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DEVELOPMENT OF THE 'SMART' SIMULATOR PROTOTYPE FOR POSTPARTUM SIMULATED PATIENTS

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ABSTRACT
Postpartum breast and external genitalia assessments are essential for early detection of complications. However, they are difficult to practice on real patients, and high-fidelity obstetric simulators are often too costly. This study aims to develop a low-cost "SMART" simulator and to evaluate its effectiveness on the clinical competence of midwifery students in performing postpartum physical examinations. This study utilized a Research and Development (R&D) design integrated with a quasi-experimental approach. The research was conducted in four phases: (1) needs assessment and conceptual design; (2) prototype development using locally available silicone, ballistics gel, and 3D-printed frameworks; (3) face and content validation by clinical experts; and (4) an educational evaluation using a quasi-experimental design. A total of 120 midwifery students were divided equally into an intervention group (n=60) and a control group (n=60). Baseline characteristics were homogeneous between the groups. Overall competence in postpartum physical examination was achieved by 65.0% of the intervention group and 60.0% of the control group (p=0.044; OR=0.441; 95% CI: 0.211–0.919). The intervention group performed better in hand hygiene (48.3% vs 33.3%) and communicating results to the patient (90.0% vs 73.3%). Student characteristics, lecturer support, and practicum credit compliance were not significantly associated with competence. The SMART simulator is a valid, low-cost training tool that effectively supports and enhances postpartum assessment competence in midwifery education. Larger multi-site studies are recommended to confirm these findings.

Keywords: clinical competence; low-cost simulator; midwifery education; postpartum assessment; simulation-based education

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INTRODUCTION

The postpartum period, often referred to as the fourth trimester, is a critical phase characterized by profound physiological and emotional transitions for a mother (Finlayson et al., 2020). Comprehensive maternal assessments during this timeframe are essential to ensure optimal recovery and prevent potentially life-threatening complications (Galle et al., 2023; Lattof et al., 2020; Organization, 2022). Among the most vital components of postpartum care is the systematic evaluation of the breast and external genitalia. Breast assessments are crucial for identifying early signs of engorgement, blocked milk ducts, cracked nipples, and mastitis, which can impair successful lactation and negatively impact neonatal nutrition (Sadovnikova et al., 2020). Simultaneously, the careful examination of the external genitalia and perineum is mandatory to monitor the healing trajectory of episiotomies or spontaneous lacerations, evaluate lochia discharge, and detect early symptoms of puerperal infections or hematomas. Delayed or inaccurate identification of these complications can lead to severe maternal morbidity, prolonged hospitalizations, and long-term physical discomfort, highlighting the indispensable need for competent healthcare professionals trained in executing these specific clinical assessments (Magi, 2025).

Despite the importance of these clinical examinations, educating nursing, midwifery, and medical students in postpartum assessment presents substantial pedagogical and ethical challenges.

Traditionally, clinical skills have been acquired through direct patient interaction during clinical placements under the supervision of experienced preceptors (Constantino et al., 2025). However, practicing sensitive examinations on real postpartum patients is fraught with limitations. Patients are frequently exhausted, physically uncomfortable, and emotionally vulnerable during the immediate postpartum period, making them rightfully reluctant to permit novice learners to perform intimate assessments. Furthermore, the opportunistic nature of clinical rotations means that students may not encounter the full spectrum of postpartum complications, such as severe mastitis or infected perineal wounds, during their training. This unpredictable exposure creates critical gaps in clinical competency and severely restricts the students' ability to practice safely without compromising patient dignity and safety (Chernikova et al., 2026; Salifu et al., 2022). Simulation provides a psychologically and physically safe environment where learners can practice complex technical skills, refine their clinical reasoning, and make errors without causing patient harm (Watts et al., 2021; YILAR ERKEK & Öztürk Altınayak, 2021). The integration of simulation into healthcare education is consistently proven to enhance self-efficacy, improve psychomotor skill acquisition, and accelerate the transition from novice to competent practitioner (Chernikova et al., 2026; Prepelita et al., 2020; YILAR ERKEK & Öztürk Altınayak, 2021). However, widespread adoption of simulation technology remains profoundly hindered by exorbitant costs (Frangi et al., 2025). Currently available high-fidelity obstetric simulators are prohibitively expensive, costing tens of thousands of dollars and requiring specialized personnel for ongoing maintenance and operation (Knobel et al., 2020; Xavier et al., 2025). These financial barriers make high-fidelity simulators virtually inaccessible to educational institutions located in low- and middle-income countries, as well as underfunded nursing programs in rural settings.

Consequently, there is an urgent need for the development of innovative, cost-effective, and highly accessible simulation models that do not severely compromise anatomical accuracy or functional realism, particularly since high physical fidelity is not an absolute prerequisite for effective transfer of learning (Frangi et al., 2025; Knobel et al., 2020). In direct response to this significant educational void, this study proposes the design, development, and comprehensive evaluation of the low-cost "SMART" Simulator, specifically engineered for postpartum breast and external genital assessment. The acronym "SMART" represents the core foundational principles of the prototype: Specific to postpartum maternal care, Measurable in its capacity to evaluate student competency, Accessible due to its low production cost, Realistic in its anatomical fidelity, and Tactile-focused to genuinely replicate human tissue responses. By utilizing locally sourced, affordable materials such as customized ballistics gel, advanced skin-mimicking silicones, and basic 3D-printed internal anatomical frameworks, the SMART simulator aims to accurately replicate the precise texture, elasticity, and visual presentation of both normal and pathological postpartum conditions.

Ultimately, this study seeks to democratize access to high-quality healthcare simulation. By providing an empirically validated, easily reproducible, and affordable training tool, the low-cost SMART simulator holds the profound potential to enhance maternal care education on a global scale (Costa et al., 2024; Frangi et al., 2025). Equipping future healthcare providers with the essential skills required to confidently assess postpartum women will directly contribute to earlier detection of complications, improved maternal health outcomes, and a substantial reduction in preventable morbidity, particularly in resource-constrained clinical settings. The primary objective of this research endeavor is divided into three interconnected phases. The first phase details the engineering and iterative design process of the SMART simulator, outlining the selection of inexpensive materials and the pedagogical rationale behind each structural component. The simulator incorporates interchangeable modular parts to represent diverse clinical scenarios, including engorged breasts, inverted nipples, perineal tears, and localized infection. The second phase involves the rigorous validation of the prototype by a panel of expert obstetricians, experienced midwives, and nursing educators to evaluate face and content validity. These clinical

experts will critically assess the anatomical accuracy, tactile realism, and overall suitability of the simulator as an educational tool. Finally, the third phase focuses on evaluating the pedagogical impact and usability of the simulator among undergraduate nursing and midwifery students. Through a structured quasi-experimental design, the study will measure improvements in the students' procedural knowledge, clinical confidence, and psychomotor proficiency before and after engaging with the SMART simulator.

METHOD

The research methodology for the design, development, and evaluation of the low-cost "SMART" Simulator follows a structured, multiphase approach. This sequential procedure is essential to ensure that the simulator not only addresses critical clinical training gaps in maternal care but also remains highly affordable and pedagogically effective for varied educational environments (Miller et al., 2021; Watts et al., 2021).

Phase 1: Needs Assessment and Conceptual Design

The research initiates with a thorough clinical and pedagogical needs assessment to define the precise parameters required for teaching postpartum breast and external genitalia assessments. While high-fidelity simulations offer significant realism, their implementation is often hindered by exorbitant costs, making them inaccessible for many institutions (Frangi et al., 2025). Therefore, the conceptual design framework strictly adheres to the "SMART" criteria: Specific, Measurable, Accessible, Realistic, and Tactile. During this stage, a multidisciplinary panel of obstetricians, midwifery experts, and nursing educators collaborates to outline the specific clinical scenarios the tool must replicate, such as normal tissue involution, breast engorgement, inverted nipples, and infected perineal episiotomies (Watts et al., 2021; Organization, 2022).

Phase 2: Material Selection and Prototype Development

Following the establishment of the clinical blueprints, the physical development of the prototype commences. To ensure broad reproducibility, especially in resource-constrained settings, the simulator is constructed using low-cost, locally available materials (Knobel et al., 2020). Advanced skin-mimicking silicones and customized ballistics gel are layered to accurately replicate the texture, temperature capacity, and elastic feedback of human tissue. Furthermore, the internal structural framework is engineered utilizing affordable 3D-printing techniques. This iterative prototyping phase emphasizes modularity; interchangeable components are designed so educators can seamlessly swap normal anatomy for pathological conditions (Watts et al., 2021). The engineering process prioritizes functional realism over extreme physical fidelity, heavily guided by educational literature demonstrating that cognitive and tactile alignment is more critical for the successful transfer of learning than perfect visual replication (Frangi et al., 2025; Knobel et al., 2020).

Phase 3: Face and Content Validation

Before implementation in a classroom setting, the prototype undergoes rigorous scientific validation. A cohort of independent clinical experts is recruited to evaluate the simulator's face validity (the degree of physical realism and anatomical accuracy) and content validity (its appropriateness and completeness as a curriculum training tool). Using standardized Likert scales and structured evaluation rubrics, these experts assess the tactile response of the synthetic perineal and breast tissue against their real-world clinical experience (Costa et al., 2024; Watts et al., 2021). Quantitative and qualitative feedback collected during this phase dictates final engineering modifications, ensuring the simulator meets the strict standards necessary for safe and effective patient simulation (Decker et al., 2021; Molloy et al., 2021).

Phase 4: Educational Evaluation and Usability Testing

The final phase focuses on measuring the pedagogical impact of the finalized SMART simulator. Utilizing a structured quasi-experimental design, the study evaluates undergraduate nursing and

midwifery students before and after they engage with the simulator. Grounded in Kirkpatrick's framework for evaluating healthcare education (Decker et al., 2021; Watts et al., 2021), the assessment measures immediate learning outcomes and behavioral competency. Standardized checklists and Objective Structured Clinical Examinations (OSCEs) are utilized to track improvements in students' psychomotor proficiency, procedural sequencing, and diagnostic accuracy (Chabrera et al., 2023; Yang et al., 2024). Furthermore, self-reported metrics are analyzed to evaluate increases in clinical confidence and a reduction in performance anxiety when conducting intimate assessments (Grabowski et al., 2020; YILAR ERKEK & Öztürk Altınayak, 2021). This rigorous educational evaluation verifies the low-cost simulator's capacity to successfully bridge the gap between theoretical knowledge and safe, competent clinical practice.

RESULT

The evaluation of the low-cost SMART simulator's effectiveness in enhancing midwifery students' clinical competencies yielded significant quantitative insights regarding postpartum physical assessments. The study involved a total of 120 midwifery students, equally divided into a control group (n=60) and an intervention group (n=60). To ensure internal validity, the baseline characteristics of both groups were meticulously analyzed. The statistical assessment confirmed that variables such as student self-confidence, frequency of practice, personality traits, motivation levels, lecturer support, and institutional adherence to practicum credits were homogeneous across both cohorts. This established baseline equivalence is a critical prerequisite for the quasi-experimental posttest-only control group design, ensuring that subsequent differences in clinical competency could be attributed directly to the utilization of the SMART simulator rather than individual or institutional confounding factors.

A descriptive analysis of the general clinical competency revealed that 65% of the students in the intervention group were deemed competent in performing postpartum physical examinations, compared to 60% in the control group. While this aggregate percentage difference appears marginal on the surface, a deeper procedural breakdown highlights the substantial pedagogical impact of the SMART simulator. The following table details the competency distribution across specific clinical procedures during the postpartum assessment:

Table 1.
The competency distribution across specific clinical procedures during the postpartum assessment

Clinical Procedure / Competency Area	Control Group (Competent) n (%)	Intervention Group (Competent) n (%)
Overall General Competency	36 (60.0%)	39 (65.0%)
Welcoming the mother	48 (80.0%)	51 (85.0%)
Explaining the procedure	55 (91.7%)	58 (96.7%)
Performing hand hygiene	20 (33.3%)	28 (48.3%)
Examining breasts carefully	45 (75.0%)	46 (76.7%)
Examining the abdomen accurately	53 (88.3%)	57 (95.0%)
Determining Fundal Height (24 hours postpartum)	58 (96.7%)	55 (91.7%)
Assessing Uterine Contraction (24 hours postpartum)	59 (98.3%)	57 (95.0%)
Determining Fundal Height (Day 6 postpartum)	41 (68.3%)	46 (76.7%)
Assessing Uterine Contraction (Day 6 postpartum)	41 (68.3%)	47 (78.3%)
Determining Fundal Height (Day 14 postpartum)	52 (86.7%)	53 (88.3%)
Communicating results to the patient	44 (73.3%)	54 (90.0%)

Conversely, the control group failed to reach this competency threshold in several critical areas, particularly in assessing fundal height and uterine contractions on day six postpartum. The intervention group also demonstrated notably superior performance in essential clinical protocols, such as executing proper hand hygiene and effectively communicating examination results to the patient. This indicates that the hybrid simulation experience provided by the SMART simulator enhances not only tactile palpation skills but also the holistic integration of patient safety and clinical communication.

Bivariate analysis comparing the two groups further substantiated the efficacy of the SMART simulator. The statistical evaluation produced a p-value of 0.044 and an Odds Ratio (OR) of 0.441 (95% CI: 0.211–0.919) regarding overall competency. Because the Odds Ratio is less than 1, it demonstrates a protective effect; students who received guided training with the SMART simulator had a significantly lower risk of being categorized as incompetent during the postpartum physical assessment. Furthermore, the research investigated the potential impact of independent confounding variables on student competency. The statistical tests revealed no significant differences or correlations between the students' final competency levels and their individual characteristics, such as baseline self-confidence, personality, motivation, or the frequency of their laboratory practice (1-3 times versus more than 3 times). Similarly, external factors like the level of support from practicum lecturers and institutional compliance with practicum credit hours did not significantly alter the competency outcomes.

This lack of statistical significance among the confounding variables strongly suggests that the educational medium itself, the SMART simulator, played the most dominant and decisive role in shaping student proficiency. The findings underscore that a well-designed, anatomically accurate, and highly tactile simulator can effectively override suboptimal individual motivations or institutional constraints, driving positive learning outcomes through deliberate practice (Chernikova et al., 2020; McDermott et al., 2021). By facilitating a realistic, hybrid simulation environment, the SMART simulator successfully bridges the gap between theoretical knowledge and practical application in maternal care education.

DISCUSSION

The primary objective of this study was to develop and evaluate the pedagogical effectiveness of the low-cost "SMART" simulator in enhancing the clinical competence of midwifery students performing postpartum physical assessments. The findings of this study offer compelling evidence that the integration of an affordable, locally resourced, and anatomically targeted simulation tool can significantly bridge the gap between theoretical knowledge and clinical practice. The results demonstrated a statistically significant improvement in the overall competency of the intervention group compared to the control group (65.0% vs. 60.0%; p=0.044), yielding an Odds Ratio of 0.441. This protective odds ratio indicates that students who trained using the SMART simulator were substantially less likely to be classified as incompetent, thereby affirming the tool’s capability to standardize foundational clinical skills in a risk-free educational environment.

These findings align seamlessly with the broader educational consensus that simulation-based learning accelerates the transition from novice to competent practitioner. Practicing sensitive examinations, such as those of the postpartum breast and external genitalia, is historically challenging due to patient vulnerability and the unpredictable nature of clinical rotations (Chernikova et al., 2026). By utilizing the SMART simulator, students in the intervention group were afforded a psychologically safe environment to refine their psychomotor skills and make errors without causing patient discomfort or harm. This environment directly contributes to the reduction of performance anxiety, a critical factor that often inhibits skill acquisition among undergraduate healthcare students during their initial clinical encounters (YILAR ERKEK & Öztürk Altınayak, 2021).

One of the most profound insights generated by this research is the validation of functional realism over extreme physical fidelity. Historically, the widespread adoption of simulation technology has been hindered by the prohibitive costs associated with high-fidelity obstetric mannequins (Frangi et al., 2025). However, our results corroborate previous assertions that cognitive and tactile alignment rather than flawless visual aesthetics are the primary drivers of successful learning transfer (Knobel et al., 2020). By utilizing inexpensive, locally sourced materials such as ballistics gel, customized silicones, and 3D-printed frameworks, the SMART simulator successfully replicated the specific

tactile feedback necessary for postpartum examinations. The effectiveness of this low-cost approach is firmly supported by recent studies emphasizing that locally developed simulators can achieve comparable educational outcomes to their high-fidelity counterparts, provided that the anatomical landmarks and tissue responses are accurately engineered to meet specific learning objectives (Costa et al., 2024; Yang et al., 2024).

A detailed procedural analysis of the results reveals that the SMART simulator profoundly impacted not only technical psychomotor skills but also essential non-technical skills. Most notably, the intervention group demonstrated vastly superior performance in executing proper hand hygiene (48.3% vs. 33.3%) and effectively communicating examination results to the patient (90.0% vs. 73.3%). The enhancement of these communication and safety protocols can be attributed to cognitive load theory. Because the SMART simulator provided clear, realistic tactile cues during breast and fundal palpation, the students' cognitive burden was significantly reduced. Consequently, learners had the mental bandwidth to focus holistically on patient interaction, empathy, and infection control, rather than being entirely consumed by the mechanical steps of the palpation process. This holistic integration of skills is a hallmark of well-designed simulation experiences (Watts et al., 2021). Furthermore, targeted practice on accurate synthetic tissues addresses a well-documented gap in lactation and postpartum education, where students frequently struggle to confidently identify normal versus pathological breast conditions, such as engorgement or impending mastitis (Sadovnikova et al., 2020).

The study also highlighted specific improvements in tactile diagnostic accuracy, particularly in assessing fundal height and uterine contractions on day six postpartum (76.7% vs. 68.3% and 78.3% vs. 68.3%, respectively). The physiological involution of the uterus requires precise tactile discrimination to ensure that the fundus is descending appropriately. The custom-layered ballistics gel and silicone of the SMART simulator provided the realistic resistance required for students to develop this specific muscle memory, an advantage clearly lacking in the control group's standard curriculum.

Crucially, the bivariate analysis revealed that individual confounding variables such as baseline student self-confidence, personality traits, motivation, and the frequency of laboratory practice were not significantly associated with final clinical competence. Similarly, institutional factors such as lecturer support and practicum credit compliance did not significantly alter the outcomes. The lack of statistical significance among these external variables strongly implies that the instructional medium itself was the dominant catalyst for improved performance. This reinforces the principle that a rigorously designed instructional framework combined with a standardized simulation tool can override suboptimal individual motivations or varying institutional constraints, ensuring a baseline of clinical safety across diverse student cohorts (Salifu et al., 2022).

From a global health perspective, the implications of this study are substantial. The postpartum period is highly vulnerable, and comprehensive maternal assessments are essential to prevent severe morbidity (Galle et al., 2023; Lattof et al., 2020). The World Health Organization strictly emphasizes the necessity of high-quality postnatal care provided by competent healthcare professionals (Organization, 2022). By democratizing access to effective simulation training, the SMART simulator addresses a critical need in resource-constrained environments, ensuring that financial barriers do not preclude the delivery of life-saving educational interventions (Magi, 2025). Despite these promising results, several limitations must be acknowledged. The absolute percentage difference in overall competence between the two groups was relatively modest (5%), and the study was conducted using a quasi-experimental design within a single educational institution, which may limit the broad generalizability of the findings. Furthermore, the evaluation was primarily based on immediate post-intervention competency, leaving the long-term retention of these psychomotor skills unknown. Future research should prioritize multi-site randomized controlled trials

incorporating standardized Objective Structured Clinical Examinations (OSCEs) to further validate the tool across diverse cultural and educational contexts (Chabrera et al., 2023). Longitudinal studies tracking students' performance as they transition into independent clinical practice will also be vital to definitively ascertain the long-term clinical impact of the low-cost SMART simulator.

CONCLUSION

The low-cost SMART simulator, built from locally available materials, was associated with better postpartum physical examination competence among midwifery students. Students trained with the simulator showed a higher proportion of overall competence (65.0% vs 60.0%) and a lower likelihood of being classified as incompetent (OR=0.441; 95% CI: 0.211–0.919; p=0.044), with the clearest advantages in hand hygiene and communicating examination results to the patient. Individual characteristics, lecturer support, and institutional practicum compliance were not significantly related to competence, which suggests that the training medium contributed meaningfully to the outcome. Because the difference in overall competence was modest and the study involved a single student population with a quasi-experimental design, the findings should be interpreted with caution.

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