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Simulator-Limb Training in Phlebotomy among Health Science Students: Implications for Technique-Related Preanalytical Errors—A Systematic Review

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ABSTRACT

Introduction: Phlebotomy is an essential skill that health science students need to develop for future clinical practice. Proper phlebotomy technique can help prevent technique-related preanalytical errors that may compromise specimen quality and patient safety. Simulator-limb training gives students opportunities to practice venipuncture in a controlled environment before performing procedures on actual patients. This study examined the effectiveness of simulator-based limb training in phlebotomy and its potential to minimize technique-related preanalytical specimen errors. Methods: A systematic review was conducted in accordance with the PRISMA 2020 reporting guidelines to examine simulator limb training in phlebotomy among health science students and its implications for technique-related preanalytical specimen errors. Google Scholar, PubMed, and EBSCOhost were searched for English-language studies published from January 2016 to September 2026. Eligible studies evaluated simulator-limb training in phlebotomy among health science students and reported outcomes related to procedural competency or preanalytical specimen errors. Methodological quality was assessed using the Mixed Methods Appraisal Tool (MMAT), version 2018. Due to heterogeneity in study designs, populations, and outcome measures, the findings were synthesized narratively and organized into three themes: clinical competency and learner readiness; safe, repetitive, and experiential learning; and implications for patient safety and the prevention of technique-related preanalytical errors. Results and Discussion: The reviewed literature showed that simulator-limb phlebotomy training improved venipuncture competency, confidence, and psychomotor skills while providing a safe environment for repetitive practice, error recognition, and feedback. However, no included studies directly measured the potential effect on reducing technique-related preanalytical specimen error rates before and after simulator-limb training; improved procedural competency and consistent phlebotomy performance may contribute to specimen quality and patient safety. Lastly, challenges include equipment and maintenance costs, limited funding, faculty training, curriculum integration, and limited clinical authenticity in integrating simulator-limb training for health science students practicing phlebotomy. Conclusion: Simulator-limb training may complement phlebotomy competency development among health science students. Further research directly measuring preanalytical errors and specimen rejection rates is needed to establish its effectiveness in reducing technique-related preanalytical errors.

Keywords: *simulation training, phlebotomy, preanalytical error, health science students*

ISSN: 3116-3475
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of Education, Research, and Innovation Perspectives
Volume 2 Issue 10 (October 2026)

INTRODUCTION

Phlebotomy is the procedure of cutting a vein to draw blood; it dates back to 1400 B.C. and is performed by professionals called phlebotomists. The word phlebotomy comes from the Greek words *phlebo*, meaning "vein," and *-tomy*, meaning "to cut." Historically, people performed this procedure to cure diseases and maintain health. At that time, barber-surgeons were allowed to perform bloodletting to maintain the body's balance, per Hippocrates' standard. This practice gave rise to the red-and-white pole we see as a barbershop symbol today. Red symbolizes blood, while white symbolizes bandages. In addition, leeches were historically used to remove blood from patients—a practice we now call therapeutic phlebotomy—to treat blood disorders (Warekois & Robinson, 2016).

Today, phlebotomy helps diagnose and monitor patients' health conditions. Three main phases must be followed to ensure a successful, accurate result: preanalytical, analytical, and postanalytical. The preanalytical stage occurs before testing; the analytical stage occurs when the specimen is in the laboratory, ready for testing; and the postanalytical stage is the final phase, when the results are ready to be reported. Although all phases are vital to reliable findings, preanalytical error accounts for about 32-75% of laboratory errors (Naz & Sadaruddin, 2012). Because it directly affects the overall quality of the specimen result, it is considered a crucial step. According to Nordin et al. (2024), major preanalytical errors include inappropriate test requests, patient preparation, sample collection, sample handling, transportation, and storage. To reduce errors at this stage, standard practice guidelines, education, and quality monitoring using automated methods are important. Although the World Health Organization (2010) guidelines, manuals, and principles must be followed to ensure a safe phlebotomy procedure, it is still vital for allied health professionals to enhance their clinical competencies without compromising patient safety.

Although conventional or traditional teaching methods have long formed the foundation of clinical training, Simulation-based training (SBT) is an innovative technique that provides a controlled, safe learning environment (Naseem et al., 2026). SBT was introduced centuries ago but has grown significantly in the healthcare field in the 21st century (Bienstock & Heuer, 2022). Simulation-based training can use low-fidelity to high-fidelity simulations. High-fidelity simulations use computerized mannequins that an instructor can control (Walker & Thrasher, 2013). On the other hand, low-fidelity simulations utilize mannequins or task trainers to mimic real-life situations and procedures (Naseem et al., 2026), while Dzhumatovich & Salimrouhi (2025) considered mannequins or intravenous (IV) arm models as medium-fidelity simulations. Low-fidelity simulations use partial-task trainers, models that represent a specific anatomic part or body structure and let students practice and focus on that part (Walker & Thrasher, 2013). Incorporating them into the healthcare field has improved clinical practice related to patient safety, as a 2022 study by Bienstock and Heuer found that 1 in 10 patients in high-income countries is harmed during hospital stays, and 50% of these harms are preventable.

Today, institutions use venipuncture-simulated limbs to improve students' competencies before they encounter real patients. Simulator limbs, such as IV arm trainers, mimic human arm anatomy, including the vascular system, with blood flowing through the veins. Thus, they are useful for phlebotomy practice.[10] While simulator limbs are widely used to build phlebotomy competency, evidence directly linking this training to reduced technique-related preanalytical errors has not been systematically synthesized.

This study aims to answer the following questions to determine the relevance and implications of utilizing simulator limbs on technique-related preanalytical errors in phlebotomy among students.

1. What are the implications of using a simulator limb as an intervention to potentially reduce technique-related preanalytical specimen errors in phlebotomy during clinical practice?
2. Is simulator-limb training effective in developing phlebotomy competency and enhancing procedural skills among health science students before clinical patient encounters?

Goals and Objectives

The main objective of this study was to systematically review the literature on simulator-limb training, focusing on its effectiveness in developing procedural competency and enhancing phlebotomy skills among health

ISSN: 3116-3475
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of Education, Research, and Innovation Perspectives
Volume 2 Issue 10 (October 2026)

science students, and its potential implications for reducing technique-related preanalytical specimen errors during clinical practice.

METHODS

Research Design

A systematic review was conducted to synthesize literature from past to present on the potential of using a simulator limb to minimize phlebotomy preanalytical errors among health science students. A systematic review is a structured method for integrating and analyzing data from different research studies that share common research topics (Ahn & Kang H, 2018). Moreover, this research paper followed the reporting recommendations of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses 2020 statement (Page et al., 2021).

Eligibility Criteria

This study used inclusion criteria associated with the problem statement and objectives; the criteria include: (a) studies published between January 2016 and September 2026 and in the English language; (b) study designs including cross-sectional, case–control, experimental, quasi-experimental, correlational, and descriptive studies; (c) studies that align with the implications of simulator limb training in phlebotomy; (d) studies that examine the effects of simulator limb training on phlebotomy practice among health science students; and (e) studies that address the impact of simulator limb training on outcomes relevant to technique-related preanalytical specimen errors, whether measured directly (e.g., specimen rejection or error rates) or indirectly through the procedural competency outcomes that mediate error risk.

Conversely, exclusion criteria for this study include: (a) unpublished articles, letters to the editor, and studies with inaccessible full-text versions; (b) studies that do not correlate with the main objective and statement of the problem of this study; and (c) studies that do not involve health science students.

Information Sources and Search Strategy

This study used different terms for the simulator limb, phlebotomy, preanalytical errors, and health science students, including simulator arm, artificial arm, artificial limb, nursing students, medical technology students, medical laboratory sciences students, interns, and preanalytical specimen errors. The search also utilized Google Scholar (2016 to present), PubMed (2016 to present), and the EBSCOhost interface (2016 to present). The literature search started on August 1, 2026, and ended on October 3, 2026. All citations and references of relevant studies have been screened and listed using Google Docs.

Data Collection Process

Included citations were identified and evaluated for relevance to the concepts and theories. The citations, their titles, and their concepts and themes were tabulated to organize the data. After systematizing and classifying the concepts of each study, the researchers carefully analyzed, assessed, and compared the listed journals to synthesize them further.

Outcomes of Interest and Extracted Data

The study primarily evaluated reductions in technique-related preanalytical specimen errors by comparing specimen rejection and error rates before and after simulator limb training. Secondary outcomes were venipuncture procedural competency, psychomotor skill acquisition, self-confidence, self-efficacy, learning motivation, anxiety, knowledge and attitudes, and perceived readiness for clinical practice.

From each included study, the following data items were extracted: author(s) and year, country and setting, study design, participant population and sample size, simulator type, intervention and comparison conditions, outcome measures, and main findings relevant to the review questions. The extracted data were tabulated to identify structural patterns before thematic analysis.

ISSN: 3116-3475
International Journal
of Education, Research, and Innovation Perspectives
Volume 2 Issue 10 (October 2026)

Risk of Bias in Individual Studies

This review included only peer-reviewed and published studies in English from reliable electronic databases. A common limitation in published reviews is omitting eligible studies, which can introduce selection bias.

To minimize bias, the researchers prioritized quality evaluation of included studies to ensure reliable findings. The researchers evaluated the methodological quality of each included study using the Mixed Methods Appraisal Tool version 2018, which provides design-matched criteria for qualitative, quantitative, and mixed-methods study designs, including two screening questions and five design-specific quality criteria (Hong et al., 2018). Studies that included the title, author, year, statement of the problem, objectives, and conclusion were also included. Findings were synthesized only across studies with equivalent methodological quality, and per-study ratings are summarized in the quality appraisal table. The PRISMA 2020 checklist guided transparent reporting of the review; it did not substitute for quality appraisal of the included studies.

Data Synthesis

The included studies were heterogeneous in design, population, and outcome measures, so statistical pooling was not possible. Thus, an explicit narrative synthesis was adopted, following the ESRC Methods Program guidance, and conducted in three steps: preliminary synthesis through tabulation and thematic analysis; exploration of relationships across studies through concept mapping; and assessment of the strength of the synthesis using the Best Evidence Synthesis technique. For preliminary synthesis, this study employed a mixed-methods approach utilizing tabulation and thematic analysis. This study used tabulation to identify structural patterns and establish key elements for the subsequent synthesis. Thematic analysis, on the other hand, identified major, recurring, and central themes and concepts across multiple studies (Popay et al., 2006).

Concept mapping was applied to explore relationships among the included studies. It provided a visual representation of the synthesized evidence from diverse studies to better understand and assess their collective insights (Popay et al., 2006).

The Best Evidence Synthesis (BES) technique was used to assess the strength of the synthesis. Only studies that met eligibility criteria and aligned with the research goals and objectives were incorporated. Included studies were summarized through their titles, abstracts, and full-text versions to provide a comprehensive understanding of thematic association (Popay et al., 2006).

Data Management and Analysis

Study Records

1. Data management

Google Docs was used as the primary platform for drafting the manuscript and organizing APA-formatted reference citations. We stored the document in Google Drive, with access restricted exclusively to the researchers for safety purposes.

2. Selection process

A comprehensive review of studies was conducted to identify research gaps and provide evidence on the current state of knowledge regarding the association between integrating simulator limb training and reducing preanalytical error in phlebotomy among health science students.

A computer-based approach was used to search for related literature. Online databases such as Google Scholar and PubMed, and search interfaces like EBSCOhost, were systematically used to gather relevant studies.

ISSN: 3116-3475
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of Education, Research, and Innovation Perspectives
Volume 2 Issue 10 (October 2026)

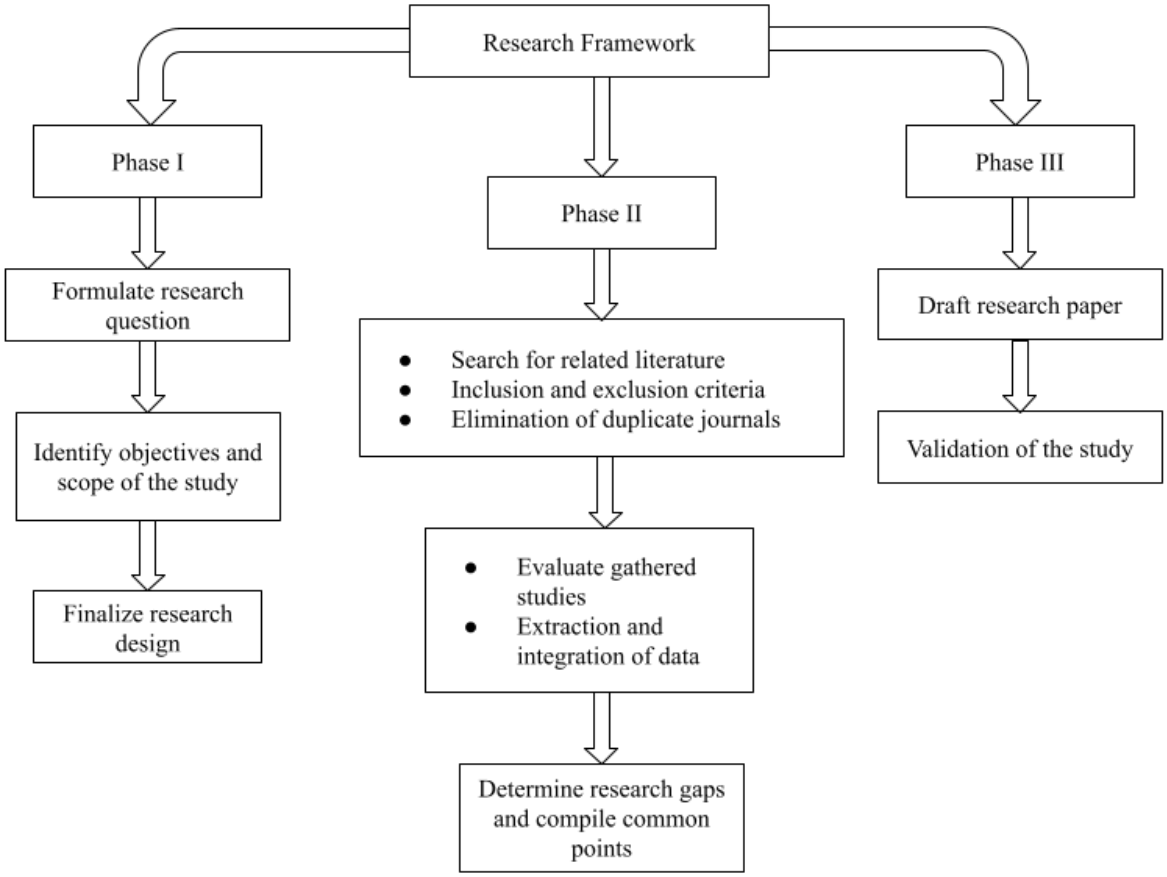


Figure 1. *Research Framework*

All retrieved literature was screened, stored in Google Docs, and synchronized with Google Drive. Gathered journals were assessed, and duplicate versions were excluded and recorded. The remaining articles were initially screened by title and abstract against the eligibility criteria. We retrieved and evaluated full-text versions of relevant studies—particularly examining their methodology and discussion of results—to confirm final inclusion. The count of included studies was recorded and maintained in Google Drive.

Presentation of Findings

The findings and conclusions of this study were reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses 2020 statement, the guideline for reporting completed systematic reviews that replaced the 2009 statement (Page et al., 2021). The review is reported as a completed systematic review following PRISMA 2020: the rationale, objectives, and review questions are presented in the introduction; the eligibility criteria, information sources, search strategy, selection process, data collection, risk-of-bias assessment, and synthesis methods are described in the methods; and the results of the search and selection process are documented in the PRISMA flow diagram, with the characteristics of the six included studies summarized in Table I. Study-level methodological quality was appraised using the Mixed Methods Appraisal Tool version 2018. However, statistical pooling was not possible because the included studies were heterogeneous in design, population, and outcome measures. The findings are therefore presented as a clear narrative synthesis organized around three themes: (1) enhancement of clinical competency and learner readiness; (2) a safe, repetitive, and

ISSN: 3116-3475
International Journal
of Education, Research, and Innovation Perspectives
Volume 2 Issue 10 (October 2026)

experiential learning environment; and (3) implications for patient safety and prevention of technique-related preanalytical errors.

Ethical Considerations

The study relies on publicly available studies online. The study did not require approval from the Philippine Health Research Ethics Board (PHREB). Nevertheless, the review process strictly upheld ethical standards through objective data synthesis.

Problems Anticipated

The researchers encountered several challenges while conducting this study. One restriction was the inability to access relevant articles and literature in subscription-based databases. Additionally, the published literature on this topic was limited between January 2016 and September 2026. The researchers used all available online databases and an institutionally affiliated library subscription to ensure comprehensive data collection.

RESULTS AND DISCUSSION

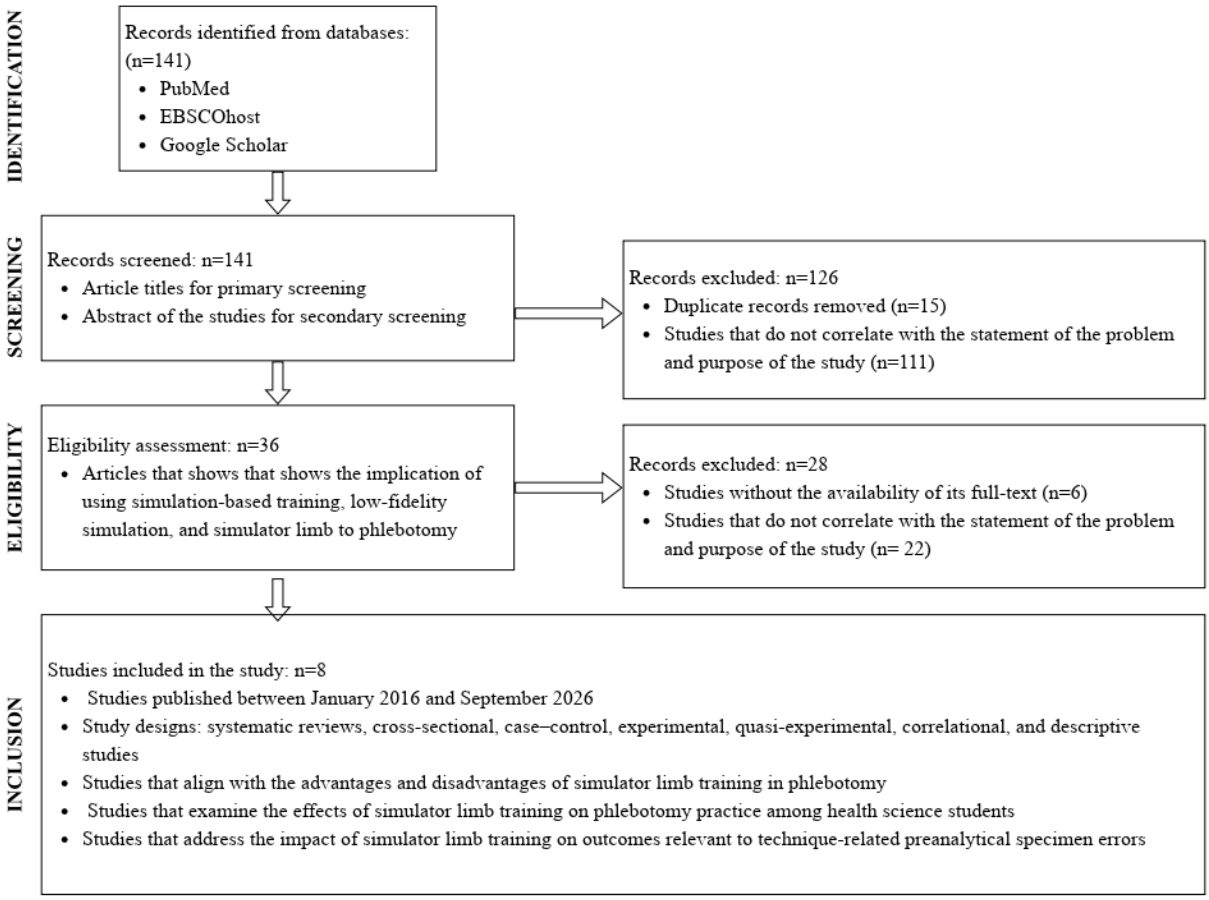


Figure 2. *PRISMA Flow Diagram*

ISSN: 3116-3475
International Journal
of Education, Research, and Innovation Perspectives
Volume 2 Issue 10 (October 2026)

Table 1. *Characteristics of the Included Studies*

Author	Design	Population and sample	Simulator/ intervention	Key outcomes
Kodikara et al. (2023)	Prospective cohort (two phases)	55 second-year (pre-clerkship) medical students	Mannequin-based procedural training with standardized patients	Improved self-confidence and perceived competency; skills retained at 1-year clinical reassessment
Khan et al. (2026)	Quasi-experimental comparison	75 undergraduate medical students (SBT n = 38; bedside n = 37)	Skills-lab simulation with mannequins vs. bedside teaching	Higher OSCE skill scores in SBT group (84.6 ± 6.8 vs. 76.2 ± 7.5; $p < 0.001$); higher confidence and satisfaction
Hsieh et al. (2026)	Single-group pretest–posttest with qualitative interviews	31 fourth-year nursing internship trainees	Inductive Venipuncture Arm Simulator with embodied cognitive learning	Improved learning achievement, motivation, and self-efficacy; reduced anxiety
Erdmann & Oliveira Filho (2018)	Randomized comparative study	30 first- and second-year medical students with no previous peripheral venous access experience (intervention n=15, control n=15). Final completers: 11 intervention and 14 control.	Low-fidelity haptic simulation using homemade ballistic-gel phantoms with latex-balloon artificial veins filled with grape juice, plus Laerdal Multi-Venous IV Training Arms; role-playing. Control received basic-life-support training instead.	Students receiving haptic simulation achieved higher blood-collection success (82% vs 68%; $p = .037$) and fewer technical errors (median 1 vs 2; $p = .005$) during real-patient procedures. Haptic simulation independently predicted success (OR = 2.46), while between-group differences in self-efficacy were not significant.
Saengpayab et al. (2021)	Experimental/ repeated-measures technical evaluation of a sensor-assisted venipuncture system	3 testers each performed 10 venipuncture attempts at each of 3 sites (median cephalic, median basilic, median cubital)	Rubber arm system simulating a human arm with artificial veins and circulating fluid and an integrated electrical needle/arm sensors and LCD/LED feedback	Mean overall accuracy was 76 ± 10%. Accuracy increased from 60 ± 18% in the first five attempts to 76 ± 10% in the last five attempts. Through-venipuncture percentage decreased across sites, suggesting improvement with repeated sensor-assisted practice.
Hernon et al. (2024)	Mixed-methods, two-phase (cross-sectional survey + observational)	38 final-year nursing and midwifery students (survey phase; 47% response rate)	Simulation-based training plus supervised clinical venipuncture/PIVC practice	Identified knowledge and performance gaps; need for improved simulation and more practice opportunities
Tserovski et al. (2026)	Descriptive educational evaluation study with a simulator development component	50 medical students.	Low-cost, reusable venipuncture simulator with embedded artificial veins and visual blood flashback for student practice; 10-item questionnaire with a 5-point Likert scale.	Students reported high usability, realism, and educational value; objective competency and preanalytical error reduction were not measured.

ISSN: 3116-3475
International Journal
of Education, Research, and Innovation Perspectives
Volume 2 Issue 10 (October 2026)

Sneha et al. (2026)	Descriptive questionnaire-based educational evaluation (single-group, post-course)	63 fourth-semester BSc Medical Laboratory Technology students; all completed the course; questionnaire pilot-tested on 20 students	30-hour phlebotomy course combining theory, mannequin-arm practice, supervised venipuncture on donors and patients, and assessment.	Most students demonstrated good knowledge (88.9%) and practical competency (85.7%) after the phlebotomy course. Venipuncture technique had the lowest scores in both knowledge (80.0%) and practical skills (84.7%), and patient identification and preparation being the highest (97.4%).

Preliminary screening was performed on these studies based on the available abstracts. At this stage, 126 studies were excluded —15 duplicates were removed, and others did not align with the purpose of this paper. 36 studies were assessed in the final screening to verify eligibility against the inclusion criteria. Overall, 8 studies were included in the review.

Theme 1: Enhancement of Clinical Competency and Learner Readiness

The first theme was enhancing clinical competency and learner readiness through simulator-based limb venipuncture training. The reviewed studies consistently showed that simulation helps learners with opportunities to develop procedural competence and prepare for clinical practice. Kodikara et al. (2023) found that simulation-based procedural training (SBPT) helped medical students develop clinical skills and confidence early in their training, and students viewed SBPT as a helpful and valuable learning method. Similarly, Khan et al. (2026) reported improved psychomotor skills, procedural task performance, and confidence among learners who received simulation-based training. Hsieh et al. (2026) further supported these findings through the Inductive Venipuncture Arm Simulator (IVPAS), which incorporates principles of embodied cognitive learning and was associated with increased motivation to learn and self-efficacy, improved mastery of venipuncture skills, and reduced anxiety among nursing interns. In addition, Erdmann and Oliveira Filho (2018) reported fewer technical errors and a higher success rate in peripheral blood collection following low-fidelity haptic simulation. Saengpayab et al. (2021) also reported improved venipuncture accuracy using a rubber-arm system with electrical sensors. These findings suggest that improved procedural performance may help prevent errors by enabling students to refine their technique before clinical practice.

Low-fidelity simulation, such as simulator limbs, is particularly useful during the initial stages of skill acquisition because it provides a safe setting for learners to practice fundamental procedures and to refine their skills. Overall, simulation-based training supports the development of psychomotor competence, confidence, and clinical readiness while promoting safe preparation for actual patient encounters (Hernon et al., 2024).

Simulator-limb training may reduce technique-related preanalytical specimen errors by helping students develop the procedural skills needed to perform venipuncture correctly before working with actual patients. Through practice with simulation models, students can develop needle insertion accuracy, procedural coordination, and the ability to recognize successful venipuncture. Developing accurate and consistent venipuncture skills may reduce technique-related problems that can compromise specimen quality. However, improved competency does not necessarily reduce actual preanalytical specimen error rates.

Theme 2: Safe, Repetitive, and Experiential Learning Environment

The second theme focused on simulation's implication in providing a safe, repetitive, and experiential learning environment. Khan et al. (2026) highlighted that simulator-based training provides learners repeated opportunities to perform venipuncture procedures in a controlled setting. It allows learners to identify errors, receive feedback, and improve their techniques before transitioning to actual clinical encounters with patients.

ISSN: 3116-3475
International Journal
of Education, Research, and Innovation Perspectives
Volume 2 Issue 10 (October 2026)

This helps avoid risking harm to patients. As a simulation modality, the simulator limb provides hands-on experience, helping learners become familiar with equipment and procedural steps while developing skills through repeated practice.

Moreover, developing simulators for phlebotomy practice helps students build procedural skills through repeated, hands-on practice. Tserovski et al. (2026) developed a reusable venipuncture simulator that provides immediate visual feedback. This simulator allows repeated puncture attempts to help students practice their skills. Similarly, a simulation approach described by Erdmann and Oliveira Filho (2018) offered opportunities to practice blood collection using various low-fidelity models.

Overall, repeated practice in a controlled environment helps learners improve venipuncture techniques and identify errors before performing procedures on actual patients, which is essential, especially in phlebotomy, where improper specimen collection and handling can affect specimen quality, which then potentially affects the accuracy and reliability of laboratory results.

Theme 3: Implications for Patient Safety and Prevention of Technique-Related Preanalytical Errors

The third theme examined simulation-based training's potential contribution to patient safety and the prevention of technique-related preanalytical errors. None of the included studies demonstrated preanalytical error rates before and after simulator training. The link to error reduction is based on indirect evidence and operates through the competency outcomes in Themes 1 and 2.

Erdmann and Oliveira Filho (2018) recorded fewer technical errors and higher collection success rates among students who used low-fidelity haptic simulation during real-patient procedures, while Saengpayab et al. (2021) reported improved venipuncture accuracy and fewer failed punctures with a rubber arm system simulating a human arm in phlebotomy. Further, Sneha et al. (2026) highlighted phlebotomy competency domains among BSc MLT students through a phlebotomy course combining theory, mannequin-arm practice, and supervised venipuncture. These studies provide relevant evidence regarding procedural performance and safe phlebotomy practices, although they do not establish that simulator-limb training directly reduces the incidence of preanalytical specimen errors.

Evidence from simulation-based training in peripheral intravenous catheterization (PIVC) and venipuncture also suggests benefits for the educational and professional development of undergraduate nursing and midwifery students (Hernon et al., 2021). By providing opportunities to practice procedures before encountering real patients, simulation can help learners build procedural preparedness while reducing the risks associated with learning through direct patient encounters. Venipuncture errors can affect specimen quality, potentially causing hemolysis, clot formation, contamination, or specimen rejection. Targeted training that strengthens procedural accuracy and adherence to appropriate collection techniques may therefore help prevent these errors.

These findings collectively suggest that simulation-based training can help strengthen procedural competence and promote safer clinical practice, particularly in skills where preanalytical specimen-collection errors may affect subsequent laboratory testing.

DISCUSSION

In answer to research question 2, the reviewed evidence consistently shows that simulator limb practice improves competency, confidence, and psychomotor skills. In answer to research question 1, no included study directly measured preanalytical error rates before and after simulator training; therefore, the evidence for error reduction is indirect, based on improved procedural competency. The evidence linking these factors remains indirect since none of the included studies directly measured preanalytical error rates before and after simulator training. Thus, the current body of literature does not provide sufficient evidence to quantify the extent of any reduction in errors (Yadav & Yadav, 2025). Nevertheless, the proposed pathway remains coherent and valid, as

improved procedural technique, confidence, and reduced anxiety may support more consistent specimen collection and higher specimen quality.

Simulation provides learners with hands-on, repetitive practice in a controlled environment, helping them become familiar with equipment and procedures before they encounter real patients. This preparation may also support critical thinking and clinical judgment by exposing learners to realistic decision-making situations and promoting psychological and ethical readiness for clinical practice (Dzhumatovich & Salimrouhi, 2025). Review of related literature found consistent evidence that training on simulator limbs enhances health science students' venipuncture competency, confidence, and psychomotor skills before they encounter real patients (Hsieh et al., 2026; Khan et al., 2026; Kodikara et al., 2023).

Across the included studies, the safety and repeatability of the simulated environment allow students to develop their skills through repeated practice, assess mistakes, and receive feedback without risking patient harm (Dzhumatovich & Salimrouhi, 2025; Khan et al., 2026). These findings align with the problem this review addresses, as many laboratory errors occur during the preanalytical phase. In addition, SBT may offer advantages over traditional lecture-based instruction by promoting knowledge retention and skills development through active and experiential learning (Yadav & Yadav, 2025). Dzhumatovich and Salimrouhi (2025) highlighted simulation's role in bridging theoretical knowledge and practical application through experiential learning. This allows students to practice clinical procedures and develop decision-making and teamwork skills without compromising patient safety. Similarly, Yadav and Yadav (2025) noted that simulation-based training gives students opportunities to identify and learn from mistakes, which may reduce errors and promote patient safety. Therefore, strengthening procedural competency before clinical exposure may offer a practical way to prevent technique-related errors.

For educators, the evidence suggests that simulator limb training may serve as a preparatory approach or intervention that enhances learning while maintaining the importance of supervised clinical experience (Khan et al., 2026)**.** Future research should include direct measures of error rates and specimen quality, such as hemolysis and specimen rejection rates, in longitudinal study designs that follow students from simulation-based training through subsequent clinical practice.

Challenges of Integrating Simulation-based Training

Major challenges associated with SBE include the high cost of securing and maintaining simulation equipment, limited institutional funding, the need for adequate faculty training, and difficulty integrating simulation into existing curricula (Dzhumatovich & Salimrouhi, 2025; Kodikara et al., 2023; Yadav & Yadav, 2025). Khan et al. (2026) further emphasized that bedside teaching remains essential for providing students with real-world clinical exposure, suggesting that simulation and traditional clinical teaching should complement, not replace, one another.

Another limitation of SBE is its limited authenticity and transferability to actual clinical settings. Although simulation attempts to replicate real-life clinical situations, it cannot fully reproduce the complexity and variability encountered with actual patients (Dzhumatovich & Salimrouhi, 2025). For example, while a simulator limb can provide effective practice for basic venipuncture techniques, it cannot completely replicate the anatomical variations encountered in real patients. Students may therefore still struggle to collect blood from patients with deep, narrow, fragile, or otherwise difficult-to-access veins. Furthermore, some learners may question simulation effectiveness because it lacks authenticity, which may affect their engagement with the training. These limitations suggest that simulator-limb training works best as a complementary preparatory learning strategy, rather than replacing supervised practice with actual patients.

Limitations

This review is constrained by both the nature of the available evidence and the characteristics of the review process. First, no included study directly measured technique-related preanalytical specimen errors before and after simulator limb training; most studies focused on skill acquisition and confidence, and the literature identifies assessing long-term impacts on patient care and clinical outcomes as an open research need (Yadav & Yadav,

2025). Thus, the link between simulator training and reduced preanalytical errors is indirect, and its magnitude cannot be quantified from the current evidence. Second, the included studies were heterogeneous in design, population, simulator type, and clinical endpoint, making meta-analysis inappropriate and limiting the directness of the evidence synthesis. Third, few published studies address simulator limbs specifically as task trainers for phlebotomy or venipuncture among health science students. Fourth, the search was restricted to English-language, peer-reviewed publications, which may have excluded relevant non-English studies. Lastly, limited access to some subscription-based databases and a scarcity of relevant literature from January 2016 to September 2026 further limited the search.

CONCLUSION

Existing literature supports a potential indirect relationship between simulator limb training and reduced technique-related preanalytical errors through improved procedural competency, although direct studies regarding this remain limited. Using simulator limbs to practice phlebotomy may lead to more consistent, competent performance and potentially reduce technique-related preanalytical errors. Simulator limb training lets students repeatedly practice essential skills, such as proper needle insertion, appropriate blood collection techniques, and correct needle positioning. Therefore, simulator-limb training may serve as an important preparatory strategy to strengthen phlebotomy competency, improve specimen quality, and prevent technique-related preanalytical errors, although further research is needed to directly establish its effect on preanalytical error rates.

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