A smartphone-based augmented reality framework for bio-medical device simulation: Enhancing student learning and engagement

American Journal of Creative Education
Vol. 9, No. 1, 61-72, 2026
e-ISSN: 2706-6088

(Corresponding Author)

Adham Aleid[1]
Omar Altwijri[2]
Mahdi Alqahtani[3]
Mohammed ALmijalli[4]
Mohammed Shahbel[5]
Sulaiman Alkhulayfi[6]
Ravish Javed[7]
Ali Saad[8]

[1,2,3,4,5,6,7,8]*Department of Biomedical Technology, College of Applied Medical Sciences, King Saud University, Riyadh, Saudi Arabia.*
[1]*Email: adaleid@ksu.edu.sa*
[2]*Email: oaltwijri@ksu.edu.sa*
[3]*Email: amahdi@ksu.edu.sa*
[4]*Email: malmijalli@ksu.edu.sa*
[5]*Email: m7md.a.a.sh@gmail.com*
[6]*Email: Sualkhulayfi@gmail.com*
[7]*Email: ravish.javed@yahoo.com*
[8]*Email: alisaad@ksu.edu.sa*

ABSTRACT

Improving student engagement and comprehension of complex theoretical concepts re-mains a persistent challenge in biomedical engineering education. This study proposes a smartphone-based augmented reality (AR) framework for simulating medical devices and evaluates its impact on student learning, interaction, and engagement. Unlike conventional approaches, the proposed method integrates low-cost, accessible AR models of key biomedical equipment—MRI, centrifuge, and defibrillator—developed using SolidWorks, Blender, and Unity, enabling real-time visualization in classroom settings. A cross-sectional study involving 77 biomedical engineering students at King Saud University was conducted using a structured questionnaire following an AR-based instructional session. The results demonstrate high levels of student acceptance and perceived effectiveness, with 88% of participants reporting improved understanding and motivation, 80% indicating enhanced comprehension of complex devices, and 90% supporting the larger adoption of AR across curricula. The findings highlight the potential of AR to bridge the gap between theoretical knowledge and practical visualization, particularly in resource-limited educational environments where access to physical equipment is constrained. Despite these promising outcomes, challenges related to infrastructure, accessibility, and instructor readiness re-main critical considerations. This study contributes to the growing body of research on immersive learning technologies by presenting a scalable and cost-effective AR-based educational approach, while emphasizing the need for further investigation using objective performance metrics and larger populations to validate its long-term educational impact.

Keywords: *Active learning, AR-based learning, Augmented reality, Creative education, Medical devices, Simulation, Smart phone education.*

DOI: 10.55284/ajce.v9i1.1859
Citation | Aleid, A., Altwijri, O., Alqahtani, M., ALmijalli, M., Shahbel, M., Alkhulayfi, S., Javed, R., & Saad, A. (2026). A smartphone-based augmented reality framework for bio-medical device simulation: Enhancing student learning and engagement. *American Journal of Creative Education, 9*(1), 61–72.

Funding: This research was funded by the Ongoing Researchers Funding program (ORF-2026-1678), King Saud University, Riyadh, Saudi Arabia.
Institutional Review Board Statement: The study involved minimal risk and followed ethical guidelines for social science fieldwork. Formal approval from an Institutional Review Board was not required under the policies of Institute for Research Ethics Committee of the King Saud University, Riyadh, Saudi Arabia. Informed verbal consent was obtained from all participants, and all data were anonymized to protect participant confidentiality
Transparency: The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.
Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.
History: Received: 17 April 2026/ Revised: 20 May 2026/ Accepted: 6 June 2026/ Published: 18 June 2026
Publisher: Online Science Publishing

Highlights of this paper

- This study proposes a cost-effective, smartphone-based augmented reality (AR) framework that simulates complex medical devices—such as MRIs and defibrillators—to enhance biomedical engineering education.
- An evaluation involving 77 students demonstrated high acceptance, with 80% to 90% of participants reporting improved comprehension of theoretical concepts, increased motivation, and strong support for integrating AR into broader curricula.
- These findings highlight AR's potential to bridge the gap between theoretical knowledge and practical visualization in resource-limited settings, though challenges regarding infrastructure and the need for long-term objective assessments remain.

1. INTRODUCTION

Augmented reality (AR) is a technology that integrates virtual elements with the re-al-world environment in real time, enabling users to interact with computer-generated content overlaid on physical surroundings (Carmigniani & Furht, 2011; Julie Carmigniani et al., 2011). Unlike virtual reality, which replaces the real environment, AR enhances it by combining digital and physical components, as conceptualized in Milgram's Reality–Virtuality continuum (Milgram & Kishino, 1994). Advances in hardware and software have enabled AR applications to deliver interactive three-dimensional (3D) visualizations across multiple modalities, including text, audio, and video, thereby sup-porting more immersive and engaging user experiences.

In recent years, AR has gained increasing attention across various domains, including healthcare, engineering, and education (Alzahrani, 2020; Byrick, Naik, & Wynands, 2009; Scott et al., 2008). In medical contexts, AR has been applied to surgical navigation, visualization, and training, improving precision and decision-making (Liu et al., 2020; Nicolau, Soler, Mutter, & Marescaux, 2011; Shuhaiber, 2004). Similarly, in educational settings, AR has been shown to enhance student engagement, motivation, and conceptual understanding by enabling interactive and visual learning experiences (Jerry & Aaron, 2010; Osadchyi, Valko, & Kuzmich, 2021; Tarng & Ou, 2012). These capabilities are particularly valuable in disciplines that involve complex systems and abstract concepts, such as biomedical engineering.

Despite these advantages, the integration of AR into higher education remains limited. Practical constraints including the high cost of medical equipment, limited laboratory access, and insufficient technical infrastructure, continue to hinder effective hands-on learning, especially in resource-constrained environments (Akungu, 2014; Fjeld & Voegtli, 2002; Glewwe & Jacoby, 1994). While AR offers a promising alternative by providing virtual simulations of real-world systems, existing studies report mixed results regarding its effectiveness in improving learning outcomes, particularly in specialized domains such as medical device education.

Moreover, most prior research has focused on general educational contexts or specific AR applications, with limited attention given to the use of accessible, smartphone-based AR systems for biomedical engineering training. There is also a lack of empirical studies examining how students perceive and interact with AR simulations of complex medical devices in real classroom settings. Addressing this gap is essential to understanding the practical value and scalability of AR as an educational tool.

Therefore, this study proposes and evaluates a low-cost, smartphone-based AR framework for simulating key biomedical devices, including MRI, centrifuge, and defibrillator systems. The developed models created using SolidWorks, Blender, and Unity, enable students to visualize and explore device structures and functions through interactive AR applications. A questionnaire-based evaluation was conducted to assess the impact of this approach on student engagement, understanding, and learning experience.

The main contributions of this study are threefold: (1) the development of an accessible AR-based simulation framework for biomedical device education; (2) the empirical evaluation of student perceptions and engagement in a real classroom environment; and (3) the demonstration of AR's potential to enhance learning in contexts where access to physical equipment is limited. By addressing both technological and educational aspects, this work contributes to the growing field of immersive learning technologies and supports the integration of AR into higher education.

2. MATERIALS AND METHODS

2.1. Study Design and Participants

This study adopted a quasi-experimental pretest–post-test design to evaluate the impact of augmented reality (AR)-based learning on biomedical engineering students. The study was conducted at the Biomedical Technology Department, College of Applied Medical Sciences, King Saud University, Riyadh, Saudi Arabia.

A total of 77 undergraduate students participated voluntarily. Inclusion criteria required enrolment in the biomedical technology program and attendance at both instructional sessions. Participation was anonymous, and informed consent was obtained prior to data collection.

To strengthen internal validity, participants were exposed to both:

Traditional instruction (baseline condition)

AR-based learning (intervention condition)

This within-subject comparison enabled evaluation of perceived differences in learning effectiveness.

2.2. AR System Development and Device Selection

Three biomedical devices were selected to represent distinct application domains: in centrifuge (laboratory systems, Figure 1), MRI (diagnostic imaging, see Figure 2), and defibrillator (emergency care, see Figure 3). These devices were chosen due to their complexity and limited availability in conventional teaching laboratories.

The AR framework was developed using a three-stage pipeline.

3D Modelling: SolidWorks (Dassault Systèmes, USA).

Animation: Blender (open source).

AR Deployment: Unity with Vuforia SDK for marker-based tracking.

Each device was linked to a unique visual marker, enabling real-time interaction via smartphone-based AR.

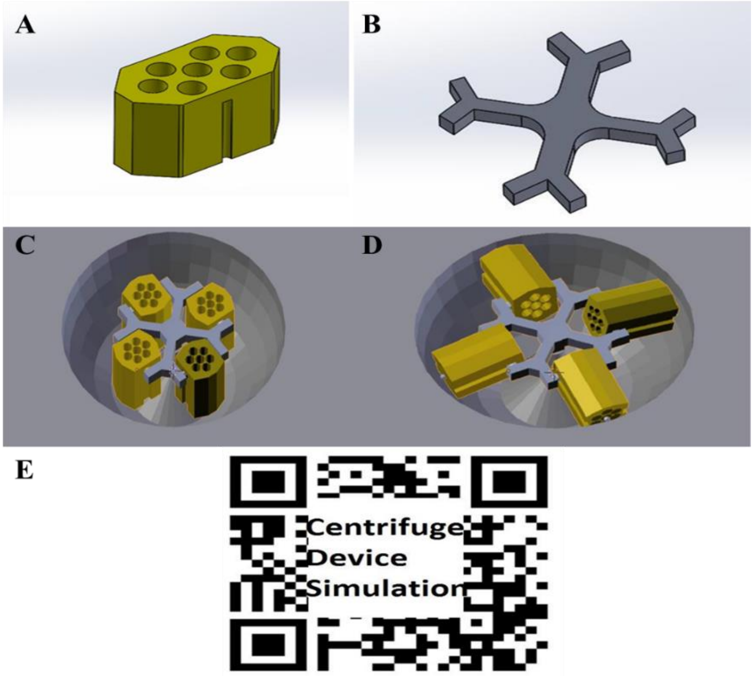

Figure 1. (A) Blocks/buckets to hold samples, (B) Rotator for holding blocks/buckets, (C) Combined blocks/buckets and rotator inside chamber, (D) Moving blocks/bucket while holding samples and (E), Centrifuge Machine Barcode.

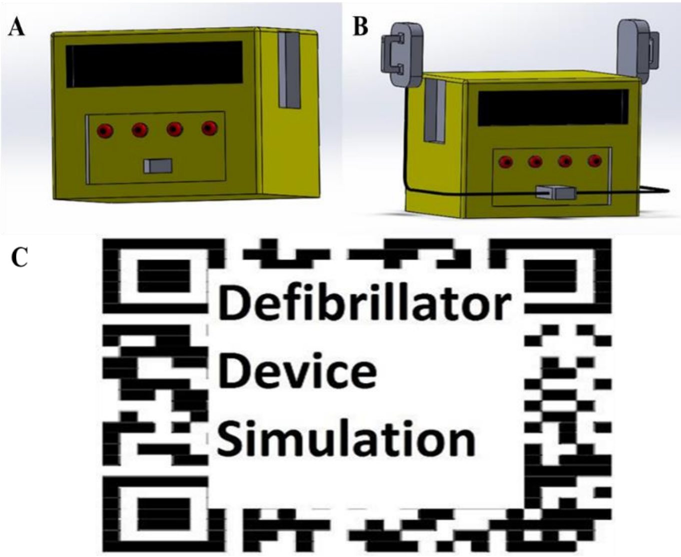

Figure 2. (A) Defibrillator front view, (B) Defibrillator with moving peddles and (C) Defibrillator Machine Barcode.

Figure 3. (A) Display of MRI machine using AR technology and (B) MRI machine barcode.

2.3. Experimental Procedure

The study was conducted in three phases.

Baseline (Traditional Learning): Students received conventional instruction using standard teaching materials (e.g., slides, verbal explanation).

AR Intervention: Students interacted with AR models using smartphones, enabling visualization and exploration of device structures and functions.

Post-Intervention Assessment: A structured questionnaire was administered to evaluate perceived improvements in understanding, engagement, and usability.

2.4. Questionnaire Design, Validity, and Reliability

A structured questionnaire consisting of eight items was developed, including demographic variables and six evaluation items measuring.

- Educational effectiveness.
- Conceptual understanding.
- Engagement.
- Usability and ease of use.
- Accessibility of otherwise unavailable equipment.
- Overall learning preference.

Responses were recorded on a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree).

Content Validity: The questionnaire items were developed based on prior AR education studies (Braun, Clarke, Boulton, Davey, & McEvoy, 2021; Osadchyi et al., 2021; Tarng & Ou, 2012) and reviewed by two subject-matter experts in biomedical engineering and educational technology to ensure relevance, clarity, and coverage of key constructs.

Construct Validity: Construct validity was assessed by examining the logical alignment between questionnaire items and study objectives (learning effectiveness, usability, engagement), ensuring that each item measured the intended dimension.

Reliability Analysis: Internal consistency reliability was evaluated using Cronbach's alpha coefficient. A threshold of $\alpha \geq 0.70$ was considered acceptable for reliability. The questionnaire demonstrated good internal consistency ($\alpha = 0.84$), indicating that the items reliably measure the underlying constructs.

2.5. Statistical Analysis

Statistical analysis was conducted using SPSS version 28 (IBM Corp., USA).

Descriptive statistics: Frequencies, percentages, and mean ± standard deviation.

Reliability analysis: Cronbach's alpha.

Comparative analysis: Paired comparisons between traditional and AR-based learning responses.

Chi-square tests for categorical associations.

One-way ANOVA to assess differences across demographic variables.

A significance level of $p < 0.05$ was used.

3. RESULTS

A total of 77 students volunteered for the present study (see Figure 4), 47 male and 30 female, with a mean age of 21.03 ± 1.70, which can be seen in Table 1. A strong and positive statistically significant association was witnessed for most of the responses using the chi-square method in Table 2. Additionally, the study variables also showed a significant level of differences for a few of the responses received from the participants, which can be seen in Table 3.

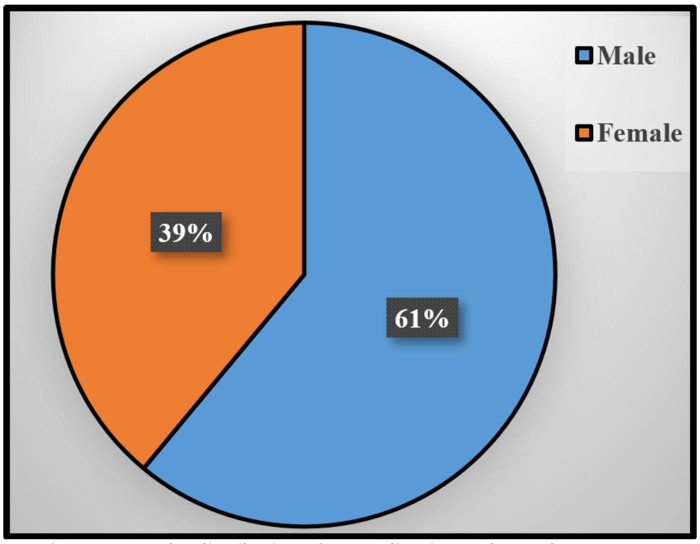

Figure 4. Gender distribution of responding in number and percentage.

Table 1. Summary of the participants and their responses.

Question No.	Responses					
		Male		Female		
1	*Gender*	47		30		
2	*Age*	21.03 ± 1.70 Years				
3	*Semester*	1st: 1		5th: 1		
		2nd: 4		6th: 2		
		3rd: 4		7th: 1		
		4th: 38		8th: 26		
	Respondents	***Strongly Disagree***	***Disagree***	***Neutral***	***Agree***	***Strongly Agree***
4	77	1	0	8	37	31
5	77	0	2	7	26	42
6	77	0	1	26	29	21
7	77	1	3	12	39	22
8	77	0	0	8	34	35

Table 2. Chi-Square Test for finding level of association within the question.

Question No.	***3***	***4***	***5***	***6***	***7***	***8***
Approximate Chi-Square	147.312	47.416	52.506	24.766	63.195	18.260
df	7	3	3	3	4	2
Asymp. Sig. (p-Value)	< .001	<.001	<.001	<.001	<.001	<.001

Note: * Presence of statistical significance association for all p-values.

Table 3. Statistical Analysis between the study variables and the responses to each question.

Question No.	**Independent Variables**		
	Gender	**Age**	**Semester**
	ANOVA (p-Value)		
4	0.709	0.623	0.385
5	0.034 *	0.857	0.007 *
6	0.017 *	0.110 *	0.260
7	0.477	0.391	0.361
8	0.386	0.750	0.144

Note: * Presence of statistical significance association for all p-values.

In Figure 5, a highly statistically significant association ($p<0.001$) was found between responses regarding whether AR has educational benefits and facilitates access to educational content. Many of the participating volunteers expressed agreement; specifically, 88% agreed, while 11% were neutral, 0% disagreed, and only 1% strongly disagreed.

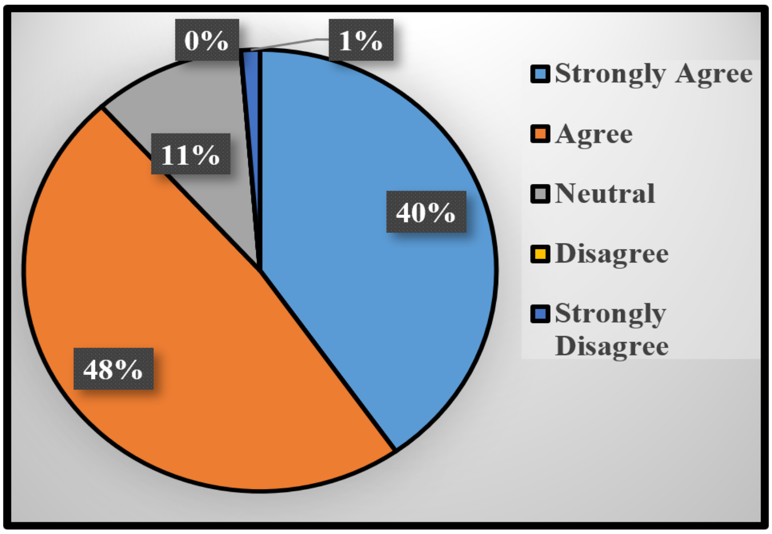

Figure 5. Students' response for question number 3.

When asked if the AR program is included in teaching, will it help students to understand more about the medical device mechanism and working? The replies displayed a highly statistically significant association ($p<0.001$) between the responses. More than 88% of students agreed with the idea; however, 7% and 2% of students were neutral and disa-greed with the question, respectively. Most participants agreed with the question, as seen in Figure 6.

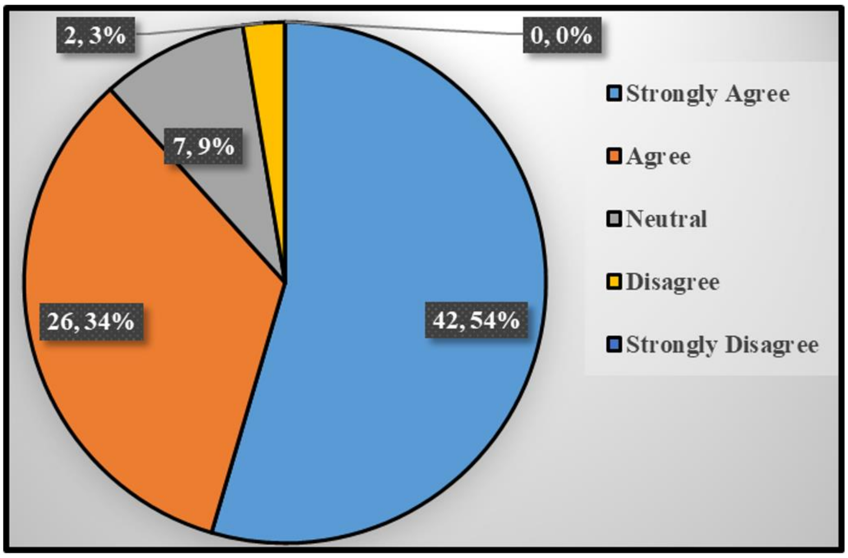

Figure 6. Participating students' response for question number 4.

As seen in Figure 7 a highly significant association ($p<0.001$) was measured for the response to question, whether the application was simple and easy to use. Here 65% of the students' response agreed, and neutral 34% were neutral. However, 1% of the students did not agree with the question asked, also zero response was recorded for strong disagreement.

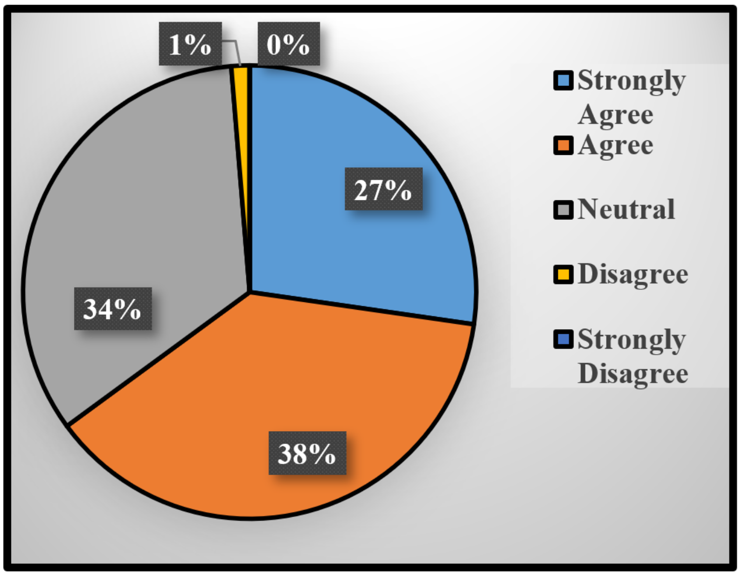

Figure 7. Students' response for question number 5.

Figure 8 displays a high statistically significant association ($p<0.001$) when asked, "Does the application make it easy to view medical devices that we couldn't see in real life?" 84% of the students agreed with question 7; whereas 15% of students selected neutral. However, 4% and 1% of students disagreed and strongly disagreed with the idea, respectively.

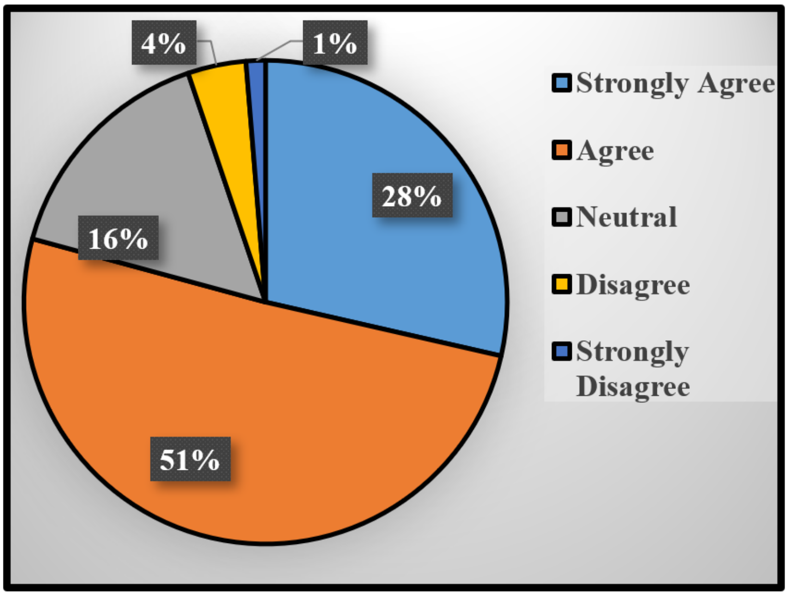

Figure 8. Students' response for question number 6.

In Figure 9 we observe a highly statistically significant association ($p < 0.001$) regarding whether students believe this application should be implemented in other sub-jects. 90% of the students agreed with this statement, and only 10% selected a neutral response. Notably, no students disagreed or strongly disagreed with the statement.

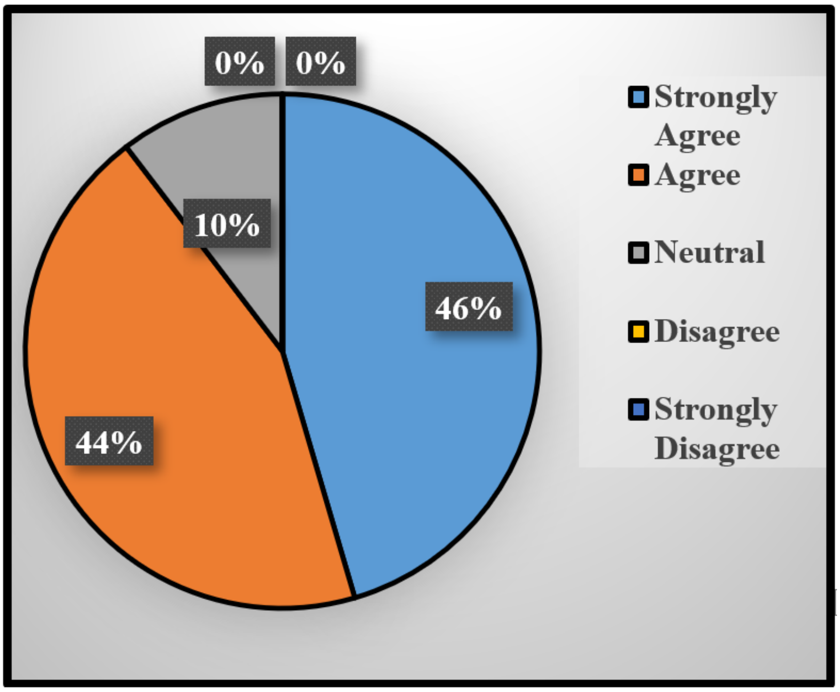

Figure 9. Participating students' response for question number 7.

4. DISCUSSION

This study explored the impact of augmented reality (AR)-based simulation on biomedical engineering students' learning experience, with particular emphasis on conceptual understanding, engagement, and accessibility to complex medical devices. The findings indicate that AR can serve as an effective complementary educational tool, supporting prior evidence that immersive and interactive technologies enhance student learning through multimodal engagement (Elmqaddem, 2019; Huang et al., 2019). A large proportion of participants (88%) reported that AR improved their understanding of medical device mechanisms and facilitated access to educational content. These findings are consistent with earlier studies demonstrating that AR enhances visualization and supports the comprehension of abstract or complex concepts (Jerry & Aaron, 2010; Osadchyi et al., 2021; Tarng & Ou, 2012). However, it is important to note that the present study relies primarily on self-reported perceptions, which may introduce response bias. Moreover, the absence of a control group limits the ability to establish causal relationships between AR usage and learning outcomes. Future research employing experimental or quasi-experimental designs is therefore warranted. The usability of the AR application was positively evaluated, with approximately 90% of students indicating that the system was easy to use. This suggests that smartphone-based AR platforms can be effectively integrated into classroom environments without imposing substantial technical barriers. Nevertheless, a minority of participants reported usability challenges, which may be attributed to differences in device specifications, user familiarity with digital tools, or varying levels of technological adaptability. Similar concerns have been highlighted in previous studies, emphasizing the need for user-centred design and technical support (Niedlich, Kallfaß, Pohle, & Bormann, 2021; Tschannen-Moran, 2017). An important contribution to this work lies in its applicability to resource-constrained educational settings. The results suggest that AR can mitigate limitations associated with the lack of physical access to expensive medical equipment, a challenge commonly reported in low- and middle-income contexts (Akungu, 2014; Fjeld & Voegtli, 2002; Glewwe & Jacoby, 1994). By providing interactive simulations, AR enables students to explore device structures and functions in a cost-effective manner. However, AR should not be considered a replacement for hands-on training but rather a supplementary tool that enhances traditional laboratory-based learning. Despite the promising findings, several challenges remain.

The implementation of AR in education requires not only adequate technological infrastructure but also sufficient instructor training and institutional support. Previous literature has identified a lack of technical proficiency among educators as a significant barrier to effective adoption (Billinghurst & Duenser, 2012). Additionally, the time and effort required to develop AR-based educational content may limit its scalability. Addressing these challenges will be critical for the sustainable integration of AR into academic curricula. The current findings also align with broader research indicating that AR can improve student motivation and engagement; however, evidence regarding its impact on measurable academic performance remains inconclusive (Dhaas, 2024; Rodriguez-Saavedra et al., 2025). While this study demonstrates strong student acceptance and perceived benefits, further investigation is needed to evaluate long-term learning outcomes, knowledge retention, and skill acquisition. Incorporating objective assessment metrics and larger, more diverse samples would strengthen the generalizability of future studies. In summary, AR technology offers significant potential to enhance biomedical engineering education by bridging the gap between theoretical knowledge and practical application. Its effectiveness is particularly evident in improving visualization, engagement, and accessibility. Nonetheless, its successful implementation depends on careful pedagogical integration, technological readiness, and ongoing evaluation. Future research should focus on longitudinal studies, comparative analyses with traditional methods, and the development of standardized frameworks for AR-based learning in higher education.

5. CONCLUSIONS

This study examined the use of augmented reality (AR) for simulating biomedical devices, including MRI, centrifuge, and defibrillator systems, using SolidWorks, Blender, and Uni-ty. The results indicate that AR enhances student engagement, understanding, and access to complex equipment, supporting its role as an effective complementary educational tool.

Despite these positive findings, limitations include the small sample size, reliance on self-reported data, and lack of objective performance measures. Future studies should adopt larger, more diverse samples and experimental designs to better assess learning outcomes and generalizability.

REFERENCES

Akungu, J. A. (2014). *Influence of teaching and learning resources on students' performance in Kenya Certificate of Secondary Education in free day secondary education in Embakasi District, Kenya.* Master's Thesis, University of Nairobi University of Nairobi Repository.

Alzahrani, N. M. (2020). Augmented reality: A systematic review of its benefits and challenges in e-learning contexts. Applied Sciences, *10*(16), 5660. https://doi.org/10.3390/app10165660

Billinghurst, M., & Duenser, A. (2012). Augmented reality in the classroom. Computer, *45*(7), 56-63. https://doi.org/10.1109/MC.2012.111

Braun, V., Clarke, V., Boulton, E., Davey, L., & McEvoy, C. (2021). The online survey as a qualitative research tool. International Journal of Social Research Methodology, *24*(6), 641–654. https://doi.org/10.1080/13645579.2020.1805550

Byrick, R. J., Naik, V. N., & Wynands, J. E. (2009). Simulation-based education in Canada: Will anesthesia lead in the future? Canadian Journal of Anesthesia, *56*(4), 273-278. https://doi.org/10.1007/s12630-009-9053-6

Carmigniani, J., & Furht, B. (2011). Augmented reality: An overview. In B. Furht (Ed.), Handbook of augmented reality. In (pp. 3–46). New York: Springer.

Carmigniani, J., Furht, B., Anisetti, M., Ceravolo, P., Damiani, E., & Ivkovic, M. (2011). Augmented reality technologies, systems and applications. Multimedia Tools and Applications, *51*(1), 341-377. https://doi.org/10.1007/s11042-010-0660-6

Dhaas, A. (2024). Augmented reality in education: A review of learning outcomes and pedagogical implications. American Journal of Computing and Engineering, 7(3), 1-18. American Journal of Computing and Engineering 7(3):1-18
https://doi.org/10.47672/ajce.2028

Elmqaddem, N. (2019). Augmented reality and virtual reality in education: Myth or reality? International Journal of Emerging Technologies in Learning, *14*(3), 234–254. https://doi.org/10.3991/ijet.v14i03.9289

Fjeld, M., & Voegtli, B. M. (2002). *Augmented chemistry: An interactive educational workbench.* Proceedings of the International Symposium on Mixed and Augmented Reality (ISMAR), 259–260. Darmstadt, Germany https://doi.org/10.1109/ISMAR.2002.1115100

Glewwe, P., & Jacoby, H. (1994). Student achievement and schooling choice in Ghana. Journal of Human Resources, *29*(3), 843–864. https://doi.org/10.2307/146255

Huang, K. T., Ball, C., Francis, J., Ratan, R., Boumis, J., & Kuo, J. (2019). Augmented versus virtual reality in education. Cyberpsy-chology, Behavior, and Social Networking, *22*(2), 105–110.

Jerry, T. F. L., & Aaron, C. C. E. (2010). *The impact of augmented reality software with inquiry-based learning on students' learning of kinematics graph.* Paper presented at the In 2010 2nd International Conference on Education Technology and Computer (ICETC) (Vol. 2, pp. V2-1–V2-5). IEEE. https://doi.org/10.1109/ICETC.2010.5529447

Liu, T., Tai, Y., Zhao, C., Wei, L., Zhang, J., Pan, J., & Shi, J. (2020). Augmented reality in neurosurgical navigation: a survey. The International Journal of Medical Robotics and Computer Assisted Surgery, *16*(6), 1-20. https://doi.org/10.1002/rcs.2160

Milgram, P., & Kishino, F. (1994). A taxonomy of mixed reality visual displays. IEICE TRANSACTIONS on Information and Systems, vol. E77-D, no. 12, pp. 1321-1329.

Nicolau, S., Soler, L., Mutter, D., & Marescaux, J. (2011). Augmented reality in laparoscopic surgical oncology. Surgical oncology, *20*(3), 189-201. https://doi.org/10.1016/j.suronc.2011.07.002

Niedlich, S., Kallfaß, A., Pohle, S., & Bormann, I. (2021). Trust in education: A systematic review. Review of Education, *9*(1), 124–158.

Osadchyi, V., Valko, N., & Kuzmich, L. (2021). Using AR technologies for STEM education. Journal of Physics: Conference
Series, *1840*(1), 012027. https//doi.org/10.1088/1742-6596/1840/1/012027

Rodriguez-Saavedra, M. O., Barrera Benavides, L. G., Cuentas Galindo, I., Campos Ascuña, L. M., Morales Gonzales, A. V., Lopez, J. W. M., & Arguedas-Catasi, R. W. (2025). Augmented reality as an educational tool: Transforming teaching in the digital age. Information, *16*(5), 372. https://doi.org/10.3390/info16050372

Scott, D. J., Cendan, J. C., Pugh, C. M., Minter, R. M., Dunnington, G. L., & Kozar, R. A. (2008). The changing face of surgical education: Simulation as the new paradigm. Journal of Surgical Research, *147*(2), 189-193. https://doi.org/10.1016/j.jss.2008.02.014

Shuhaiber, J. H. (2004). Augmented reality in surgery. Archives of Surgery, *139*(2), 170-174. https://doi.org/10.1001/archsurg.139.2.170

Tarng, W., & Ou, K. L. (2012). *A study of campus butterfly ecology learning system based on augmented reality and mobile learning.* Paper presented at the IEEE Seventh International Conference on Wireless, Mobile and Ubiquitous Technology in Education (pp. 62-66). IEEE. Japan, https://doi.org/10.1109/WMUTE.2012.17

Tschannen-Moran, M. (2017). *Trust in education oxford research encyclopedia of education.* New York: Oxford University Press.