RESEARCH ARTICLE

Editorial Process: Submission:12/08/2025 Acceptance:07/08/2026 Published:07/27/2026

Augmented Reality-Based Breast Self-Examination Education and Its Effects on Knowledge and Perceived Behavioral Control Among Indonesian Adolescent Girls: A Quasi-Experimental Study

Nur Khasanah*, Anita Liliana, Melania Wahyuningsih, Nurhadi Wijaya Sugiarto

Abstract

Background: Breast cancer is the most common malignancy among women, with an increasing burden among adolescents and young adults. Breast self-examination (BSE) is a simple and low-cost method for early detection; yet, its practice remains suboptimal in this age group. Augmented Reality (AR) is a promising approach to enhancing cancer education. **Objective:** This study aims to rigorously compare the effects of AR-based education and traditional learning on breast self-examination (BSE) knowledge and perceived behavioral control (PBC) among adolescent girls, with the goal of identifying the more effective approach for empowering this population. **Methods:** A quasi-experimental posttest-only non-equivalent control group design was conducted among tenth-grade female students at a public senior high school in Yogyakarta, Indonesia. A total of 140 adolescents were assigned to an intervention group (n = 70) or a control group (n = 70). The intervention group received AR-based BSE education using a three-dimensional mobile application, whereas the control group received lecture-based education with posters and leaflets. Knowledge and PBC were assessed three months after the intervention using validated, self-administered questionnaires, and data were analyzed using appropriate nonparametric tests ($\alpha = 0.05$). **Results:** The AR group demonstrated a substantially higher proportion of participants with high knowledge compared to the control group (71.4% vs. 28.6%; $p < 0.001$, $r = 0.26$), as well as significantly higher total knowledge scores ($p = 0.002$). Participants in the AR group were significantly less likely to perceive BSE as time-consuming, expensive, complex, or embarrassing (all $p < 0.01$). Notably, perceived behavioral control (PBC) increased in the AR group ($p < 0.001$, $r = 0.767$). **Conclusions:** AR-based education was superior to conventional learning, resulting in significant improvements in BSE-related knowledge, substantial reductions in perceived barriers, and a marked increase in perceived behavioral control among adolescent girls.

Keywords: Breast self-examination- augmented reality- cancer education- adolescents- perceived behavioral control

Asian Pac J Cancer Prev, **27 (7)**, 2653-2662

Introduction

Breast cancer is the most common malignancy among women and a leading cause of morbidity and mortality, including in younger age group [1]. According to the World Health Organization, there are approximately 2.3 million new breast cancer cases globally, accounting for 11.6% of all cancer cases, with an estimated 670,000 deaths or 6.9% of all cancer deaths [2]. Almost 45.4% of these cases occur in Asia, with about 985,400 new cases and 315,100 deaths, corresponding to an incidence rate of 34.3 per 100,000 women and a mortality rate of 10.5 per 100,000 [3, 4]. In Indonesia, breast cancer ranks first among cancers affecting women, with an age-standardised incidence rate of 42.1 per 100,000 and a mortality rate of 16.6 per 100,000 [5]. Globally, Indonesia is among the eight countries with the highest number of new breast cancer cases, with approximately 66,271 cases per year [3]. Adolescents and young adults (AYAS, aged 15–39 years) also face a significant cancer burden. In 2022, there were about 1.3 million new cancer cases in this age group worldwide, and breast cancer is one of the most frequently diagnosed cancers [5]. In Southeast Asia, an increasing trend in breast cancer incidence among AYAS has been observed from 1990 to 2021 [6].

Although breast cancer is most prevalent among older women, its incidence is increasing among younger populations [7], underscoring the importance of awareness and early detection strategies such as breast self-examination (BSE) [8, 9]. Despite this, BSE practice remains low due to limited knowledge, low confidence, and psychological barriers [10–12]. Concurrently, psychological factors such as shame, body image concerns, fear, and low self-efficacy have been identified

*Department of Xxxx, Universitas Respati Yogyakarta, Yogyakarta, Indonesia. *For Correspondence: nurkhasanah@respati.ac.id*

as major barriers that discourage women from performing breast self-examinations (BSE), even when the importance of this practice is clearly understood [13]. Therefore, innovative and participatory educational methods are required to improve BSE skills and confidence.

A recent systematic review and meta-analysis conducted in Indonesia revealed that the prevalence of breast self-examination (BSE) is relatively low, at roughly 43–44%, despite typically sufficient levels of awareness [14]. A psychosocial study in Surabaya found that only a small number of women regularly do breast self-examinations (BSE). The researchers said that the low practice rates are due to negative attitudes, embarrassment, and problems with the approach [15]. Similarly, provincial data from the Yogyakarta Health Office in 2023 show very low coverage of clinical breast examination (SADANIS), with proportions of 0.01% in Gunungkidul, 2.75% in Sleman, 6.0% in Bantul, 3% in Yogyakarta City, and 0.03% in Kulon Progo.

Simultaneously, school-based reproductive health and sexuality education in Indonesia is frequently perceived as taboo and sensitive. Numerous educational institutions often eschew comprehensive talks of sexuality or cover the topic just superficially [16]. Topics such as breast health, the female body, and early detection of breast cancer are frequently addressed only briefly within other subjects or non-curricular programmes [17]. Research on the implementation of comprehensive sexuality education in Indonesia also indicates that delivery remains fragmented and faces multiple barriers related to values, religious norms, and social resistance [16]. This situation highlights the need for more creative, engaging, and culturally sensitive educational approaches to effectively reach adolescents.

As digital natives, adolescents tend to learn more effectively through interactive, technology-based approaches, and the use of digital tools can enhance engagement, motivation, and learning outcomes, particularly given the intensive use of the internet, social media, and digital games among this age group [18]. Evidence suggests that the use of Augmented Reality (AR) in health education can improve knowledge, skills, and learning motivation compared with conventional methods [19]. In several health education studies, the use of AR has been consistently linked to better academic performance compared to traditional methods. However, research on the use of AR for BSE education among adolescents remains very limited.

Perceived behavioral control (PBC), as outlined in Ajzen's (1991) Theory of Planned Behaviour, strongly influences intention and health behaviour. In BSE, greater knowledge and PBC are likely to increase women's regular screening. While AR is used in medical education, few studies address its application in BSE education for adolescents, especially its impact on knowledge and PBC. Existing research primarily examines video or face-to-face methods; evidence for AR's effectiveness in improving knowledge, reducing barriers, and boosting PBC among adolescents with BSE remains limited. This study compares AR-based versus conventional BSE education to guide engaging adolescent cancer prevention strategies.

Materials and Methods

AR-based Breast Self-Examination (BSE) Education Module

The researchers developed an Augmented Reality (AR) application as an educational medium for Breast Self-Examination (BSE). The application was an Android-based prototype and was not publicly available on the Google Play Store. It was distributed via direct installation using an Android application package file. The application was developed using Unity 3D and the Vuforia Software Development Kit, employing marker-based tracking due to its stability and widespread use in health education settings. A three-dimensional model of the breast was created in Blender, preserving the main anatomical structures, including the skin, adipose tissue, lobules, and the areola nipple complex, to ensure that the visual representation was informative while remaining lightweight in terms of system resources.

The sequence of palpation was structured according to the World Health Organization's BSE guidelines and the Ministry of Health of the Republic of Indonesia. When the smartphone camera recognized the printed marker, the application overlaid the 3D breast model onto the real-world environment. The interface allowed users to rotate and zoom the model and select different examination stages. At each stage, the system provided step-by-step instructions in both text and audio to support multimodal information processing. The Cognitive Theory of Multimedia Learning informed the overall design to reduce extraneous cognitive load and maintain learners' focus on key educational elements. The display was tested under various lighting conditions to ensure consistent tracking and legibility. The content validity of the AR module was assessed by an expert panel comprising three midwifery lecturers and two educational technology specialists. Using a standardized approach, the panel rated the relevance and clarity of each component, and the overall Content Validity Index (CVI) exceeded 0.80, indicating that the application was suitable for field use. Following content validation, the application did not undergo a separate, standalone usability trial; instead, it was deployed directly during the intervention group's training sessions.

The AR application was installed on Android devices used by participants in the intervention group. A facilitator provided a brief 10-minute orientation on how to operate the application. After this introduction, participants used the AR module for approximately 10 minutes during the supervised school session, with support from the research enumerators and the class teacher. After the school session, participants were instructed to repeat the module independently at home during the three-month follow-up period. The multimodal and interactive nature of the AR experience was intended to enhance engagement and support the transfer of conceptual knowledge into practical BSE skills, consistent with prior findings on AR/VR-based learning in nursing and health professions education (Figure 1).

Study Design

This study employed a quasi-experimental posttest-only non-equivalent control group design to evaluate the effectiveness of an Augmented Reality (AR)–based educational intervention on adolescents' knowledge and perceived behavioral control (PBC) regarding Breast Self-Examination (BSE), compared with conventional education. This design was chosen because complete randomization was not feasible in the school setting, yet it still enabled a rigorous comparison between the intervention and control groups. A posttest-only approach was adopted to minimize potential pretest sensitization and because baseline assessment could not be accommodated within the school schedule. To enhance comparability, both groups were recruited from the same school. The study was conducted at Senior High School 04 Yogyakarta between January and August 2025. The school was selected based on accessibility, the school administration's willingness to collaborate, and the relative homogeneity of student characteristics. Initial coordination meetings were held with school officials to obtain permission and schedule the intervention sessions, ensuring they did not disrupt regular teaching activities. Ethical approval for the study was obtained from the Health Research Ethics Committee of the Faculty of Public Health, with approval number 047.3/FIKES/PL/V/2025.

Population and Sample size

The study population comprised all tenth-grade female students at the selected school (N = 161). The minimum required sample size was calculated using Slovin's formula with a 5% margin of error, yielding a minimum of 115 participants. A sample size calculation based on power analysis was not conducted due to the unavailability of prior estimates required for this calculation, particularly concerning PBC, at the time of study planning. To increase statistical power and make optimal use of the available population, the researchers ultimately recruited 148 students who met the eligibility criteria.

Inclusion criteria were: (1) female students aged 15–19 years; (2) no prior formal training on breast self-examination (BSE); (3) ownership of an Android-based smartphone to access the AR media; and (4) willingness to participate in all stages of the study, indicated by signing an informed consent form after receiving an explanation of the study aims and procedures. Exclusion criteria were: (1) absence during the intervention or questionnaire administration; and (2) the presence of medical or psychological conditions that could interfere with full participation in the study. Sampling was conducted proportionally based on the number of eligible female students in each class, as detailed in Table 1.

Sampling Technique

After determining the proportional sample allocation for each class, 77 students were assigned to the intervention group and 71 to the control group. Within each class, all female students who met the inclusion criteria were assigned a sequential number. These numbers were then randomized using the Research Randomizer web application until the required number of participants for each class was reached, in accordance with the predetermined sampling quota.

Data Collection

Data collection began with coordination and briefing sessions involving school administrators, teachers, and prospective participants. Once institutional permission was granted, enumerators received training to ensure consistency in delivering the intervention and in data collection procedures. The intervention group received AR-based BSE education via an interactive 3D application that visualized breast anatomy and the step-by-step BSE procedure. Each session lasted approximately 45 minutes and began with a brief explanation of the educational

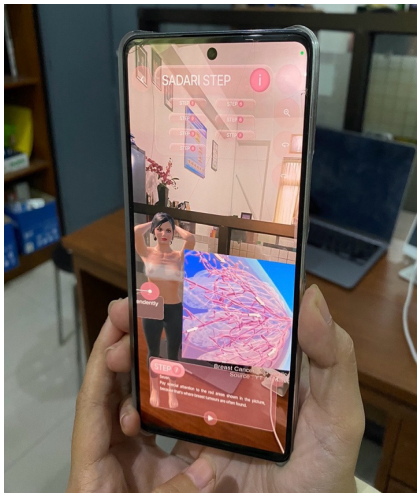

Figure 1. Illustration of the AR-based BSE Module Displaying a 3D breast model with Palpation Guidance and Text–Audio Instructions Overlaid in the Real Environment

Table 1. Sample Distribution by Class Using Proportional Random Sampling (N = 161; n = 148)

Group	Class	Number of Students (N_i)	Calculation $n_i = (N_i/161)\times148$	Sample per Class (n_i rounded)
Intervention	X-1	21	(21/161) × 149 = 19.43	19
	X-2	20	(20/161) × 149 = 18.51	19
	X-3	20	(20/161) × 149 = 18.51	19
	X-4	20	(20/161) × 149 = 18.51	19
Control	X-5	24	(24/161) × 149 = 22.21	22
	X-6	21	(21/161) × 149 = 19.43	19
	X-7	20	(20/161) × 149 = 18.51	19
	X-8	12	(12/161) × 149 = 11.11	11

program's purpose, followed by the facilitator's demonstration of the application. Participants were then given time to explore the application independently, under the enumerators' supervision.

The control group received BSE education through a conventional lecture supported by posters and leaflets containing comparable material. The content, duration, and core educational messages were matched across the two groups, allowing any differences in outcomes to be attributed primarily to the educational medium. Three months after the intervention, follow-up data were collected using an online questionnaire administered via Google Forms. During data cleaning, eight participants were excluded from the analysis due to incomplete or inconsistent responses, including seven from the intervention group and one from the control group. The final analytic sample, therefore, consisted of 140 adolescents, with 70 in the intervention group and 70 in the control group (Figure 2).

Instruments

Based on a review of the literature, two self-administered Indonesian-language questionnaires were used to measure breast cancer and BSE knowledge as well as Perceived Behavioral Control (PBC). The instruments comprised two sections with distinct rating formats. Knowledge was assessed using a dichotomous Agree or Disagree response format, while PBC was assessed using a dichotomous Yes or No response format. The first instrument, which assessed knowledge, consisted of 26 items grouped into five dimensions. The first dimension, breast cancer signs and symptoms, included items on participants' understanding of changes in breast shape, the presence of lumps, abnormal nipple discharge, and skin changes as early warning signs of breast cancer. The second dimension, timing of BSE, evaluated knowledge of the most appropriate time to perform BSE relative to the menstrual cycle and the recommended frequency. The third dimension, benefits of BSE, assessed the understanding of BSE's role in early detection of breast abnormalities and its potential to facilitate timely management. The fourth dimension, follow-up after detecting abnormalities, measured knowledge about appropriate actions when a lump or suspicious symptom is found, such as seeking evaluation at a health facility. The fifth dimension, frequency of BSE, focused on how often BSE should be performed to optimize early breast cancer detection. All items used a dichotomous response format (Agree or Disagree). Correct responses were scored as 2 and incorrect responses as 1, and total knowledge was calculated by summing all items. Because incorrect responses were scored as 1, percentage knowledge was computed using an adjusted transformation that reflects the proportion of correct answers, calculated as total score minus 26 divided by 26 and multiplied by 100. Percentage scores were categorized as high (76 percent or above), moderate (60 to 75 percent), and low (below 60 percent). This categorization follows a modified Bloom-type cut-off commonly used in KAP scoring, with the 76 percent threshold used to avoid overlap at 75 percent [20]. Higher scores indicate better knowledge of breast cancer and breast self-examination. The questionnaire was reviewed by experts in public health and reproductive health, and internal consistency in this study was good

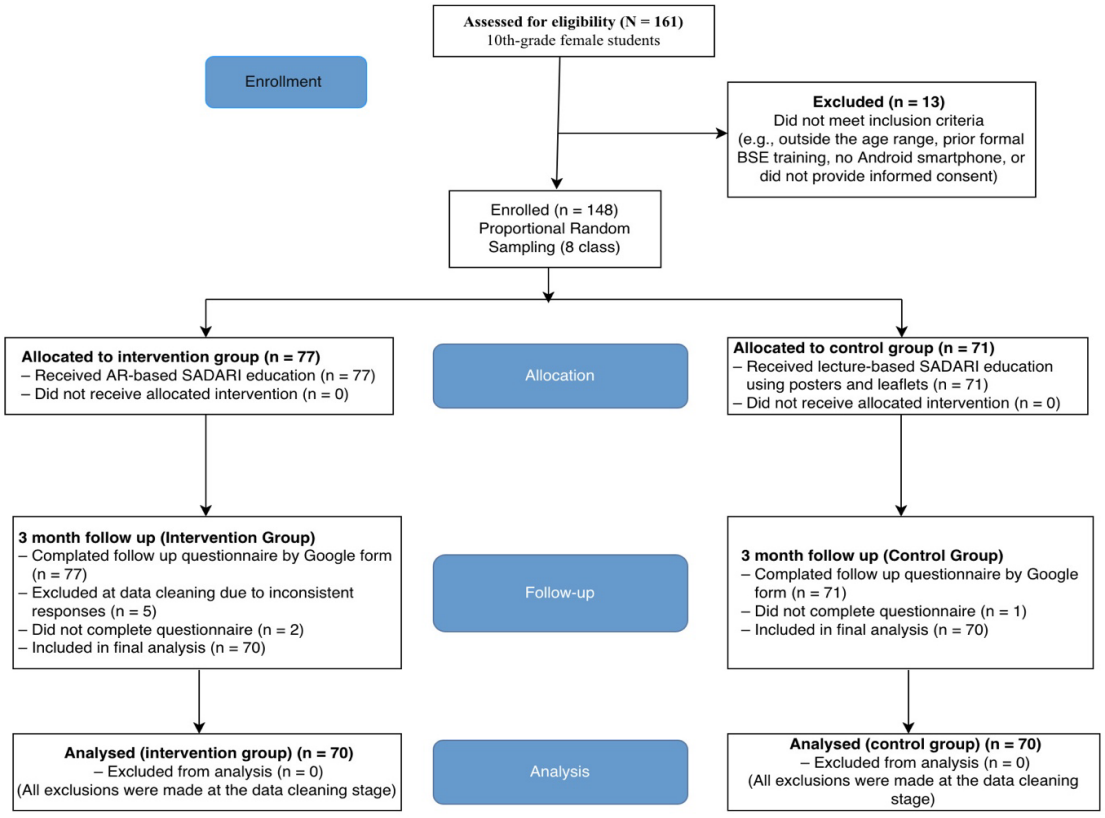

Figure 2. CONSORT Flow Diagram of the Study

with Cronbach's alpha of 0.834.

Perceived Behavioral Control (PBC) was assessed using four dichotomous ("Yes"/"No") items capturing respondents' perceived barriers to performing breast self-examination (BSE), namely whether BSE was considered time-consuming, costly, difficult to perform, or embarrassing/unpleasant. Item development was guided by the Theory of Planned Behavior (Ajzen, 1991), in which PBC reflects the extent to which individuals feel they have control over internal and external factors that influence their ability to perform a behaviour. Each response was scored 1 (barrier present) or 2 (no barrier), and the item scores were summed to yield a total PBC score ranging from 4 to 8. Higher scores indicate greater perceived behavioral control, that is, lower perceived barriers to performing BSE. In the main analyses, the PBC score was treated as a continuous variable. Construct validity was examined using corrected item total correlations, with r greater than 0.30 and p less than 0.05 as the minimum criteria for item retention. Internal consistency in this study was acceptable, with Cronbach's alpha of 0.811.

Data Analysis

Normality of post-test scores was assessed using the Shapiro–Wilk test to guide the choice of appropriate statistical procedures. Descriptive statistics were used to summarize the data, including means, standard deviations, frequencies, and percentages. Comparisons between the intervention and control groups were conducted using independent t-tests for normally distributed variables or the Mann–Whitney U test for non-normally distributed variables. A significance level of $p < 0.05$ was applied in all inferential analyses. In addition, effect sizes were calculated using Cohen's d or the effect size coefficient r to aid interpretation of the magnitude of the intervention's impact on knowledge and PBC.

Results

Participant Characteristics

A total of 140 respondents were included in the final analysis, with 70 assigned to the AR-based education group and 70 to the conventional learning group. All participants were 15–19-year-old female tenth-grade students who had not previously received formal education on BSE. Because the sociodemographic characteristics of the two groups were homogeneous, no further statistical comparisons of baseline characteristics were conducted, and the groups were considered comparable at the start of the study.

Normality Test and Homogeneity of Variances

The distribution of the data was examined using both the Kolmogorov–Smirnov and Shapiro–Wilk tests for each variable in the experimental and control groups. For knowledge scores, the Shapiro–Wilk test indicated significant deviation from normality in both the experimental ($SW = 0.959$, $p = 0.021$) and control ($SW = 0.932$, $p < 0.001$) groups. Perceived behavioral control (PBC) scores also showed clear departures from normality in the experimental ($SW = 0.695$, $p < 0.001$) and control ($SW = 0.661$, $p < 0.001$) groups. Consistent with these findings, the Kolmogorov–Smirnov tests likewise supported non-normal distributions. As the assumption of normality was not met for any of the main outcome variables, non-parametric tests (Mann–Whitney U test) were used for between-group comparisons.

Homogeneity of variances between the experimental (AR-based) and control groups was assessed using Levene's test for both outcome variables. For knowledge scores, Levene's test was non-significant ($F(1, 138) = 0.161$, $p = 0.689$), indicating that the variances of the two groups were comparable. Similarly, for perceived behavioral control (PBC), Levene's test was also non-significant ($F(1, 138) = 0.359$, $p = 0.550$), suggesting no significant difference in variances between the intervention and control groups. These results indicate that the assumption of homogeneity of variances was met for both knowledge and PBC in the between-group comparisons.

Distribution of Knowledge Categories Between the Intervention and Control Groups

Table 2, presents the distribution of knowledge categories (low, moderate, and high) between the intervention and control groups. The intervention group had a substantially higher proportion of participants in the high-knowledge category (71.4%) than the control group (28.6%). In contrast, the control group showed higher proportions in the low (28.6%) and moderate (42.9%) categories. A chi-square analysis indicated a statistically significant difference between the two groups ($\chi^2 = 13.94$, $df = 2$, $p < 0.001$). Fisher's Exact Test confirmed this significance ($p < 0.001$). These findings suggest that the AR-based educational intervention yielded significantly better knowledge outcomes compared to conventional learning methods.

Table 3 presents the comparison of total knowledge scores between the Augmented Reality (AR)-based learning group and the conventional learning group. The AR group had a higher median score (38, IQR 31–52) than the conventional group (36, IQR 26–51). The Mann–Whitney U test indicated a statistically significant difference between the two groups ($U = 1725.000$, $Z = -3.033$, $p = 0.002$). The effect size ($r = 0.26$) falls within the small-to-medium range according to Cohen's

Table 2. Distribution of Knowledge Categories between the Intervention and Control Groups

Knowledge Category	Intervention Group (n = 70)	Control Group (n = 70)	Total (n = 140)	Pearson χ^2 (df = 2)	Fisher's Exact Test	p-value
Low	5 (7.1%)	20 (28.6%)	25 (17.9%)	13.94	13.84	< 0.001
Moderate	15 (21.4%)	30 (42.9%)	45 (32.1%)			
High	50 (71.4%)	20 (28.6%)	70 (50.0%)			
Total	70 (100%)	70 (100%)	140 (100%)			

Table 3. Comparison of Total Knowledge score and Perceived Behavioral Control Between the Intervention and Control Groups

Variable	Group	Median (IQR)	U	Z	p-value	r	Interpretation
Total Knowledge Score	Intervention	38 (31–52)	1725	−3.033	0.002	0.26	Small–Medium
	Control	36 (26–51)					
Perceived Behavioral Control	Intervention	7 (6–8)	350.5	-9.075	<0.001	0.767	Large effect
	Control	4 (3–5)					

Table 4. Mann–Whitney U Test Results for Knowledge Dimensions Between the AR and Conventional Groups

Dimension	Median (IQR) AR	Median (IQR) Conventional	U	Z	p-value	r	Interpretation
Breast Cancer Signs	10 (9–11)	9 (8–10)	1953	−2.100	0.036	0.177	Small effect
BSE Timing	7 (6–8)	7 (6–7)	2099.5	−1.515	0.13	0.128	Small effect
BSE Benefits	8 (7–9)	7 (6–8)	2130.5	−1.398	0.162	0.118	Small effect
BSE Follow-up	6 (5–6)	5 (5–6)	2101.5	−1.574	0.115	0.133	Small effect
BSE Frequency	7 (6–8)	7 (6–7)	2063	−1.797	0.072	0.152	Small effect

criteria. Overall, these findings indicate that AR-based learning improves total knowledge scores compared with conventional learning. However, the magnitude of its impact remains within the small to medium range.

In terms of perceived behavioral control, the intervention group demonstrated a substantially higher median score (7, IQR 6–8) than the control group (4, IQR 3–5). The Mann–Whitney U test showed a highly significant difference between the groups ($U = 350.5$, $Z = -9.075$, $p < 0.001$), with a large effect size ($r = 0.767$), indicating a substantial practical impact of the intervention on enhancing perceived behavioral control. Overall, these findings suggest that AR-based learning is more effective than conventional methods in improving both students' knowledge and their perceived ability and confidence to perform BSE, with a modest effect on knowledge and a pronounced effect on perceived behavioral control.

Table 4 presents a comparison of knowledge scores between the Augmented Reality (AR)-based learning group and the conventional learning group across five knowledge dimensions. Median (IQR) values are reported for each dimension, along with the Mann–Whitney U test results, Z-scores, p-values, and effect sizes (r). The analysis shows that the AR group achieved higher median scores across all dimensions than the conventional group. A statistically significant difference was observed only in the Breast Cancer Signs dimension ($U = 1953$, $Z = -2.100$, $p = 0.036$, $r = 0.177$), indicating a small effect size. Across the BSE Timing, BSE Benefits, BSE Follow-up, and BSE Frequency dimensions, although the AR group demonstrated higher median scores, the differences did not reach statistical significance ($p > 0.05$). Overall, these findings suggest that the AR-based intervention tends to yield better improvements in knowledge, particularly regarding breast cancer signs and symptoms. However, the effect's magnitude remains relatively small.

Table 5 presents the distribution of perceived barrier dimensions toward Breast Self-Examination (BSE) in the intervention and control groups. The findings indicate that a substantially higher proportion of respondents in the control group perceived BSE as time-consuming (71.4%), expensive (94.3%), complex (87.1%), and embarrassing or unpleasant (84.3%) compared with the intervention group, which reported much lower proportions for each respective barrier (34.3%, 7.1%, 8.6%, and 20%). All barrier dimensions demonstrated statistically significant differences between groups ($p < 0.05$). These results suggest that the intervention was effective in reducing perceived barriers to performing BSE, indicating a positive impact of the AR-based educational approach on participants' attitudes toward breast self-examination.

Discussion

This study aimed to evaluate the effectiveness of an Augmented Reality (AR)–based educational intervention compared with conventional learning in improving knowledge, reducing perceived barriers, and enhancing perceived behavioral control (PBC) related to breast self-examination (BSE) among adolescent girls. Overall, the findings showed that participants in the AR-based education group had higher total knowledge scores, lower perceived barriers, and significantly stronger PBC than those in the control group. Outcomes were evaluated at 3-month follow-up; therefore, these findings reflect short-term effects, and longer follow-up is necessary

Table 5. Distribution of Perceived Barrier Dimensions Toward Breast Self-Examination in the Intervention and Control Groups

Item	Intervention n (%)	Control n (%)	Total n (%)	p-value
BSE is time-consuming	24 (34.3)	50 (71.4)	74 (52.9)	0.001
BSE is expensive	5 (7.1)	66 (94.3)	71 (50.7)	0.001
BSE is difficult	6 (8.6)	61 (87.1)	67 (47.9)	0.001
BSE is embarrassing/unpleasant	14 (20)	59 (84.3)	73 (52.1)	0.001

to determine whether the improvements are sustained. These results highlight the potential of AR as an innovative educational tool for breast cancer prevention in adolescence. Accordingly, the discussion distinguishes cognitive gains (knowledge) from behavioral readiness (reduced perceived barriers and increased PBC) as determinants of preventive practice.

Impact of AR-based education on knowledge of breast cancer and BSE

Regarding knowledge, participants in the AR group showed better outcomes than those in the control group. The distribution of knowledge categories revealed that a substantially higher proportion of adolescents in the AR group achieved a high level of knowledge. In contrast, the control group was predominantly characterized by low and moderate levels. Mann–Whitney U test further indicated that the total knowledge score in the AR group was significantly higher than in the conventional learning group, with a small to medium effect size. Although only the "Breast Cancer Signs" dimension showed a statistically significant difference, the AR group consistently achieved higher median scores across all knowledge dimensions. These findings are consistent with previous research, which reports that AR can enhance understanding, attention, and retention by presenting learning content in a more visually and realistically engaging manner. For example, Uribe et al. [21] reported that an AR-based anatomy tool improved students' ability to visualise and understand anatomical structures and health-related concepts through more authentic learning experiences, while Gnidovec et al. [22] found that AR significantly enhanced conceptual understanding of the human circulatory system.

In the specific context of breast cancer and BSE, several non-AR educational interventions, such as video-based teaching, virtual modules, and structured teaching programmes, have demonstrated improvements in BSE knowledge and skills among adolescents and adult women, for instance, showed that a video-assisted teaching program significantly improved BSE knowledge among adolescent girls, while Kucheki et al. [23] reported that a virtual educational intervention based on self-efficacy theory enhanced women's BSE skills and confidence. The present study extends these findings by demonstrating that when similar educational content is delivered through an interactive and immersive AR format, improvements in knowledge are evident not only in total scores but also in more specific aspects, such as recognizing the signs and symptoms of breast cancer.

The lack of statistically significant differences in several other knowledge dimensions may be due to both groups receiving the same core educational content and the limited sample size. Similar trends have been observed in multimedia-based interventions, where overall knowledge improves but not all sub-dimensions achieve statistical significance [24]. These findings are consistent with the existing literature and indicate that AR may offer additional benefits, particularly for content that requires clinical visualization.

Reduction of perceived barriers to BSE

Perceived barriers represent the psychological and practical readiness to initiate BSE, distinct from knowledge as a cognitive outcome. The intervention was also effective in reducing perceived barriers to performing BSE. As shown in Table 5, participants in the control group were significantly more likely to perceive BSE as time-consuming, expensive, complex, or embarrassing. In contrast, the AR group reported markedly lower proportions for all of these barriers. This pattern suggests that AR helps to correct misconceptions, increase comfort, and provide a clearer understanding of the BSE procedure. The ability of AR to simulate BSE steps in a realistic yet controlled manner likely helps reduce both psychological and practical barriers. These results are consistent with previous research showing that augmented reality–based patient education can reduce preoperative anxiety, increase comfort with the educational process, and improve understanding of complex medical procedures [25, 26]. They are also supported by reviews indicating that visual and interactive educational technologies can reduce misconceptions, clarify procedures, and lessen psychological barriers to screening behaviors [19, 23]. By offering step-by-step simulations of BSE, AR may reduce internal resistance and improve adolescents' perceptions of the procedure's safety and feasibility.

Systematic reviews on cancer awareness in adolescents have shown that this age group often has low awareness of cancer symptoms and faces multiple psychosocial barriers, including fear, embarrassment, and the perception that health examinations are uncomfortable [27]. This is consistent with the initial profile of participants in the present study. However, the post-intervention findings indicate that AR can help mitigate some of these barriers, possibly by allowing adolescents to "practice virtually" in a safe, private, and non-threatening environment before attempting BSE on themselves.

Moreover, a national observational study among adult women in Italy found that subjective barriers and lack of information contributed to low BSE practice and suboptimal participation in breast cancer screening programs among both Italian and Chinese women living in Italy [28]. The present study contributes to this body of evidence by demonstrating that technology-based educational interventions, such as AR, have the potential to reduce perceived barriers from adolescence onward, before maladaptive behavioral patterns become more ingrained in adulthood.

Perceived behavioral control (PBC) and its relevance to preventive behavior

Within the TPB framework, PBC reflects perceived capability and control to perform BSE as an indicator of behavioral readiness. The most striking finding of this study is the very substantial increase in PBC observed in the AR group, with a large effect size. This result is significant when viewed through the lens of the Theory of Planned Behavior, which posits PBC as one of the key determinants of intentions and health behaviors, including BSE and breast cancer screening. Several theory-based interventions have demonstrated that improvements in

knowledge and self-efficacy are closely linked to increased intention and practice of BSE [23].

Virtual interventions grounded in self-efficacy theory have been shown to enhance women's skills and confidence in performing BSE correctly [23]. Likewise, randomized trials of AR-based or immersive technology training among health professionals have reported significant improvements in self-efficacy, confidence, and perceived competence following exposure to AR [19]. Consistent with these findings, the present study shows that adolescent girls who received AR-based education reported higher levels of confidence and perceived ability to perform BSE independently.

Recent research on cancer awareness among adolescents has emphasized that higher perceived control and a stronger sense of agency are critical for promoting help-seeking and early detection behaviors [27]. Therefore, the significant increase in PBC observed in the AR group may lead to stronger intentions and more consistent BSE practice in the future. However, this study did not assess these outcomes longitudinally. Readiness indicators such as PBC are not equivalent to actual BSE practice; thus, behavioral measures and longer-term follow-up are necessary.

The results of the normality and homogeneity tests further support the methodological robustness of the study. All outcome variables were non-normally distributed but showed homogeneous variances across groups, justifying the use of non-parametric statistical tests. In addition, the homogeneity of participants' baseline demographic characteristics suggests that the differences observed between groups are likely attributable to the intervention rather than pre-existing differences.

Practical implications and contribution to the literature

The findings suggest that breast self-examination (BSE) serves as a practical and socially acceptable approach for integrating breast cancer education into school-based Adolescent Reproductive Health (Kesehatan Reproduksi Remaja, KRR) programs. In the Indonesian context, where reproductive health and sexuality topics are frequently considered sensitive and are not comprehensively addressed in the senior high school curriculum, an AR-based BSE module may be incorporated as a thematic component emphasizing breast health, early detection, and self-care, thereby avoiding more controversial aspects of sexuality education.

Implementation could be integrated into KRR activities, the school health unit (Usaha Kesehatan Sekolah, UKS), or broader healthy school initiatives. The primary target audience is girls in grades 10–12; however, including boys may broaden support and understanding among students. A typical session may begin with an overview of breast cancer risks in younger populations, followed by individual or small group use of the AR application to facilitate learning about breast anatomy and BSE procedures. Sessions may conclude with structured discussions addressing three key areas: recognition of signs and symptoms, correct timing and technique for BSE, and strategies to overcome psychological barriers such as embarrassment, perceived difficulty, or fear of results. School counselors, biology teachers with relevant training, and healthcare professionals such as midwives or nurses from local primary health centers can provide facilitation and additional support.

This study contributes to the literature by demonstrating that augmented reality (AR) is not only pertinent for university students and health professionals but is also viable and valuable for senior high school adolescents in a middle-income country. Technology-based interventions should be formulated to augment knowledge and directly address and mitigate perceived barriers, thereby improving behavioral control. This viewpoint can inform subsequent studies and program development aimed at investigating the application of alternative immersive technologies, such as virtual reality or serious games, to enhance cancer and reproductive health education among adolescents across varied cultural settings.

Limitations and directions for future research

Despite its promising results, this study has several limitations. The quasi-experimental design and the use of a single educational setting sample may limit the generalizability of the findings to broader adolescent populations. Since a posttest-only design was employed, baseline equivalence between groups could not be confirmed. Outcomes were based on self-reported measures, which may be subject to social desirability bias. In addition, the study assessed knowledge, perceived barriers, and PBC only in the short term and did not include behavioral outcome measures (i.e., objectively verified BSE practice) or longer follow-up to determine sustainability. A novelty effect associated with the use of a new technology-based intervention may also have influenced engagement and responses.

Future studies should apply power-based sample size calculations once adequate prior estimates are available. Longitudinal or randomized controlled designs with larger, more diverse samples are also warranted and should include behavioral indicators such as the frequency and accuracy of BSE practice. Qualitative approaches may further explore adolescents' experiences with AR-based education, including comfort, motivation, and any residual barriers. Such work would strengthen the evidence base on the effectiveness of AR for breast cancer education and inform wider implementation.

In conclusion, this quasi-experimental study found that an Augmented Reality AR-based educational intervention was associated with better breast self-examination BSE-related outcomes among adolescent girls than conventional learning. Participants in the AR group showed higher total knowledge scores, lower perceived barriers, and greater perceived behavioral control (PBC) than those in the control group. The large effect size for PBC suggests that AR may support not only cognitive learning but also adolescents' perceived capability and control to perform BSE. Overall, these findings position AR as a promising and feasible complementary tool to support conventional breast cancer education in school settings, rather than a replacement. By providing interactive and visually rich learning experiences, AR may facilitate recognition of breast cancer signs and

symptoms, reduce misconceptions and perceived barriers, and strengthen perceived behavioral control. Given the importance of establishing preventive practices early, integrating AR-based modules into adolescent health education programs may enhance preparedness for breast cancer early detection. Future studies should assess longer-term outcomes and include behavioral measures of actual BSE practice, using larger and more diverse samples and, where possible, randomized controlled designs.

Author Contribution Statement

NK was the principal investigator and led study design, protocol, data collection, and manuscript preparation. AL supervised the intervention, refined the study design, interpreted findings, and revised the manuscript. MW developed instruments, managed data, performed analyses, interpreted results, and contributed to writing. NWS developed the Augmented Reality application, provided technical support, and assisted in manuscript preparation. All authors approved the final manuscript.

Acknowledgements

We thank Universitas Respati Yogyakarta (UNRIYO) for funding (Grant No. 01/Pen/Hibah.Int/LPPM/IV/2025) and the Ministry of Higher Education, Science, and Technology (Kemdikti Saintek), Indonesia, for publication support (No. 0488/C/DT.06.01/2025).

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