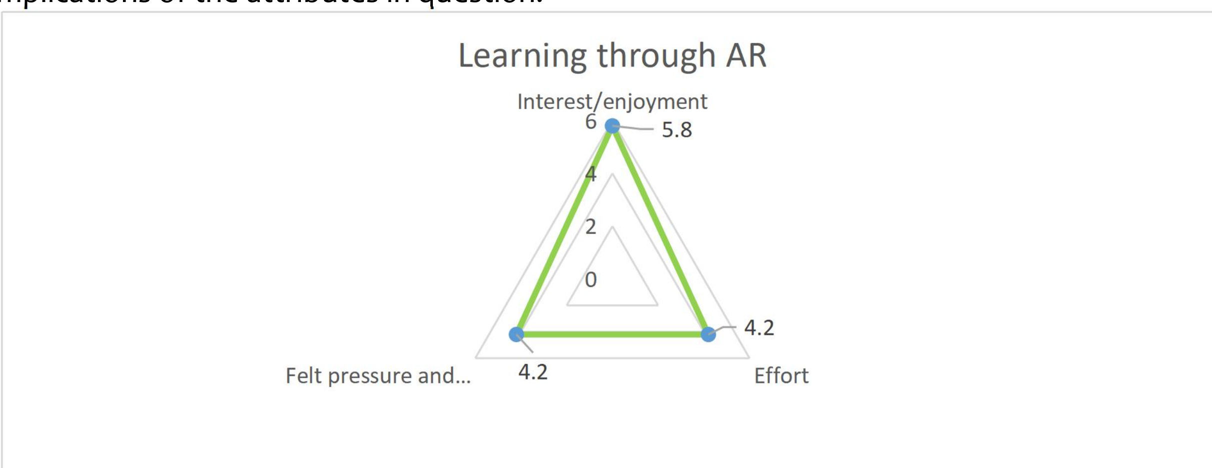

Figure 11: Outcomes Of Learning Through Augmented Reality

Moreover, the development of the multi-item scale for each attribute helped ensure the reliability and validity of the measurements. Due to the multiplicity of indicators used to assess each attribute, measurement errors and the possibility of an idiosyncratic response were minimized. In this way, the assessment was more valid and reliable due to its rigour and highly detailed nature. The process of developing the items, strict adherence to recognized psychometric principles, and inherent multi-dimensionality of each attribute materialized in high-quality data. All of these instruments contributed to a more profound understanding of the attributes in question, helping the researchers make informed conclusions and create more knowledge in the discipline.

Figure 12 illustrates the outcomes of the learning through text, as well as those of the learning through augmented reality. A paired-sample t-test was rigorously applied to evaluate the proposed theory. The employment of this robust quantitative measure optimally followed all statistical principles to generate meaningful and statistically aligned outcomes. This specific analytical approach was chosen because it was sensitive to the paired nature of the data, ensuring that each subject naturally acted under his/her own control and allowing for a robust assessment of the within-subject variation. All necessary assumptions concerning the paired-sample t-test were then examined after the completion of the test. This is a vital step to ensure that the data is accurately and appropriately aligned with the statistical test.

The paired sample t-test is a statistical method used to compare the means of two related or paired samples. It is based on the differences between the pairs of observations. Here's a mathematical model of the paired sample t-test using mathematical notations:

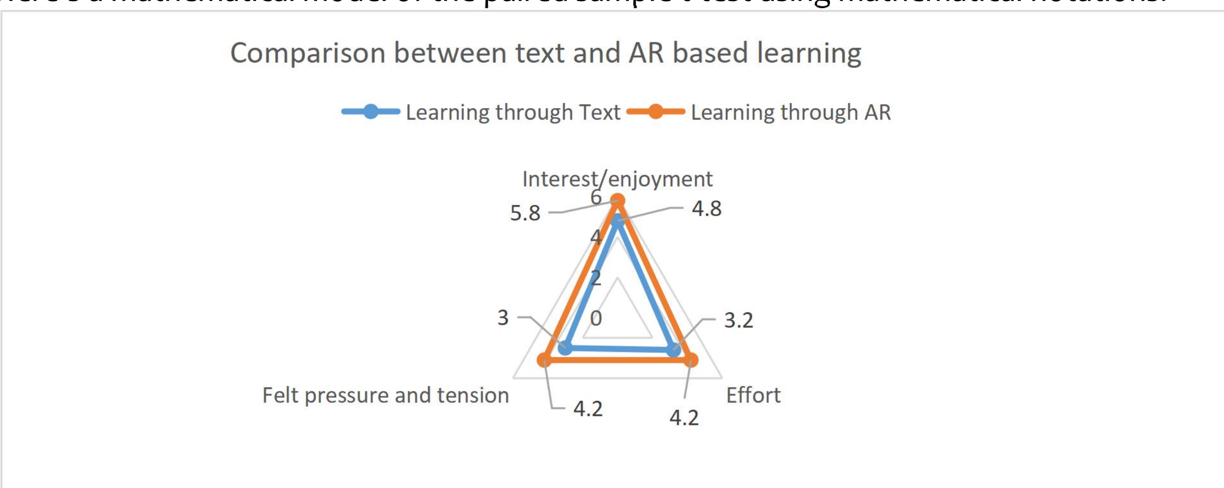

Figure 12: Comparison Between Text And Ar Based Learning.

It can be defined as in equation 2, 3, 4

Let:

n = number of pairs of observations(2)

d_i = difference between the ith pair of observations ($d_i = x_i - y_i$) (3)

μ_d = mean of the differences (4)

The null hypothesis (H_0) and alternative hypothesis (H_1) for the paired sample t-test can be represented as:

H_0: μ_d = 0 (the mean difference is zero)

H_1:μ_d ≠ 0 (the mean difference is not zero)

The test statistic for the paired sample t-test is calculated as:

$$t = \frac{\overline{d}}{s_d/\sqrt{n}} \qquad (5)$$

where in equation 5:

$\overline{d} = \frac{\sum d_i}{n}$ (sample mean of the differences)

$s_d = \sqrt{\frac{\sum (d_i - \overline{d})}{n-1}}$ (sample standard deviation of the differences)

The test statistic t follows a student's t-distribution with $(n - 1)$ degrees of freedom under the null hypothesis.

The decision rule is to reject the null hypothesis (H_0) if the calculated t-value exceeds the critical value from the t-distribution table at a chosen significance level (α), typically 0.05 or 0.01.

Mathematically, the decision rule can be represented as follows:

- Reject H_0 if |t| > t_(α/2, n-1) (for a two-tailed test)
- Reject H_0 if t > t_(α, n-1) or t < -t_(α, n-1) (for a one-tailed test)

Where t_(α/2, n-1) and t_(α, n-1) are the critical values from the t-distribution table with (n - 1) degrees of freedom and significance levels α/2 and α, respectively.

The paired sample t-test assumes that the differences between the pairs of observations are normally distributed. If this assumption is violated, a non-parametric alternative, such as the Wilcoxon signed-rank test, may be more appropriate.

The assumptions that were tested and evaluated are the normality of the difference scores, the lack of duly influential outliers, and the independence of observations. Following these procedures attentively, the researchers were able to make certain that the data satisfies the conditions required for the paired-sample t-test to be valid and meaningful. Subsequently, only when presented with the thorough certainty that the data is valid and suitable to be used was the paired-sample t-test employed to explore the anticipated impact. The fact that considerable attention had been paid to selecting an appropriate statistical technique and checking the required assumptions demonstrates that the design of the present study has received a solid statistical background. As a result, the outcomes presented in Table 1 below are statistically justified by the high quality of the analysis performed.

TABLE 1 Statistical Test Results

		Paired Sample T-Test							
		Paired Differences			95% Confidence Interval of the Difference				
		Mean	**Std. Deviation**	**Std. Error Mean**	**Lower**	**Upper**	**t**	**df**	**Sig. (2-tailed)**
Pair 1	**IEAR - IEText**	0.68293	1.52216	0.11314	0.45967	0.90618	6.036	180	0.000
Pair 2	**EffortAR - EffortText**	0.64199	1.85951	0.13822	0.36926	0.91472	4.645	180	0.000
Pair 3	**FPTAR - FPTText**	1.00331	1.62993	0.12115	0.76426	1.24237	8.281	180	0.000

Discussion

A paired-sample t-test was conducted using SPSS version 26 to enable a valid comparison of the means. Statistical software is a widely recognized package that offers the necessary tools for data analysis. The use of paired samples as data was collected two times led to the selection of this analytical technique. A within-subject analysis of the data to establish the actual differences between the two conditions was ideal in this case. Table 1 presents the comparison of the paired-sample t-test conducted using a selected number of acronyms to ensure the presentation is readable and follows the standards of the field. The abbreviation granted is then defined accordingly to ensure it is communicated effectively and understood.

Apart from the visual form of the report, a vital, comprehensive statistical report is provided, incorporating slightly diverse measures and indicators for a better interpretation of the outcomes, which includes the t-statistic. This is vital since, with the visual and statistical report, the researchers ascertain transparency, specialty amongst the readers, and the accumulation of a fitting analysis, which further accumulates the suitable interpretation of the study. The accurate implication of the paired-samples t-test, and the authoritative usage of the software and conventions, indicate the methodological strength and statistical composition of the report. The following abbreviations are used during the statistical text.

IEAR - *'Interest/ Enjoyment'* using AR,
IEText - *'Interest/ Enjoyment'* using text,
EffortAR - *'Effort'* using AR,
EffortText - *'Effort'* using Text,
FPTAR - *'Pressure/ Tension'* using AR,
FPTText - *'Pressure/ Tension'* using Text.

As indicated, the analysis of the data demonstrated statistically significant differences between AR-based learning and the text-based learning condition in different aspects of intrinsic motivation. As such, the appropriate demonstration of a mean difference of 0.68 in the interest/enjoyment Ratings between IEAR and IEText, with a standard deviation of 1.52 and a p-value of 0.00, clearly presents this outcome in learner interest and enjoyment in using AR-enabled materials in comparison to text-based methods.

It is probable that the increased interest and sense of enjoyment emanate from the incorporation of multimodal supplementary resources that introduce a degree of dynamism to the static textbook learning materials. In other words, with the implementation of AR technology, the learners may have experienced a more stimulating and interactive learning environment that increased their interest.

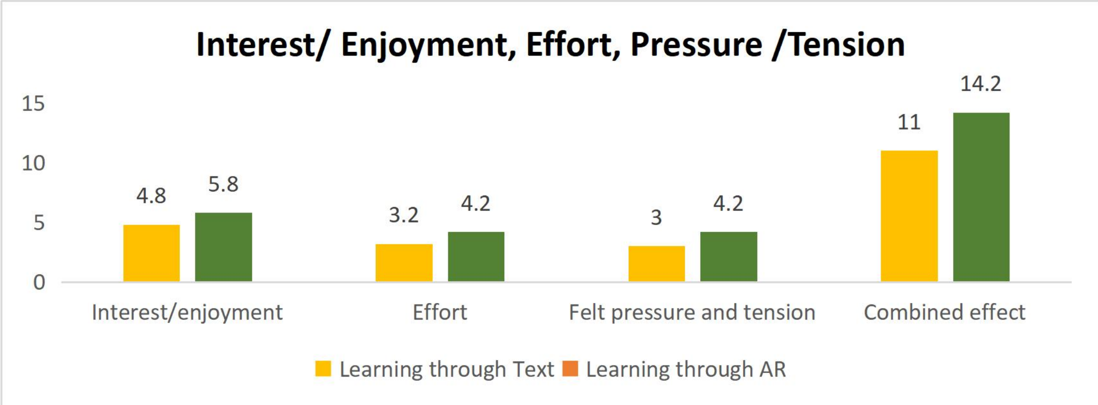

Figure 13: Complete Overview Of Both Learning Methodologies.

Figure 13. illustrates the complete overview of both learning methodologies. The difference in the amount of effort exerted by students was significant. The mean difference of 0.64 between effort experiencing AR and effort experiencing text, with a standard deviation of 1.86 and a p-value of 0.00, implies that students exerted more effort when utilising AR-enabled materials compared to the text-based condition. It is evident that the AR intervention affected the level of students' engagement and motivation, requiring more effort in the learning process. It means students engage themselves more during the AR learning experience, which is good for the student learning curve. The difference between the levels of pressure and tension experienced by students was also notable. With a mean difference of 1.00 between FPTAR and FPTText, a standard deviation of 1.63, and a p-value of 0.00, it is clear that students experienced more pressure and tension when utilising AR-enabled materials compared to the text-based condition. The results imply the conclusion that pressure and tension, as perceived by the students, are not good determinants, which can be directly translated to the amount of effort or intrinsic motivation. It is interesting that one would expect students to experience more pressure and tension with AR, as evidenced by the difference in the amount of effort applied to text-based learning. However, this result can be attributed to a significant factor, the level of experience with AR technology. Since this was the students' first time utilizing augmented reality in any of their instructional content, it can be deduced that they might have developed high levels of anxiety and pressure when utilizing the new technology.

The statistical results accept all three hypotheses, H1, H2, and H3. Statistically, I have proved that AR learning resources are associated with more interest and enjoyment than text-based learning texts. Participants used more effort in the AR learning tools versus traditional text-based learning tools. Also, participants learning through text feel less pressure and tension compared to augmented reality.

Conclusion and Future Scope

The results of the study provide information about AR application implementation along with details regarding the role of this technology in improving or changing students' motivation for learning. The primary idea is that this innovative learning technique can be implemented to supplement traditional teaching methods and facilitate the quality of the educational process through the incorporation of more interactive and content-rich experiences. The role of this technique is also in its ability to influence student motivation and their attitudes to the use of AR technologies. More to the point, AR can be used by students and teachers to develop new teaching techniques and approaches and engage students by making the learning process with the help of AR more meaningful and interesting. Overall, in response to the research question, AR can be applied to enhance traditional teaching methods by developing more interactive and interesting learning experiences. Overall, the authors call for more research, especially longitudinal, to extensively examine the long-term effects of AR on students' learning experiences and academic performance. Such research should cover more diverse populations of students and be based on strict methodologies to ensure the validity and quality of the findings. Thus, such technologies can be a foundation for new pedagogical practices in medical education and beyond.

Conflict of Interest

The authors share no conflict of interest.

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