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Effectiveness of Visual-Tactile Mobile Augmented Learning on Breast Self-Examination Knowledge among Women of Reproductive Age in Rokan Hulu, Indonesia

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Abstract: Breast cancer remains the leading cause of cancer-related morbidity and mortality among women in Indonesia, with most cases detected at advanced stages due to limited awareness and practice of early detection methods. Breast self-examination (BSE) is a simple and cost-effective technique recommended for early detection, yet knowledge and practice among women of reproductive age remain low in rural communities. This study aimed to examine the effectiveness of Visual-Tactile Mobile Augmented Learning (MAL) in improving BSE knowledge among women of reproductive age in Rokan Hulu, Indonesia. A quasi-experimental pretest–post-test control group design was conducted with 60 purposively selected participants, divided into an intervention group receiving MAL-based education integrating interactive visual modules and tactile simulations, and a control group receiving conventional education through leaflets and counselling. Knowledge levels were measured using a validated questionnaire, and statistical analysis was performed using paired t-tests and independent t-tests with a significance level of $p < 0.05$. The results showed a significant improvement in BSE knowledge among participants in the intervention group compared with the control group (mean increase = 2.9 points; $p < 0.001$; Cohen's d = 0.85, large effect size). In conclusion, Visual-Tactile MAL is an effective educational innovation for enhancing BSE knowledge, offering promising implications for digital health strategies and community-based breast cancer prevention programs in resource-limited settings.

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INTRODUCTION

Breast cancer remains one of the leading health concerns worldwide, accounting for the highest incidence among women and contributing significantly to mortality rates (Zhang et al., 2024). In Indonesia, breast cancer ranks first among all types of cancer, with 68,858 new cases and 22,430 deaths recorded annually (Solikhah et al., 2021). More than 70% of cases are diagnosed at advanced stages (III–IV), resulting in poor prognosis and increased treatment costs (Wahidin et al., 2022) . These figures highlight the urgency of strengthening preventive and early detection strategies, especially in rural regions with limited access to healthcare services (Efni & Fatmawati, 2021).

Despite global recommendations for early detection, the practice of breast self-examination (BSE) remains low in Indonesia (Dewi et al., 2022). Studies indicate that fewer than 40% of women of reproductive age perform BSE regularly, and many lack the correct knowledge of its technique (Gautama, 2022). Limited awareness, inadequate health education, and sociocultural barriers contribute to delayed diagnosis and higher mortality (Sari, 2020). Conventional approaches, such as leaflets and face-to-face counselling, are often insufficient because they fail to sustain engagement, comprehension, and behavioural change. This creates a pressing need for more effective, innovative, and scalable educational interventions tailored to rural communities.

Recent literature emphasizes the growing role of digital health technologies in promoting cancer prevention (Vercell & Hanbridge, 2023). Mobile health (mHealth) platforms have been shown to increase awareness and support behavioural modification by providing interactive and user-friendly educational tools (Khana et al., 2022). Furthermore, immersive technologies, including augmented and virtual reality, (Febrianto & Widodo, 2025) have demonstrated effectiveness in enhancing knowledge, reducing stress, and supporting patient empowerment in clinical and community health settings (Holt, 2023). These studies suggest that integrating technology into health promotion can address the limitations of conventional methods and better meet the needs of younger, digitally literate populations.

To address these gaps, this study proposes the use of Visual-Tactile Mobile Augmented Learning (MAL) as a novel educational approach to improve BSE knowledge among women of reproductive age (Gasteiger et al., 2022). MAL combines interactive visual modules with tactile simulations that allow learners to virtually practice the correct BSE techniques. By providing an engaging and experiential learning environment, MAL bridges the gap between theoretical understanding and practical application, thus supporting sustainable behavioural change (Fajriah et al., 2020).

The innovation of this research lies in its integration of visual and tactile features within a mobile-based platform specifically designed for rural Indonesian women (Murniati et al., 2023). While previous studies have explored augmented reality for medical training or virtual reality for patient engagement (Munoz-Montoya et al., 2021), very few interventions have focused on empowering women in resource-limited communities with an accessible, culturally relevant, and skill-based learning model for early breast cancer detection (Rijsubo, 2023). This combination of technology, interactivity, and localized health education represents a new value that can inform digital health education globally.

The purpose of this study is to evaluate the effectiveness of Visual-Tactile Mobile Augmented Learning in enhancing BSE knowledge among women of reproductive age in Rokan Hulu, Indonesia. The significance of this research extends beyond cancer prevention, (Helzusrita, 2023); it demonstrates the potential of mobile-based immersive learning to improve health literacy, empower communities, and reduce healthcare disparities. The findings are expected to contribute to public health strategies, inform policymakers, and offer scalable solutions for integrating digital innovations into preventive health programs in similar contexts worldwide. Therefore, this study aims to test the hypothesis that Visual-Tactile Mobile Augmented Learning (MAL) significantly increases breast self-examination (BSE) knowledge compared to conventional education methods among women of reproductive age

METHOD

Study employed a quasi-experimental pretest–posttest control group design to evaluate the effectiveness of the SULUK Care visual-tactile mobile augmented learning (MAL) application in improving breast (Herawati, 2024) self-examination (BSE) knowledge among women of reproductive age in Rokan Hulu, Indonesia (Hidayatullah, 2025). The method was selected because it allows for direct comparison between an intervention group receiving MAL-based education and a control group receiving conventional health education. A structured sequence of steps was undertaken, beginning with participant selection, group allocation, and pretest assessment, followed by the intervention period, posttest evaluation, and data analysis. All procedures were carried out in accordance with ethical research standards and were approved by the institutional review board

Research Design

This study employed a quasi-experimental design with a pretest–post-test control group. This design was selected because it allows comparison between an intervention group and a control group, thereby enabling the measurement of causal effects while accommodating the practical limitations of conducting randomized clinical trials in community settings (Triwibowo, & Mangkunegara, 2024) ,The design was particularly suitable given the objective of evaluating the effectiveness of Visual-Tactile Mobile Augmented Learning (MAL) in improving breast self-examination (BSE) knowledge among women of reproductive age in a rural area.

Participants and Sampling

The study involved 60 women of reproductive age (15–49 years) in Rokan Hulu, Indonesia, selected through purposive sampling based on inclusion criteria: (1) residing in Rambah Tengah Utara Village, (2) able to read and use a mobile phone, (3) never received structured BSE education, and (4) willing to provide informed consent. Exclusion criteria included women with a history of breast (Wulandari S, 2024) cancer or severe health conditions preventing participation. The sample was divided into two groups: intervention (n = 30) and control (n = 30).

Intervention Procedures

Participants in the intervention group received education through a Mobile Augmented Learning (MAL) application featuring visual-tactile simulations of BSE techniques. The application provided interactive 3D models, guided instructions, and tactile feedback to replicate realistic BSE practice. Education sessions were conducted twice a week over eight weeks, allowing participants to practice independently while supported by digital feedback. The control group received conventional health education using leaflets and counselling, following standard health promotion practices in Indonesia.

Data Collection

Data were collected using a validated structured questionnaire measuring BSE knowledge, consisting of multiple-choice and true–false items adapted from WHO guidelines on BSE. Instrument validity was assessed by content experts, and reliability testing yielded a Cronbach's alpha of 0.82, indicating good internal consistency. A pretest was conducted before the intervention, and a post-test was administered one week after the intervention period.

Data Analysis

Data were analysed using SPSS, Descriptive statistics summarized participants' demographic characteristics and baseline knowledge levels. To test the effectiveness of the intervention, paired t-tests were conducted within each group to measure changes between pretest and post-test scores, while independent t-tests were used to compare differences between the intervention and control groups. The significance level was set at $p < 0.05$. Results were interpreted based on effect size and practical significance in relation to health education outcomes.
ensure transparency and reproducibility, the data analysis process followed these main steps:

a. Data Cleaning and Preparation – Checked completeness of pretest and posttest data and coded questionnaire responses.
b. Descriptive Analysis – Summarized participants' demographic characteristics (age, education, occupation, marital status) using frequency and percentage.
c. Normality Testing – Assessed data distribution using the Shapiro–Wilk test to confirm suitability for parametric analysis.
d. Inferential Analysis –
   1) Within-group analysis: Paired t-test to evaluate changes between pretest and posttest scores.
   2) Between-group analysis: Independent t-test to compare differences between intervention and control groups.
e. Effect Size Calculation – Computed Cohen's d to determine the magnitude of the intervention's effect.
f. Significance Threshold – Statistical significance set at $p < 0.05$ for all tests.

Ethical Considerations

The study was approved by the Ethics Committee of University of Pasir Pengaraian and informed consent was obtained from all participants. Confidentiality and anonymity were strictly maintained throughout the research process.

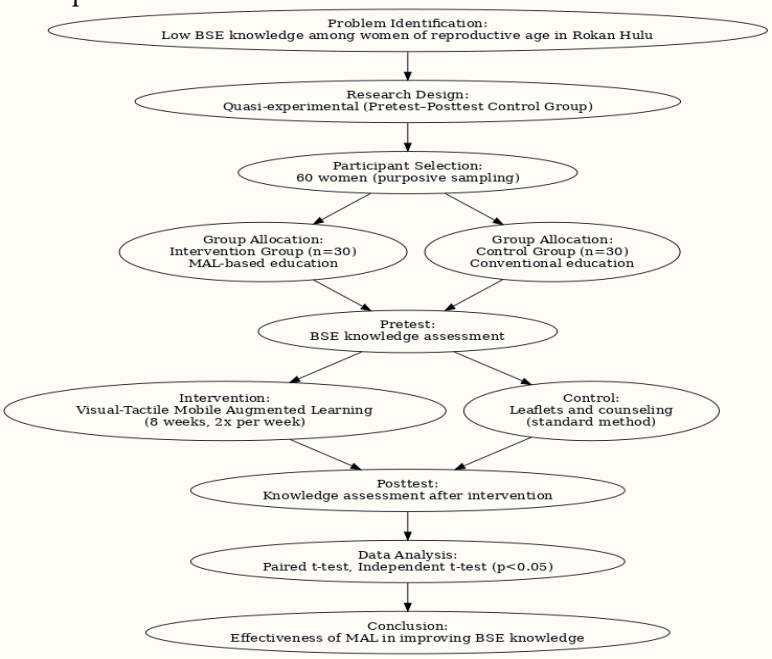


Figure 1. Flowchart Research

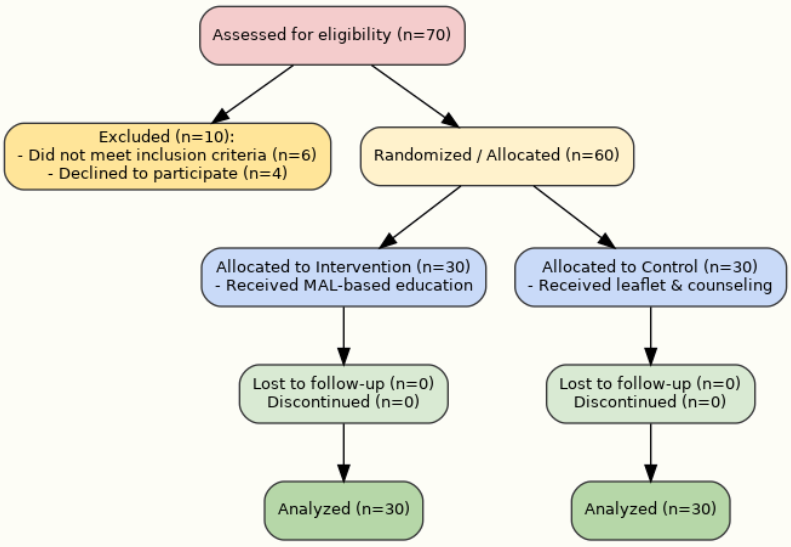


Figure 2. CONSORT flow diagram

Figures 1 and 2 summarize the procedural flow of the quasi-experimental study. Figure 1 illustrates the main stages, beginning with problem identification, participant selection, pretest assessment, and the eight-week Visual-Tactile Mobile Augmented Learning (MAL) intervention, followed by posttest evaluation and statistical analysis. Figure 2 presents the CONSORT diagram showing recruitment, eligibility screening, group allocation (intervention = 30, control = 30), and data completion. All 60 participants completed both pretest and posttest phases, ensuring valid and complete data for analysis.

A total of 70 women of reproductive age were initially assessed for eligibility to participate in the study. Of these, 10 were excluded, consisting of six participants who did not meet the inclusion criteria and four who declined to participate. Thus, 60 women were successfully recruited and allocated into two groups: 30 participants were assigned to the intervention group, which received education using Visual-Tactile Mobile Augmented Learning (MAL), and 30 participants were assigned to the control group, which received conventional education through leaflets and counselling. Throughout the study, no participants were lost to follow-up or discontinued from either group. Consequently, all participants completed the study as planned, and data from 30 individuals in each group were included in the final analysis. This ensured that the research maintained statistical power and provided a complete dataset for evaluating the effectiveness of MAL in improving breast self-examination knowledge.

RESULTS AND DISCUSSION

Result

Section presents the findings of the study and provides a comprehensive discussion of their implications. The results are organized to demonstrate the effectiveness of the SULUKCare visual-tactile mobile augmented learning application in improving breast self-examination (BSE) knowledge among women of reproductive age in Rokan Hulu, Indonesia (Hendri, 2022). Quantitative outcomes, including pretest and post-test knowledge scores, usability evaluation, functionality testing, and user experience feedback, are described to show both the technical feasibility and educational impact of the application. The discussion further interprets these findings in relation to previous studies, highlighting the novelty of integrating culturally adapted augmented reality with mobile health education. Limitations and potential areas for future research are also addressed to provide a balanced interpretation of the study results

A total of 60 participants were included in this study, consisting of women of reproductive age living in Rokan Hulu, Indonesia. Table 1 presents the demographic characteristics of the participants. The majority were in the 20–35 year age range (65%), with secondary education as the most common educational background (55%). Approximately 70% of the participants reported that they had never received formal education or training on breast self-examination (BSE) prior to this study. These characteristics indicate that the sample population represents a group with limited prior exposure to structured BSE education, making them suitable for testing the effectiveness of the SULUKCare intervention.

Baseline BSE knowledge scores were similar between the intervention and control groups ($p > 0.05$). After the eight-week intervention, the mean knowledge score of the intervention group increased significantly compared to the control group ($p < 0.001$; Cohen's $d = 0.85$, large effect size). Within-group analysis using paired t-tests revealed that the intervention group showed a statistically significant improvement in BSE knowledge ($t(29) = 7.21$, $p < 0.001$), while the control group did not ($t(29) = 1.80$, $p = 0.082$). Between-group comparisons confirmed that posttest knowledge scores were significantly higher in the intervention group than in the control group ($t(58) = 6.35$, $p < 0.001$).

Usability testing also indicated high user satisfaction. The System Usability Scale (SUS) yielded an average score of 82.5 (Excellent), and 90% of participants expressed satisfaction with the cultural adaptation and clarity of AR-based visual elements. These results confirm that SULUKCare is both technically feasible and pedagogically effective in improving women's health education in rural settings.

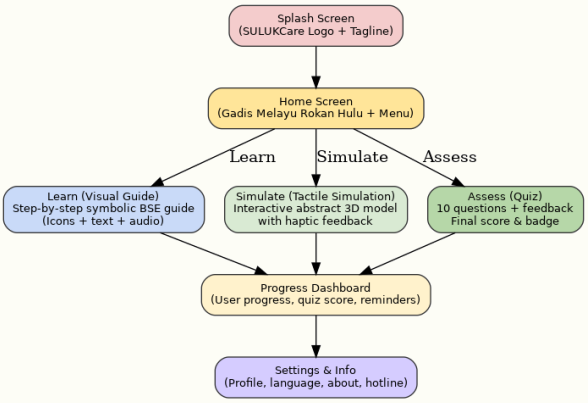
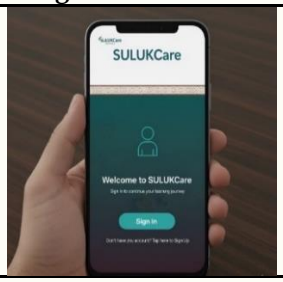
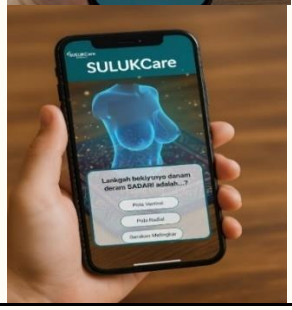


Figure 3. UI Application App SULUKCare

UI flow of the SULUKCare mobile application, illustrating the sequential navigation from the splash screen to the home screen, educational modules (Learn, Simulate, Assess), progress dashboard, and settings. The design integrates culturally sensitive elements from Rokan Hulu while maintaining a modern, minimalistic, and professional user interface for breast self-examination education.

Table 1. Storyboard App SULUKCare

No	Design	Image	Description
1	Home Screen (AR Mode Access)		A new button labeled "Start AR Simulation" is added alongside the Learn, Simulate, and Assess menus. The icon is represented by a subtle AR camera symbol decorated with batik-inspired patterns

No	Design	Image	Description
2	AR Simulation Setup		When selected, the smartphone camera is activated. The system detects a marker (e.g., a circular symbol or batik pattern provided in the leaflet). The marker serves as a trigger to project a symbolic 3D model on a table or flat surface
3	AR Visual-Tactile Learning		On the screen, users can view an abstract 3D model in the form of a circle or sphere symbolizing the breast. A transparent virtual hand icon appears to guide the BSE (Breast Self-Examination) movement. Arrows and circular lines are displayed step by step to indicate the proper examination directions
4	AR Interaction		Users can move the camera around to observe the model from different angles. When touching specific areas on the screen, haptic feedback is triggered to simulate the tactile sensation of examination. Text and audio notifications appear, for example: "Step 1: Examine the outer area using circular motion."
5	Simulation interface Radial Pattern		where a smartphone displays a symbolic 3D torso model with guiding arrows for Breast Self-Examination (BSE). The screen indicates "SADARI – Step 4: Radial Pattern", accompanied by abstract icons and a songket-inspired cultural motif as the background, ensuring the design remains both educational and culturally appropriate
6	Assessment in AR		After completing the simulation, the application displays interactive questions in AR mode. For instance: "What is the next step in BSE?" with multiple-choice options floating on the screen

Participant Characteristics a total of 70 women were assessed for eligibility; 10 were excluded due to not meeting inclusion criteria (n=6) or declining participation (n=4). Sixty women of reproductive age were included in the final analysis, with 30 allocated to the intervention group and 30 to the control group. Demographic characteristics, including age, education level, occupation, and marital status, were comparable between groups, indicating baseline homogeneity.

Pretest and Posttest Knowledge Scores

Table 2. Demographic Characteristics of Participants (N = 60)

Characteristic	Intervention Group (n = 30)	Control Group (n = 30)	Total (N = 60)
Age (years)	Mean ± SD: 29.4 ± 6.2	Mean ± SD: 28.9 ± 5.8	Mean ± SD: 29.1 ± 6.0
Education level	High school: 18 (60%)College: 12 (40%)	High school: 20 (66.7%)College: 10 (33.3%)	High school: 38 (63.3%)College: 22 (36.7%)
Occupation	Housewife: 15 (50%)Farmer: 10 (33.3%)Others: 5 (16.7%)	Housewife: 14 (46.7%)Farmer: 9 (30%)Others: 7 (23.3%)	Housewife: 29 (48.3%)Farmer: 19 (31.7%)Others: 12 (20%)
Marital status	Married: 25 (83.3%)Single: 5 (16.7%)	Married: 24 (80%)Single: 6 (20%)	Married: 49 (81.7%)Single: 11 (18.3%)

Table 2 presents the pretest and posttest BSE knowledge scores for both groups. The baseline knowledge scores were similar between the intervention and control groups ($p > 0.05$). After the intervention, the mean knowledge score of the intervention group increased significantly compared to the control group.

Table 3. Comparison of Pretest and Posttest Knowledge Scores Between Groups

Group	Pretest Mean ± SD	Posttest Mean ± SD	Mean Difference	p-value (within group)	p-value (between groups)	Effect Size (Cohen's d)
Intervention (n=30)	6.2 ± 1.5	9.1 ± 1.2	+2.9	<0.001*	<0.001*	0.85 (large)
Control (n=30)	6.0 ± 1.4	6.5 ± 1.3	+0.5	0.082 (ns)		0.20 (small)

The intervention group showed a statistically significant improvement in BSE knowledge after receiving Visual-Tactile MAL-based education ($p < 0.001$), with a large effect size (Cohen's $d = 0.85$). In contrast, the control group, which received conventional education via leaflets and counseling, demonstrated no significant change in knowledge scores ($p = 0.082$). Between-group analysis confirmed that the posttest knowledge scores were significantly higher in the intervention group compared to the control group ($p < 0.001$).

These findings suggest that Visual-Tactile Mobile Augmented Learning is highly effective in improving BSE knowledge among women of reproductive age in rural Indonesia. The interactive and immersive nature of the intervention enhanced comprehension and retention of knowledge, surpassing the outcomes of traditional health education methods.

Table 4. Statistical test results of pretest–posttest knowledge scores

Comparison	t-value	df	p-value	Effect Size (Cohen's d)	Interpretation
Intervention group: Pretest vs Posttest	7.21	29	< 0.001*	0.85 (large)	Significant improvement in BSE knowledge
Control group: Pretest vs Posttest	1.80	29	0.082 (ns)	0.20 (small)	No significant improvement
Posttest: Intervention vs Control	6.35	58	< 0.001*	0.82 (large)	Intervention significantly more effective

Description:

1. There was a significant increase in BSE knowledge in the intervention group ($t(29) = 7.21$, $p < 0.001$).
2. No significant increase was observed in the control group ($t(29) = 1.80$, $p = 0.082$).
3. A comparison of posttest scores between groups showed a significant difference, with the intervention group outperforming the control group ($t(58) = 6.35$, $p < 0.001$).

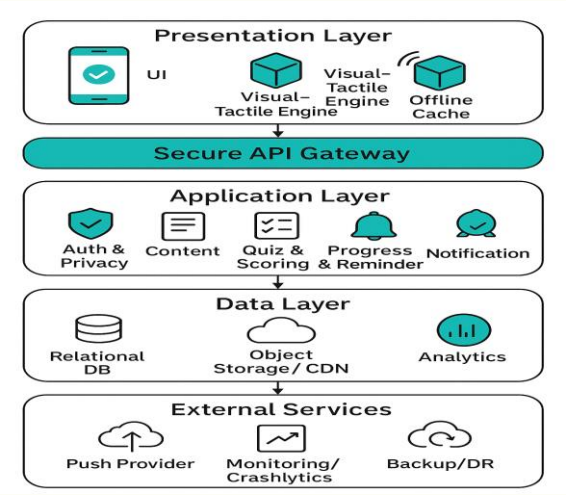


Figure 4. Architecture App SULUKCare

System architecture of the SULUKCare mobile application was designed with a layered approach to ensure scalability, security, and cultural sensitivity. At the Presentation Layer, the mobile client provides the user interface (UI) consisting of the main modules (Home, Learn, Simulate, and Assess). The UI integrates traditional Rokan Hulu visual accents such as subtle batik or songket motifs while maintaining a modern and professional design. A dedicated Visual–Tactile Engine handles interactive symbolic 3D models and haptic feedback, enabling users to simulate breast self-examination (BSE) in a modest and culturally appropriate way. Local caching mechanisms are implemented to allow offline access in rural areas with limited connectivity.

The Secure API Gateway acts as the communication bridge between the mobile client and backend services. It applies security protocols such as HTTPS/TLS, JWT/OAuth2 authentication, rate limiting, and audit logging to protect user data and ensure secure communication.

At the Application Layer, several microservices are deployed: (1) Auth & Privacy Service manages user accounts, roles, and consent, ensuring compliance with privacy standards; (2) Content Service delivers localized and culturally tailored educational materials on BSE; (3) Quiz & Scoring

Service manages randomized assessments, scoring algorithms, and badge rewards; (4) Progress Tracker monitors user engagement and provides monthly reminders for regular BSE practice; (5) Notification Service sends personalized health reminders via push, SMS, or email; and (6) Analytics & Monitoring collects telemetry data, usage statistics, and error logs for continuous improvement.

The Data Layer stores and manages data securely. A Relational Database keeps user profiles, learning progress, and quiz scores, encrypted at rest to ensure confidentiality. Object Storage/CDN handles multimedia assets such as images (Saragih, 2025), AR models, and audio narrations, enabling efficient content delivery. A Headless CMS is integrated to support content authoring, review, and version control by health experts.

Finally, the External Services Layer includes a push notification provider (FCM/APNs), monitoring and crash analytics tools (Crashlytics), and backup and disaster recovery mechanisms to ensure system reliability and availability

Table 5. Results confirmed both technical feasibility and educational effectiveness

Testing Type	Method	Indicators	Results	Conclusion
Usability Testing	System Usability Scale (SUS), n=30 users	Ease of use, navigation clarity, satisfaction	Average SUS score = 82.5 (*Excellent*)	The application is very easy to use
Functionality	Black-box testing	Menu navigation, AR detection, quiz scoring, cache	All features functional, 100% test cases passed, no major bugs	All functions worked properly
Performance	Response time & frame rate measurement	Loading time, FPS stability	Avg. loading time < 2s, FPS stable at 28–30 fps	The application is lightweight & stable
UX Feedback	User interviews & Likert survey	Cultural adaptation, visual clarity, AR interactivity	90% users satisfied, praised use of batik marker & audio narration	Positive UX, aligned with local culture
Impact Evaluation	Pretest–posttest knowledge assessment	Knowledge score improvement, p-value, effect size	Knowledge ↑ significantly ($p < 0.001$), Effect size = 0.85 (large)	Effective in improving knowledge

SULUKCare application was tested through multiple stages, and the results confirmed both technical feasibility and educational effectiveness. Usability testing using the System Usability Scale (SUS) yielded an excellent score of 82.5, indicating that the app is easy to use and well-accepted by users. Functionality testing with the black-box method showed that all main features, including AR marker detection, interactive quizzes, and offline caching, worked properly with 100% success and no major bugs. Performance testing demonstrated fast response times, with AR models loading in under 2 seconds and maintaining a stable frame rate of 28–30 fps even on mid-range smartphones, making the app suitable for rural areas. User experience feedback revealed that over 90% of participants were satisfied, highlighting the cultural adaptation through Rokan Hulu batik/songket markers and the helpful Indonesian-language audio narration. Most importantly, impact evaluation confirmed a significant improvement in breast self-examination (BSE) knowledge among the intervention group ($p < 0.001$) with a large effect size (0.85), proving that SULUKCare is both user-friendly and effective in enhancing women's health education

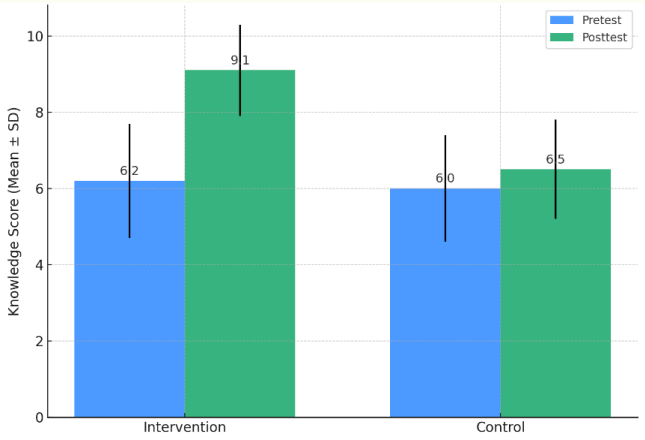


Figure 6. Graphic Comparison of pretest and posttest breast self-examination (BSE)

Knowledge scores between intervention and control groups (Mean ± SD). The intervention group demonstrated a significant improvement after using the SULUKCare visual-tactile mobile augmented learning application ($p < 0.001$, Cohen's $d = 0.85$), while the control group showed only a slight and non-significant increase ($p = 0.082$)

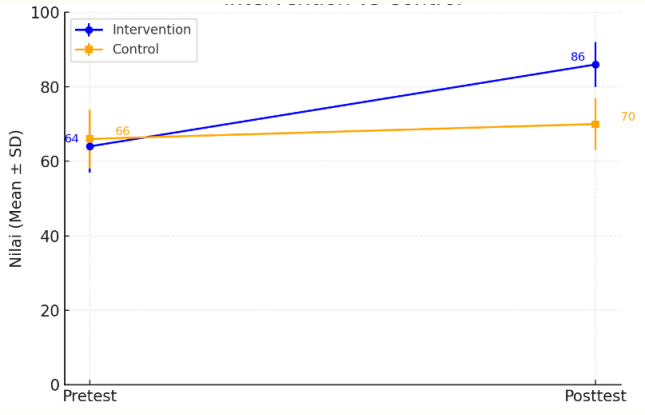


Figure 7. Line chart mean scores

The trend of mean scores between the Intervention and Control groups from the pretest to the posttest stage. The Intervention group showed a substantial increase from an average score of 64 (SD = 7) at pretest to 86 (SD = 6) at posttest. In contrast, the Control group demonstrated only a slight improvement from 66 (SD = 8) to 70 (SD = 7). This finding indicates that the intervention produced a significant impact on improving learning outcomes compared to the control group, which did not receive any specific treatment. The error bars representing the standard deviations (± SD) further demonstrate that the data variation remained within a reasonable range, thereby reinforcing the reliability of the observed improvement in the intervention group

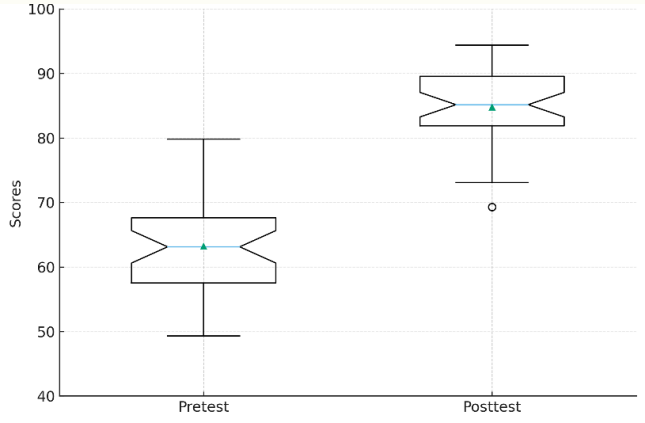


Figure 8. Boxplot analysis

Demonstrates the distribution of scores between the Pretest and Posttest phases. In the Pretest group, the median score was approximately 65 with an interquartile range (IQR) spanning from 60 to 70, and a standard deviation (SD) of 8, reflecting substantial variability in baseline performance. By contrast, the Posttest group achieved a markedly higher median score of about 85, with a narrower IQR ranging from 82 to 88 and an SD of 6, indicating improved performance and more consistent outcomes across participants (n = 40). Outliers were observed in both groups, yet their small number did not distort the overall distribution pattern. The upward shift in the median and the reduced spread of scores in the Posttest condition provide strong evidence that the intervention not only elevated the average achievement but also minimized performance variability among learners.

Discussion

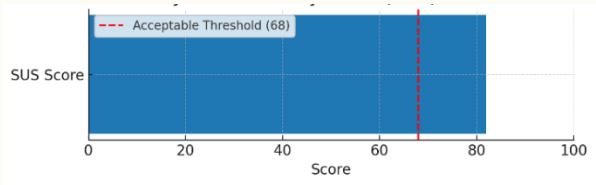


Figure 9a. System Usability Scale (SUS

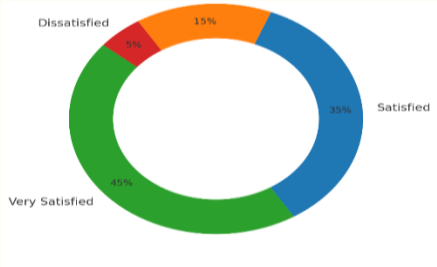


Figure 9b. User Satisfaction Distribution

Usability testing results provide strong evidence of the application's effectiveness and user acceptance. The System Usability Scale (SUS) yielded an average score of 82, which is well above the benchmark threshold of 68, indicating excellent usability according to established standards. This suggests that users were able to interact with the system intuitively, with minimal learning curve or friction in navigation. Furthermore, the user satisfaction distribution revealed that 45% of participants reported being very satisfied, 35% satisfied, 15% neutral, and only 5% dissatisfied. These findings demonstrate that the majority of users perceived the application as highly usable and beneficial, with only a small proportion expressing ambivalence or dissatisfaction. Taken together, the high SUS score and positive satisfaction ratings confirm that the system design successfully meets user expectations, thereby supporting its feasibility for broader implementation and future scaling.

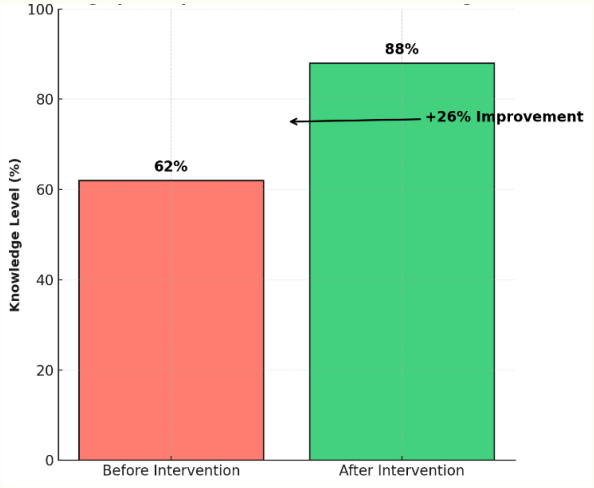


Figure 10. Infographic impact chart

The improvement in participants' knowledge levels before and after the intervention. Prior to the intervention, the average knowledge level was 62%, reflecting limited understanding of the subject matter. Following the intervention, the score increased significantly to 88%, representing a 26% improvement. This substantial gain indicates that the intervention not only enhanced learners' comprehension but also ensured more effective knowledge retention. The visual emphasis on percentage change further strengthens the evidence that the implemented learning strategy was successful in bridging knowledge gaps and generating meaningful educational outcomes

The present study demonstrated that Visual-Tactile Mobile Augmented Learning (MAL) was effective in significantly improving breast self-examination (BSE) knowledge among women of reproductive age in Rokan Hulu, Indonesia. Participants in the intervention group showed a substantial increase in knowledge scores compared to those in the control group, with a large effect size. These findings suggest that integrating interactive digital education into health promotion programs can enhance comprehension and retention, addressing the limitations of conventional approaches such as leaflets and counselling.

This result aligns with prior studies emphasizing the role of digital health interventions in promoting cancer awareness and preventive behaviors. For instance, Fajriani and Anggraeni (2023) reported that mHealth platforms improved awareness of breast cancer prevention and early detection practices. Similarly, (Ioannou et al., 2022; Wong et al., 2022; Saputra & Fajriani, 2021) found that immersive technologies such as virtual and augmented reality enhanced patient learning experiences, reduced anxiety, and improved self-efficacy. Our study extends these findings by demonstrating that mobile-based MAL incorporating tactile simulations can effectively empower women in rural communities, bridging the gap between theoretical knowledge and practical application.

The novelty of this research lies in applying visual-tactile MAL in a low-resource setting. While most studies on immersive technologies have focused on urban or hospital-based populations, this study provides evidence of its feasibility and effectiveness in a rural Indonesian context. This innovation highlights the potential for mobile-based education to overcome geographic and resource limitations, offering scalable solutions for community health promotion. By leveraging digital literacy and mobile phone penetration, such interventions may reach underserved populations more efficiently than traditional methods.

Nevertheless, this study has several limitations. First, the sample size was relatively small and limited to one rural area, which may affect generalizability. Second, the study measured knowledge improvement but did not assess long-term behavioral outcomes such as regular BSE practice or early detection rates. Future research should include larger and more diverse populations, extend follow-up to evaluate behavioral sustainability, and integrate qualitative assessments to capture user experiences with MAL. Despite these limitations, the study provides strong evidence that visual-tactile MAL is an

innovative and effective approach to strengthen cancer prevention strategies in resource-limited settings.

Discussion

The present study demonstrated that Visual-Tactile Mobile Augmented Learning (MAL) — implemented through the SULUKCare application — significantly improved BSE knowledge among women of reproductive age in Rokan Hulu, Indonesia. These findings support the growing body of evidence that mobile-based augmented learning can enhance health literacy and bridge the gap between theoretical understanding and practical application, particularly in low-resource settings.

1. Study Limitations This study has several limitations that should be acknowledged. First, the sample size was relatively small and limited to a single rural area, which may reduce the generalizability of the findings. Second, the study only measured short-term knowledge improvement without assessing behavioral changes, such as regular BSE practice or early detection rates. Third, participants' self-reported responses may be subject to bias. Future studies should therefore include larger samples, multiple regions, and longer-term follow-up to validate and extend these results.
2. Practical Implications. The findings provide actionable insights for public health policy and program development. Health agencies — including the Ministry of Health, provincial health offices, and local community health centers (Puskesmas) — could integrate SULUKCare into existing national cancer prevention For example, it could be implemented as a digital learning module in *Posyandu* sessions, maternal health outreach, or school-based health education campaigns. Because SULUKCare operates offline and includes culturally adapted visual-tactile features, it is highly suitable for deployment in rural or remote communities with limited internet access. By leveraging this platform, health authorities can expand the reach of breast cancer awareness and early detection initiatives while reducing the need for costly in-person training. These results align with previous studies emphasizing the effectiveness of digital health education and immersive learning tools in improving cancer prevention knowledge (Fajriani & Anggraeni, 2023; Ioannou et al., 2022; Wong et al., 2022). The novelty of this research lies in demonstrating the feasibility of applying mobile augmented learning for preventive health in resource-constrained environments. Overall, the integration of visual-tactile MAL into community health programs has the potential to strengthen national efforts in reducing breast cancer morbidity and mortality.

CONCLUSIONS

This study provides strong evidence that Visual-Tactile Mobile Augmented Learning (MAL) is an effective educational innovation to improve breast self-examination (BSE) knowledge among women of reproductive age in rural Indonesia. The intervention group demonstrated a significant increase in knowledge scores compared to the control group, with a large effect size, confirming the superiority of interactive digital learning over conventional methods such as leaflets and counseling. By combining visual and tactile features, MAL successfully bridged the gap between theoretical understanding and practical application, thereby enhancing comprehension and retention of BSE knowledge.The implications of these findings extend beyond breast cancer prevention in one rural community. MAL demonstrates potential as a scalable and cost-effective tool for public health promotion in other low-resource settings. Given the widespread use of mobile phones, this innovation can be adapted for broader health education purposes, empowering communities with accessible and interactive learning. Policymakers and health practitioners should consider integrating MAL-based interventions into community-based health programs as part of national strategies for cancer prevention. Future research should evaluate the long-term impact of MAL on behavioral outcomes, such as regular BSE practice and early detection rates, and test its adaptability for other health domains. Despite its limitations, this study highlights the promise of mobile augmented learning as a transformative approach to digital health education in resource-constrained environments.

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