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Original Research

Augmented Reality Enhances Indonesian Nursing Students' Knowledge and Motivation in Open Fracture Learning

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ABSTRACT

Background: *Open fracture cases have complex management that involves bleeding control based on comprehensive knowledge and training. Augmented Reality (AR) offers an interactive learning approach that may enhance nursing students' motivation and knowledge of emergency open fracture cases. This study aims to evaluate the effectiveness of augmented reality in improving the knowledge and learning motivation of Indonesian nursing students regarding open fracture learning.*

Methods: *This study used a cluster randomized pretest–posttest control group design involving four class groups of nursing students (n = 155). Two clusters received the Open Fracture Augmented Reality Application, while two received conventional lectures. Motivation was measured using the validated MSLQ, and knowledge using a 29-item validated questionnaire. Both groups completed pretest and posttest assessments. Data were analyzed using descriptive statistics, Wilcoxon, and Mann–Whitney tests (α = 0.05).*

Results: *A total of 155 nursing students participated, with balanced baseline characteristics between groups. The AR intervention significantly improved knowledge (p = 0.001, r = 0.38) and motivation (p = 0.022, r = 0.27) in the intervention group, while no significant gains occurred in the control group. Between-group analysis showed higher posttest knowledge in the AR group (p = 0.005), indicating that AR was more effective than conventional instruction, particularly for cognitive outcomes.*

Conclusion: *Augmented Reality–based learning significantly improves nursing students' knowledge of open-fracture management compared with traditional methods, while showing no significant between-group differences in motivation, highlighting AR's value as an effective supplemental tool for enhancing understanding of complex clinical content.*

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INTRODUCTION

Open fractures are among the most challenging musculoskeletal emergencies due to their complex characteristics, which typically involve bone discontinuity, extensive soft-tissue damage, contamination, and life-threatening bleeding (Vergote et al., 2024). Inadequate or delayed early management in open fractures substantially increases the risk of infection, long-term disability, and mortality (Rayner et al., 2025). Based on the 2023 Indonesian Health Survey (SKI), 0.6% of the population reported using traditional health services for fractured bone treatment at the national level. In East Java, the proportion of traditional service use for fracture management was 0.3%. (Ministry of Health of Indonesia, 2023). These epidemiological data highlight a considerable trauma burden and underscore the urgent need to enhance emergency preparedness among healthcare providers.

Nursing personnel play a pivotal role in the initial management of open fractures, including rapid assessment, bleeding control, wound protection, stabilization, and infection prevention (Davies et al., 2022; Hunter et al., 2021). To perform these tasks effectively, nursing students must develop strong cognitive, psychomotor, and affective competencies (Immonen et al., 2019). However, competency development in nursing is strongly influenced by internal and external learning determinants, such as personal factors like knowledge, motivation, learning strategies, educational environment, and technology integration (Corriveau et al., 2020; Suliman et al., 2023; Wardani, 2019). High levels of motivation are associated with improved academic performance and clinical skills (Patterson et al., 2023), whereas low motivation negatively affects the quality and safety of patient care (Saeedi & Parvizy, 2019). In addition to motivation, knowledge is a fundamental aspect in learning (Sia et al., 2024).

Traditional, lecture-based methods (lectures and PowerPoint) remain widely used in nursing education but have limited capacity to engage learners in active, spatial, and clinical reasoning tasks required for complex anatomical and emergency scenarios; alternative active approaches, such as team-based and problem-based learning, show superior outcomes for higher-order skills and student engagement (Zhang et al., 2023). Simulation with high-fidelity mannequins improves psychomotor and procedural performance in a safe environment, yet it often fails to visualize internal anatomy or dynamic injury mechanisms that are critical for understanding pathomechanics in trauma care (Elendu et al., 2024).

Advances in digital anatomy and immersive technologies demonstrate that 3-D, interactive visualisation (via AR/VR) can bridge this gap by improving spatial understanding and reducing extraneous cognitive load when learning complex structures and procedures (Wickramasinghe et al., 2022). Consequently, there is a clear pedagogical gap between current dominant teaching modalities and the competencies required for effective open-fracture management; this gap supports the need for innovative, interactive, and immersive learning strategies such as Augmented Reality (AR) to enhance both understanding and applied clinical skills (Lampropoulos et al., 2025).

Augmented Reality (AR) technology offers an innovative solution for learning about open fractures. A recent scoping review covering applications of AR in nursing found that AR interventions significantly improved theoretical knowledge, critical thinking, self-confidence, and learning motivation among nursing students (Wei et al., 2025). In the context of nursing, AR can improve memory, clinical skills, and students' interest in the material being studied (Rodríguez-Abad et al., 2022). In a human anatomy course for nursing students, use of immersive virtual reality — a modality closely related to AR — was associated with increased knowledge scores and high student satisfaction (Jallad et al., 2024).

By presenting interactive simulations, AR can help students understand complex medical concepts more easily and effectively (Khushi & Kumar, 2024; Mei-Fern et al., 2020). In addition, AR also contributes to improving students' cognitive understanding of complex learning materials by reducing excessive cognitive load (Castro-Alonso et al., 2021). In the context of open fracture learning, AR allows nursing students to better understand the mechanisms of injury, patient stabilization techniques, and initial treatment procedures more effectively than conventional learning methods.

However, research on the effect of using AR on improving nursing students' knowledge and learning motivation in open fracture learning is still limited. Therefore, this study aims to explore the effect of using Augmented Reality as an innovative approach in learning open fractures on the level of knowledge and motivation of nursing students in Indonesia.

MATERIALS AND METHOD

Research Design

This study employed a cluster randomized pretest–posttest control group design using probability sampling through cluster random sampling. Randomization was conducted at the class-group level, in which existing class groups enrolled in the Emergency Nursing course were assigned as clusters. This design was selected to minimize the risk of contamination between students within the same class during the learning activities.

Population and Sample Research

The study population consisted of all undergraduate nursing students from the Faculty of Nursing, Universitas Jember, who were enrolled in the Emergency Nursing course in 2023. Four existing class groups participated in the course. These four class groups constituted the sampling frame and were randomly assigned into two clusters for the intervention group and two clusters for the control group.

Cluster randomization was performed at the class-group level. Four existing class groups were coded and randomly assigned using a computer-generated allocation sequence, with two clusters allocated to the intervention group and two to the control group. Allocation was conducted by an independent researcher and revealed only after assignment to ensure concealment. All students within each cluster received the same learning method to prevent contamination.

The inclusion criteria were: (1) active enrollment in the Emergency Nursing course at the time of the study; (2) willingness to participate; (3) completion of both the pretest and posttest assessments; and (4) ownership of an Android smartphone with version 5.0/5.1 (Lollipop) or higher to access the AR media. A total of 161 students were assessed for eligibility. After excluding two students due to incomplete data, 159 students were randomized by cluster into the intervention and control groups. At the end of data collection on June 16th, 2023, a final sample of 155 respondents was obtained. The overall flow of the study—from recruitment, sampling, group allocation, intervention administration, to outcome assessment—can be seen in Figure 1.

Instruments

The AR media used in the intervention was the Open Fracture in Augmented Reality Application version 0.0.1, developed in 2023 by a multidisciplinary research team. This application consists of two main components: (1) educational material covering open-fracture concepts, bleeding management, splinting, and first-aid procedures; and (2) an interactive AR module that activates when scanning a designated QR marker (Figure 2). The application had undergone preliminary testing to ensure usability and functionality prior to implementation in this study.

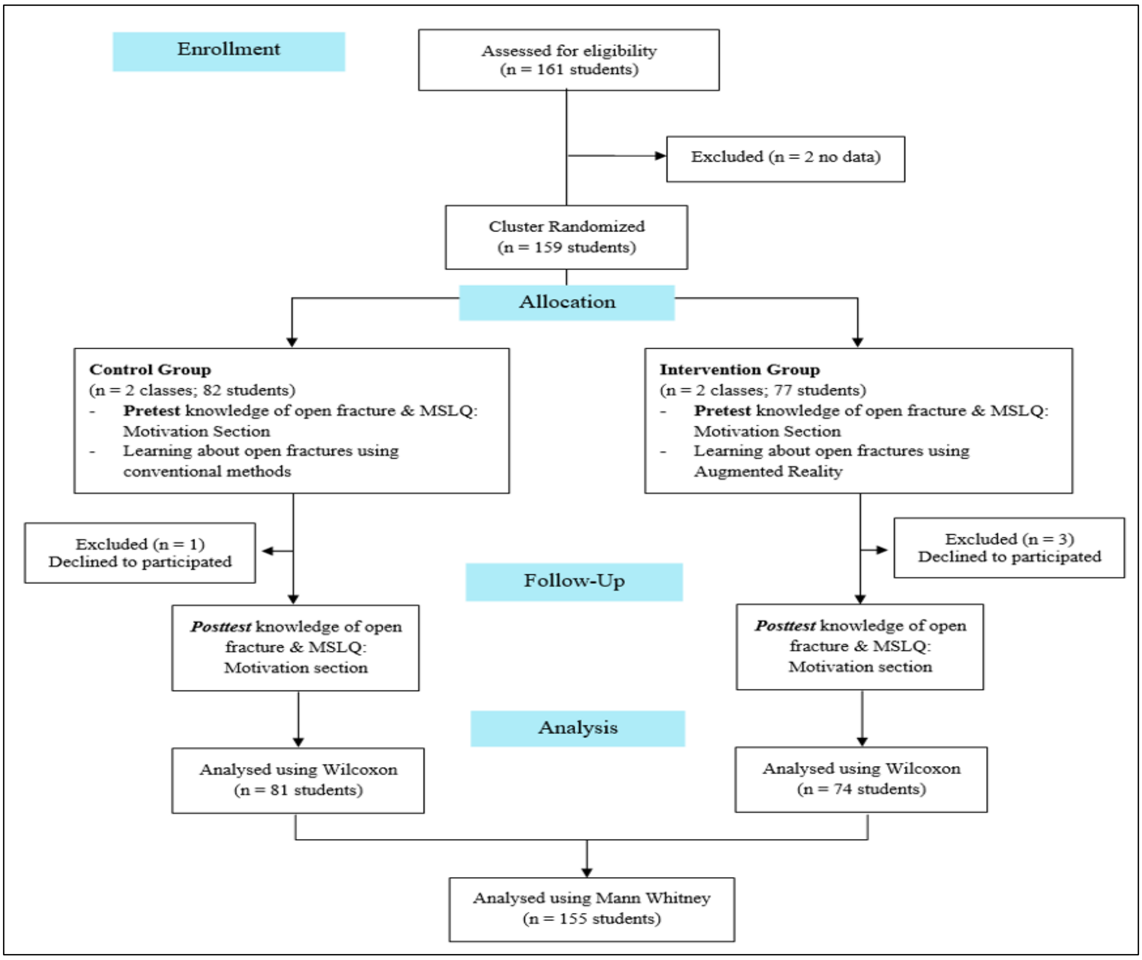

Figure 1. Research Flowchart

The Open Fracture AR Media was developed using a user-centered design approach involving emergency nursing experts and software developers. Educational content—covering open fractures, bleeding, splinting, and first-aid procedures—was compiled based on national guidelines and validated by expert reviewers. The AR module was built using Unity 3D and the Vuforia SDK, enabling QR-marker scanning and real-time 3D anatomical visualization.

The application underwent iterative internal testing to ensure functional stability, accuracy of animations, and compatibility with common Android devices. A small pilot test with nursing students (n = 10) was conducted to identify usability issues and refine navigation, visual clarity, and AR tracking performance. Usability was assessed using an adapted System Usability Scale (SUS), yielding scores in the "good" range, indicating that the interface was easy to use and the AR features were appropriate for instructional purposes.

Motivation was assessed using the Motivation section of the MSLQ, which comprises 31 items across six subscales: intrinsic goal orientation, extrinsic goal orientation, task value, control of learning beliefs, self-efficacy for learning and performance, and test anxiety. The Indonesian version of MSLQ has been tested for validity and reliability: in a study among Indonesian medical students, the instrument showed satisfactory internal consistency with Cronbach's alpha of 0.89 for the motivation dimension and 0.88 for the learning strategies dimension, indicating that MSLQ is valid and reliable for measuring motivation and learning strategies in the Indonesian higher-education context (Ningrum, 2021).

Knowledge was assessed using a developed 29-item questionnaire. The instrument was constructed based on relevant literature and expert judgment to ensure content validity. Content validity was established through evaluation by three experts in emergency nursing, yielding item-level content validity indices (I-CVI) ranging from 0.83 to 1.00 and a scale-level CVI/Average (S-CVI/Ave) of 0.92, indicating excellent content validity. Construct validity was further examined through a pilot test involving 56 students outside. Item–total correlation analysis showed acceptable construct validity, with correlation coefficients ranging from 0.32 to 0.71 ($p < 0.05$). The questionnaire also demonstrated good internal consistency, with a reliability coefficient of $r = 0.807$, confirming that the instrument was suitable for use in the main study.

Procedure

The study was conducted in the Faculty of Nursing laboratory, where participants were assigned to intervention and control groups and placed in separate rooms to prevent contamination. Before data collection, all respondents received an explanation of the study procedures and provided informed consent. Both groups then completed a pretest within 10 minutes using a Google Forms link containing the knowledge questionnaire on open-fracture first aid. During this stage, researchers provided instructions and supervised the completion process to ensure accuracy, after which the number of submitted responses was verified.

The intervention was delivered only to the AR group. The session began with an introduction to Augmented Reality and the Open Fracture in Augmented Reality Application, during which respondents listened to an explanation and downloaded the application (10 minutes) on their smartphones. This was followed by a brief explanation of key concepts—open fracture mechanisms, bleeding, splinting principles, and first-aid procedures—while participants accessed the "Open Fracture Material" menu within the application (30 minutes). Subsequently, respondents were guided through a comprehensive AR-based simulation using the QR-marker scanning feature, which displayed three-dimensional visualizations aligned with the procedural steps previously presented in the material menu (30 minutes). The intervention process was implemented according to the predetermined Learning Activity Plan.

Meanwhile, the control group received conventional lecture-based instruction covering the same theoretical content without exposure to AR media. After completing the respective learning sessions, both groups performed a posttest using the same online questionnaire, again supervised to ensure proper completion and submission.

During the intervention, the lecturer provided facilitative support, including guiding the students through the AR installation process, explaining how to navigate the application, and ensuring that each student could operate the AR simulation properly. No prior instructional sessions were provided; all students received the same standardized orientation immediately before the intervention to minimize baseline differences. In the control group, the teacher provided only standard instructional support, including a brief orientation to the topic and conventional explanations based on the existing curriculum. Students did not receive any specialized preparation or technological assistance, and no exposure to the AR materials was provided.

Figure 2. The Display of Open Fracture in an Augmented Reality Application

Data Analysis

Data were analyzed using descriptive and inferential statistics. Descriptive analysis was conducted to summarize respondent characteristics and to present pretest and posttest knowledge and motivation scores in the form of frequencies, percentages, and median values. Because the knowledge and motivation data were ordinal, the non-parametric tests were applied. The Wilcoxon Signed-Rank Test was used to evaluate within-group differences between pretest and posttest scores, while the Mann–Whitney U Test assessed differences in knowledge outcomes between the intervention and control groups. A significance level of $\alpha = 0.05$ was used for all statistical analyses.

Ethical Clearance

This study received ethical approval from the Health Research Ethics Committee of the Faculty of Nursing, Universitas Jember (Approval No. 239/UN25.1.14/KEPK/2023). All procedures adhered to the ethical principles of the Declaration of Helsinki, and informed consent was obtained from all participants prior to data collection.

RESULTS

A total of 155 nursing students participated in this study, consisting of 13% male and 87% female respondents. The age range was 19–23 years, and most students were of Javanese ethnicity (81%), followed by Madurese (16%). Parental education levels varied across groups, with high school being the most common level in both the intervention and control groups. More than half of the respondents (54%) reported high financial status, and most students entered the university through the Joint Entrance Selection for SBMPTN admission pathway. GPA distribution was balanced between groups (Table 1).

Table 1. Frequency Distribution of Respondent Characteristics (n = 155)

Variable	Intervention n (%)	Control n (%)	χ^2 p-value
Gender			
Male	11 (15)	9 (11)	**0.648***
Female	63 (85)	72 (89)	
Total	**74 (100)**	**81 (100)**	
Age (years)			
19	0 (0)	3 (4)	**0.169***
20	9 (12)	14 (17)	
21	53 (72)	47 (58)	
22	11 (15)	17 (21)	
23	1 (1)	0 (0)	
Total	**74 (100)**	**81 (100)**	
Ethnicity			
Javanese	61 (82)	65 (80)	**0.289***
Madurese	11 (15)	13 (16)	
Betawi	0 (0)	2 (2)	
Sundanese	2 (3)	0 (0)	
Sasak	0 (0)	1 (1)	
Total	**74 (100)**	**81 (100)**	
Father's Education			**0.301***
Bachelor	7 (9)	9 (10)	
Diploma	18 (24)	13 (16)	
Senior High	29 (39)	25 (31)	
Junior High	12 (16)	22 (27)	
Elementary	4 (5)	9 (11)	
Uncompleted	4 (5)	3 (4)	
Total	**74 (100)**	**81 (100)**	

Variable	Intervention n (%)	Control n (%)	χ² p-value
Mother's Education			
Bachelor	6 (8)	6 (7)	
Diploma	5 (7)	11 (14)	
Senior High	28 (38)	18 (22)	
Junior High	21 (28)	27 (34)	
Elementary	10 (13)	15 (19)	
Uncompleted	4 (5)	4 (5)	**0.319***
Total	**74 (100)**	**81 (100)**	
Financial Condition			
High	40 (54)	44 (54)	
Medium	20 (27)	13 (16)	
Low	14 (19)	24 (30)	**0.135***
Total	**74 (100)**	**81 (100)**	
Admission Pathway			
National Selection for State Universities (SNMPTN)	20 (27)	15 (17)	
Joint Entrance Selection for State Universities (SBMPTN)	37 (50)	47 (59)	**0.427***
Independent Admission	17 (23)	19 (24)	
Total	**74 (100)**	**81 (100)**	
Grade Pay Allowance (GPA)			
> 3.50	28 (38)	33 (41)	**0.932***
3.01 – 3.50	30 (40)	31 (39)	
2.76 – 3.00	16 (22)	17 (20)	
Total	**74 (100)**	**81 (100)**	

Note: All baseline characteristics were compared using chi-square tests; no significant differences were found between groups (all $p > 0.05$).

The analysis presented in Table 2 demonstrates that the AR intervention produced meaningful improvements in both knowledge and motivation. Within the intervention group, students' knowledge levels increased significantly from pretest to posttest, with the proportion of participants in the high knowledge category rising from 76% to 86%. This change was supported by a significant Wilcoxon test result ($Z = -3.238$, $p = 0.001$) and a moderate-to-large effect size ($r = 0.38$), indicating that the AR-based learning meaningfully enhanced students' understanding. In contrast, the control group showed no significant improvement, with stable category distributions and a non-significant Wilcoxon result ($p = 0.313$). A similar pattern emerged for motivation: the intervention group demonstrated a significant increase in high motivation levels (from 18% to 35%) with a small-to-moderate effect size (r = 0.27), whereas the control group exhibited only minor, non-significant changes.

Table 2. Knowledge and Motivation Levels and Wilcoxon Test Results with Effect Size (n = 155)

Variable	Category Level	High n (%)	Middle n (%)	Low n (%)	Z Score	p-value	Effect Size (r)
Knowledge							
Intervention	Pretest	56 (76)	16 (22)	2 (3)			
	Posttest	64 (86)	8 (11)	2 (3)	−3.238	0.001	**0.38**
Control	Pretest	59 (73)	20 (25)	2 (2)			
	Posttest	58 (72)	21 (26)	2 (2)	−1.009	0.313	**0.11**
Motivation							
Intervention	Pretest	13 (18)	55 (77)	6 (4)			
	Posttest	26 (35)	44 (60)	4 (5)	−2.290	0.022	**0.27**
Control	Pretest	25 (31)	51 (63)	5 (6)			
	Posttest	32 (40)	46 (56)	3 (4)	−1.217	0.223	**0.13**

Note: The Wilcoxon Signed-Rank Test was used to assess within-group differences between pretest and posttest scores. Effect size (r) was calculated as $r = Z / \sqrt{N}$, where values of 0.1, 0.3, and 0.5 correspond to small, medium, and large effects, respectively.

Between-group comparisons (Table 3) further confirmed the superior impact of AR. Posttest knowledge levels differed significantly between the intervention and control groups (p = 0.005), with the intervention group having a higher proportion of students in the high knowledge category and a small-to-moderate effect size (r = 0.22). However, motivation did not differ significantly between groups at the posttest (p = 0.484), despite within-group gains in the intervention group. Overall, these findings suggest that AR learning effectively enhances knowledge and moderately improves motivation, outperforming traditional instruction, particularly in cognitive outcomes.

Table 3. Between-Group Differences (Mann–Whitney) with Effect Size (n = 155)

Variable	Group	High n (%)	Middle n (%)	Low n (%)	p-value	Effect Size (r)
Knowledge (Posttest)	Intervention	64 (86)	8 (11)	2 (3)	0.005	0.22
	Control	58 (72)	21 (26)	2 (2)		
Motivation (Posttest)	Intervention	26 (35)	44 (60)	4 (5)	0.484	0.06
	Control	32 (40)	46 (56)	3 (4)		

Note: Mann–Whitney U Test was applied to compare posttest scores between the intervention and control groups. Effect size (r) was computed using $r = Z / \sqrt{N}$, with higher values indicating stronger group differences.

DISCUSSION

The use of AR-based learning for open fracture management demonstrated meaningful contributions to enhancing both knowledge and motivation among nursing students. The 3D simulation features provided by AR enabled richer visual processing, which strengthens cognitive functions associated with the encoding and retrieval of clinical information (Moro et al., 2021). Visual sensory integration plays a central role in supporting working memory and facilitating long-term retention (Esplendori et al., 2022). Since attention is highly susceptible to distraction, high-quality visual stimuli are crucial in supporting optimal learning outcomes (Castelhano & Krzyś, 2020; Gloede & Gregg, 2019). Repeated exposure to content and increased interest in learning materials further reinforce knowledge retention (Emad-ul-Haq et al., 2019; Alsayed et al., 2021).

AR also enhances the learning experience by making it more interactive and engaging, thereby increasing student participation throughout the session (Chen et al., 2020). Realistic 3D simulations enable students to better understand complex procedural concepts, improving conceptual clarity (Chew et al., 2024; Wu et al., 2020). Nevertheless, AR effectiveness depends heavily on the quality of 3D objects and stability of the learning environment.

Low-fidelity models may reduce engagement and diminish AR's motivational potential (Amores-Valencia et al., 2023). The intrinsic motivation observed among students aligns with motivation theory, which highlights how innovative and interactive learning formats promote curiosity and enjoyment (Ryan & Deci, 2000). AR further supports self-efficacy by allowing students to actively explore procedures, thereby increasing confidence in mastering skills (Cai et al., 2019).

Conversely, the control group—who learned without AR—showed lower improvement in knowledge, which may affect their readiness to manage open fractures effectively. Knowledge plays a critical role in shaping clinical attitudes and behaviors (Shakeri et al., 2018), and inadequate understanding may lead to suboptimal first aid responses (Kelly et al., 2019). Competent first aid practice is essential to prevent complications in open fracture cases (Ebi et al., 2019). AR supports learning through cognitive load optimization, reducing unnecessary mental burden and improving information flow within working memory (Buchner et al., 2022; Elford et al., 2022). By presenting spatial visualizations, AR strengthens long-term memory encoding and aids in procedural learning (Favila et al., 2022).

Although AR significantly improved knowledge, its effect on motivation was not statistically superior to traditional learning methods. This aligns with literature suggesting that motivation is influenced by various factors, including instructional dynamics, environmental conditions, and students' readiness to adopt new media (Elumalai et al., 2024; Tsai, 2025). Based on Keller's ARCS model, motivation depends on attention, relevance, confidence, and satisfaction, indicating that AR's impact varies depending on how well it aligns with student needs (Chang, 2021; Low et al., 2022). The short intervention duration in this study may have limited AR's capacity to produce measurable changes in motivation (Herwin et al., 2023; Prasetya et al., 2024). Additionally, some students may still prefer conventional learning formats, while others benefit more from technology-enhanced learning (Lai & Chang, 2021; Silva et al., 2023).

Despite the non-significant findings in motivation differences, AR remains a valuable pedagogical tool that enriches engagement and deepens understanding of complex clinical concepts such as open fractures (Weeks et al., 2021). Future studies should explore longer intervention periods, higher-quality AR content, and multiplatform application development. Integrating AR with laboratory practice, peer discussion, or simulation-based instruction may further maximize its impact in nursing education.

Practical implications for Indonesian nursing education include strengthening digital learning competencies among students, expanding access to low-cost simulation technologies, and supporting the national agenda for improving emergency and trauma care skills among health workers. AR-based modules can serve as supplemental learning tools in universities with limited laboratory resources, particularly in remote or resource-constrained settings.

The limitations of this study include the short intervention duration, the use of an Android-only AR application, and the need for refinement of certain anatomical and fracture-detail components within the AR model. These limitations suggest the need for cross-platform development, richer visual fidelity, and longer learning exposure in future research.

CONCLUSION

This study concludes that Augmented Reality–based learning effectively enhances nursing students' knowledge of open fracture management, producing significantly greater cognitive gains than traditional methods, while its impact on motivation did not significantly differ between groups. AR's immersive 3D visualization supports deeper understanding, better retention, and more engaging learning experiences, indicating its strong potential as a supplemental tool in nursing education, particularly for complex clinical topics and in resource-limited settings.

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