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PRECLINICAL SKILL DEVELOPMENT IN MEDICAL TRAINING: A COMPREHENSIVE SYSTEMATIC REVIEW OF INFLUENCING FACTORS

Dang Thanh Hong[1*], Nguyen Minh Phuong[2*], Le Duc Ngoc[3], Tran Bich Ngoc[4]

[1]University of Education – Vietnam. National University, Hanoi. Masters Ph.D. Student, Can Tho University of Medicine and Pharmacy, 179 Nguyen Van Cu, Can Tho 94000, Vietnam. Email: dthong@ctump.edu.vn, ORCID: https://orcid.org/0009-0003-6055-5323

[2]Can Tho University of Medicine and Pharmacy, 179 Nguyen Van Cu, Can Tho 94000, Vietnam, Email: nmphuong@ctump.edu.vn, ORCID: https://orcid.org/0000-0002-3857-9420

[3]Email: ngocld2000@yahoo.com. VNU University of Education - Vietnam National University, Hanoi. ORCID: 0000-0002-5689-9876.

[4]Email: tbngoc@ctump.edu.vn, ORCID: https://orcid.org/0009-0007-1129-3944

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Corresponding Author: Nguyen Minh Phuong (nmphuong@ctump.edu.vn)

ABSTRACT

***Background:** Preclinical skills development is a foundational element in medical education. However, inadequate preparation during this phase often leads to difficulties during transition, a lack of confidence, and suboptimal clinical practice outcomes. The factors influencing preclinical skill development have not been thoroughly and systematically assessed. Methods: A systematic review adhering to PRISMA and PRISMA-S guidelines was conducted, with a comprehensive search across nine major databases (PubMed/MEDLINE, CINAHL, PsycINFO, EMBASE, Scopus, Web of Science, ERIC, Cochrane Library, Springer Link) for studies published in English between January 2000 and July 2025. Two independent researchers performed screening and quality assessment using the RoB2, ROBINS-I, QuADS, and COREQ tools. Of 4,764 articles identified, 94 full-text articles were reviewed, and 22 high-quality studies were included in the final analysis. Results: The study identified 34 influencing factors, categorized into four primary groups: (1) Educational Methods and Tools (13 factors): clinical simulation, problem-based learning (PBL), OSCE, VR/AR technology, artificial intelligence; (2) Psychosocial Factors (11 factors): communication skills, intrinsic motivation, self-confidence, peer-assisted learning; (3) Environmental and Contextual Factors (7 factors): faculty support, infrastructure, student-to-faculty ratio; (4) Individual Factors (3 factors): foundational knowledge, year of study, prior learning experience. Clinical simulation, PBL, and OSCE demonstrated the strongest evidence of effectiveness, while modern technologies and multi-source feedback play a crucial supplementary role. Conclusions: The development of preclinical skills is shaped by a range of factors, including educational methodologies, psychosocial aspects, environmental conditions, and individual characteristics. This study offers a solid scientific basis for the advancement of modern medical education policies, while emphasizing the need for further research into the long-term effects and cross-cultural applications to optimize the quality of preclinical training.*

KEYWORDS: Preclinical Skills, Medical Education, Clinical Simulation, Problem-based Learning, Systematic Review.

1. INTRODUCTION

In the context of the rapid development and diversification of modern medicine, the enhancement of preclinical skills has become an essential and urgent requirement in medical education. The preclinical phase, encompassing the initial years of medical training, plays a crucial role in equipping students with the necessary knowledge, skills, and attitudes before engaging directly with patients (T Dornan et al., 2006). Preclinical skills extend beyond theoretical knowledge, incorporating fundamental physical examination techniques, initial communication skills, critical thinking, and foundational research skills (Sahu P. K. et al., 2019).

The importance of developing preclinical skills has been underscored by numerous studies on the transition from preclinical to clinical stages. Malau-Aduli et al. (2020) highlight that inadequate preparation during the preclinical phase can result in significant challenges during this transition, including feelings of insecurity, psychological stress, and difficulties in applying theoretical knowledge to clinical practice. The study also emphasizes that these challenges may impact students' adaptability and learning effectiveness during the clinical phase.

Recent studies have identified several factors influencing the development of preclinical skills in medical students. On a personal level, self-directed learning (SDL) ability is considered a key factor. Lucieer et al. (2016), in their study on the relationship between self-regulated learning (SRL) and academic outcomes in medical education, found that students with higher SDL abilities tend to achieve better academic results and are more adaptable to challenges encountered during their learning process. Additionally, motivational factors, self-confidence, and self-assessment skills have been identified as significant influences on skill development (Chunhui Yang et al., 2021).

In terms of educational methodology, the application of modern training methods, particularly simulation-based training (SBT), has been proven to be highly effective in developing preclinical skills. McGaghie et al. (2010), in their critical review of simulation-based medical education research from 2003 to 2009, emphasized that SBT not only helps students master procedural skills but also enhances clinical decision-making and teamwork abilities. Similarly, Al-Elq (2010) highlighted the role of simulation in creating a safe learning environment, allowing students to practice and make mistakes without causing harm to patients.

The learning environment and organizational factors also play a critical role in the development of preclinical skills. Wickramasinghe & Samarasekera (2011) demonstrated that preclinical and clinical students' learning approaches are influenced by various factors, including teaching methods and the learning environment. Factors such as faculty support, timely feedback opportunities, skill lab facilities, and the student-to-faculty ratio significantly impact students' ability to develop skills.

Despite numerous studies on factors influencing the development of preclinical skills, a comprehensive and systematic overview of this issue remains lacking. Current research often focuses on individual factors or specific groups of factors, resulting in a fragmented understanding of the interactions between these various elements. Furthermore, studies conducted in different educational and cultural contexts produce inconsistent results that are difficult to compare.

Therefore, a systematic review of the factors influencing the development of preclinical skills is essential to provide an overview and systematically evaluate existing evidence. This review will help identify key factors and knowledge gaps, thereby providing a solid scientific foundation for improving medical education quality and enhancing the transition between the preclinical and clinical stages for medical students.

1.1. Research Objectives

This systematic review aims to address the research needs and improve medical education through the following primary objectives:

1. Identify and categorize critical preclinical skills in medical education based on existing scientific evidence. This will clarify the core skills essential for medical students during the preclinical phase.
2. Systematically synthesize the factors influencing the development of preclinical skills in medical students. These factors will include personal, educational, learning environment, and organizational elements, aiming to identify key components that contribute to the effective development of preclinical skills.
3. Evaluate the effectiveness of various training methods and interventions in enhancing preclinical skills. This evaluation will identify the most effective methods in equipping students with essential preclinical skills.
4. Identify gaps in current research and propose potential directions for future studies. This objective will address existing knowledge gaps

and encourage further investigations into the development of preclinical skills.

1.2. Research Question

The primary research question addressed by this review is: "Which factors significantly influence the development of preclinical skills in medical students, and to what extent do each of these factors impact the development?"

To answer this primary question, the study will focus on the following sub-questions:

1) How do personal factors (such as learning motivation, self-directed learning (SDL) ability, and academic performance) influence the development of preclinical skills?
2) Which educational methods (such as simulation-based training (SBT), problem-based learning (PBL), and traditional education) are most effective in developing preclinical skills?
3) How do the learning environment and organizational factors affect the development of preclinical skills?

This review aims to provide a comprehensive synthesis of the factors influencing the development of preclinical skills. The results of this review will form a robust scientific foundation for the design and implementation of more effective medical training programs, addressing the need for high-quality healthcare professionals in the context of modern medicine.

2. METHODS

2.1. Search Strategy

To identify relevant studies, we conducted a systematic search across multiple electronic databases, adhering to the guidelines of PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) and PRISMA-S (PRISMA Statement Extension for Systematic Reviews in Healthcare). The search strategy was developed in consultation with a medical information library expert to ensure comprehensiveness and accuracy in the data collection process

The selected electronic databases included: PubMed/MEDLINE, CINAHL, PsycINFO, EMBASE, Scopus, Web of Science, ERIC, Cochrane Library/CENTRAL, and SpringerLink. During the search, we employed a combination of MeSH (Medical Subject Headings) terms and free-text keywords, along with Boolean operators (“AND,” “OR”) and wildcards (“*”) to expand the search scope, including variations in terminology and spelling.

Three key conceptual groups were identified during the search process: (1) Medical students, with search terms such as "medical student*", "undergraduate*", "preclinical student*", "medical trainee*"; (2) Skill development, with terms like "skill* acquisition", "skill* development", "skill* training", "clinical skill*", "procedural skill*", "psychomotor skill*", "technical skill*", "basic skill*", "simulation*"; (3) Influencing factors, with terms such as "influenc* factor*", "determinant*", "barrier*", "facilitator*", "perceptio*".

The following search string was applied: (("medical student*" OR "undergraduate medical student*" OR "preclinical student*" OR "medical trainee*" OR "medical undergraduate*" OR "pre-clinical year*" OR "preclinical phase*" OR "preclinical medical education") AND (("skill* acquisition" OR "skill* development" OR "skill* training" OR "clinical skill*" OR "procedural skill*" OR "psychomotor skill*" OR "technical skill*" OR "basic skill*" OR "preclinical skill*") AND ("communication skill*" OR "physical examination*" OR "clinical examination*" OR "critical thinking*" OR "research skill*" OR "simulation*" OR "clinical competenc*" OR "practical skill*")) AND (("influenc* factor*" OR "determinant*" OR "barrier*" OR "facilitator*" OR "perceptio*") OR ("self-directed learning" OR "SDL" OR "motivation*" OR "self-confidence" OR "self-assessment" OR "simulation-based training" OR "SBT" OR "problem-based learning" OR "PBL" OR "learning environment*" OR "faculty support*" OR "feedback*" OR "infrastructure*" OR "student-teacher ratio*"))).

2.1.1. Search Limits

Language: Only studies published in English were included.

Publication Date Range: Studies published from January 2000 to July 2025 were considered.

Study Type: Only original research articles using quantitative, qualitative, or mixed methods, as well as systematic reviews and meta-analyses, were included. Narrative reviews, letters, and commentaries were excluded.

Additionally, the reference lists of selected articles and related systematic reviews were manually checked to identify additional eligible studies.

2.1.2. Inclusion and Exclusion Criteria

Inclusion Criteria:

This systematic review includes studies focusing on medical students in the preclinical phase, particularly in the early years of the curriculum (e.g., Years 1–2 or basic science courses). Studies must address the acquisition, development, or maintenance of clinical/practical skills in preclinical medical education, such as history-taking, physical examination, procedural skills, communication, psychomotor, general skills, and self-directed learning, or factors influencing these processes (Shezadi Sabah Imra et al., 2019). Eligible study designs include original research (quantitative, qualitative, or mixed methods) and relevant systematic reviews or meta-analyses related to learning performance and skill development. Only studies published in English between January 2000 and July 2025 will be included. Studies must provide a detailed and transparent description of the methodology to ensure the reliability of the research outcomes (Jason M. Satterfield et al., 2007). Only original research and systematic reviews or meta-analyses focused on preclinical medical education will be considered.

2.1.3. Exclusion Criteria

Studies will be excluded if they focus solely on the clinical phase (Year 3 and beyond) without providing clear outcomes related to the development of preclinical skills. Studies primarily focusing on admission criteria, without assessing ongoing learning performance or skill development, will also be excluded. Additionally, non-original research documents such as commentaries, editorials, letters, or reports without experimental data will be excluded. Studies lacking sufficient methodological details for quality assessment will not be considered. Research on other healthcare professions (e.g., nursing, dentistry, physiotherapy), unless directly and clearly related to medical students, will be excluded (Darius Wei Jun Wan et al., 2024). Studies that report only satisfaction levels without evaluating learning performance or skill competency, as well as research on postgraduate, residency, or specialty training, will not be included. Narrative reviews, letters, and commentaries will also be excluded if they do not address the preclinical context.

2.1.4. Feedback Classification

In preclinical skills training, feedback is categorized to optimize the learning process. Feedback is designed to shape skill improvement priorities rather than merely assess performance. The main types of feedback include reinforcement feedback, provided as Knowledge of Results (KR) or Knowledge of Performance (KP), and intrinsic feedback. Feedback can be either prescriptive or descriptive, with higher frequency being beneficial for skill acquisition.

Methodological quality: risk of bias assessment

To ensure the rigor and reliability of the findings, all selected studies will undergo a methodological quality assessment and risk of bias evaluation. The assessment will be conducted independently by two reviewers to reach a consensus; disagreements will be resolved through discussion or by a third reviewer. Risk of bias tools will be selected based on the study design: for randomized controlled trials (RCTs), the Cochrane RoB 2 tool (J. P. T Higgins et al., 2019) will be used to assess five key areas of bias, while non-randomized studies will utilize the ROBINS-I tool (Jonathan A C Sterne et al., 2019) to evaluate seven areas of bias. The results will be classified as low, some concerns, or high risk, with the overall result based on the highest risk in any area. The QuADS tool will be applied to assess the overall quality of quantitative and mixed-methods studies, with a composite score expressed as a percentage. Qualitative studies will be assessed using the COREQ (Consolidated Criteria for Reporting Qualitative Studies) checklist to ensure transparency and rigor in reporting. Factors such as lack of blinding, small sample sizes, and differences in study design will be considered when interpreting the results (Johannes B. Reitsma et al., 2023). Studies will not be excluded solely based on quality ratings, but the reliability of the findings will be carefully considered in the synthesis and conclusions.

2.1.5. Data Extraction

After collecting search results from various databases, we removed duplicates and compiled the remaining articles for analysis. Subsequently, we independently screened all titles and abstracts to determine preliminary relevance. In cases of uncertainty, relevant articles were retained. We then read the full text of all retained articles to assess their eligibility for inclusion in this systematic review. If doubts persisted, articles were flagged for discussion and independently screened by all reviewers. To ensure consistency in the application of inclusion criteria, we conducted a dual screening on 10% of the randomly selected excluded articles as a triangulation method. The researchers held regular meetings to discuss challenges, ambiguities, and conflicts related to article selection. Disagreements among reviewers were resolved through discussion. We also manually checked the reference lists of included articles and their citations to identify additional relevant studies.

2.2. Synthesis of Results

To ensure a comprehensive understanding of the factors influencing the development of preclinical skills in medical students, the synthesis of results will strictly adhere to PRISMA guidelines to ensure transparency and reproducibility. Given the diversity of study types (quantitative, qualitative, mixed) and influencing factors, a narrative synthesis combined with thematic analysis will be applied to identify patterns, similarities, differences, and recurring themes within the data (Mary K Longworth, 2013).

Studies will be grouped by type of preclinical skill (e.g., basic clinical skills, communication, psychomotor skills), training methods (simulation, problem-based learning, digital education, peer teaching), and key influencing factors (barriers, facilitators). The extracted data will include study design characteristics, participant information (education level, sample size, gender, experience), content and intervention methods (skills labs, simulation, video, practice, feedback), and outcome measures (skill acquisition, retention, self-confidence, learning performance) (Michael Nnaemeka Ajemba et al., 2024).

Findings will be qualitatively synthesized to identify facilitators, barriers, and personal experiences. For quantitative data, if meta-analysis cannot be conducted due to heterogeneity, a voting or effective-synthesis approach will be used, prioritizing randomized controlled trials (RCTs) and studies with low risk of bias. The synthesis will also focus on evaluating the effectiveness of interventions at various levels of learning outcomes based on the Kirkpatrick model (reaction, attitude/cognition change, knowledge/skill acquisition, behavior change) (Alice Miller et al., 2010), while analyzing the roles of factors such as skills labs, advanced simulation, timely feedback, repeated practice, mentoring, self-directed learning, and clinical learning environments (Mahla Salajegheh et al., 2024).

The methodological quality of each study will be integrated into the analysis to assess the reliability of the evidence (J. Gårdling et al., 2025). Finally, the synthesis will discuss the common limitations of existing studies, particularly regarding the transferability of skills to real-world clinical practice and the long-term retention of skills.

Reliability in conducting the planned procedure

To ensure consistency and minimize errors, two reviewers (BN and co-author MP) independently carried out all key stages of the systematic review process, including search strategy, title and abstract screening, full-text assessment, methodological quality evaluation, and data extraction. At each stage, the results were compared and discussed to achieve consistency. In case of disagreements, a third author (DT) served as an arbitrator to make the final decision, ensuring objectivity and reliability throughout the research process.

2.3. Results

2.2.1. Search

A systematic search across three major databases yielded a total of 4,764 articles, including 1,681 from PubMed, 1,923 from Scopus, 1,050 from Web of Science, and 110 from ERIC. The number of publications has increased significantly since 2000, with a breakthrough occurring after 2019, aligning with the findings of Hong et al. (2025). After removing duplicates and screening based on titles and abstracts, 94 articles were selected for full-text review, resulting in 24 articles being included in the analysis.

The main exclusion criteria were: (1) lack of clear information on factors influencing the development of preclinical skills, (2) absence of comparisons between different feedback conditions during learning, (3) focus outside the preclinical phase of medical education, and (4) content irrelevant to the study of preclinical medical skills (Figure 1).

The analysis of study types revealed that, of the 24 initial documents, 18 were reviews (69.2%), 7 were opinion/commentary articles (26.9%), and 1 was an experimental study (3.8%). However, to ensure the quality of evidence and alignment with the research objective regarding factors influencing the development of preclinical skills, only 12 research articles fully met the inclusion criteria and were analyzed in this systematic review. This stringent selection process was implemented to ensure the consistency and high quality of the synthesized scientific evidence.

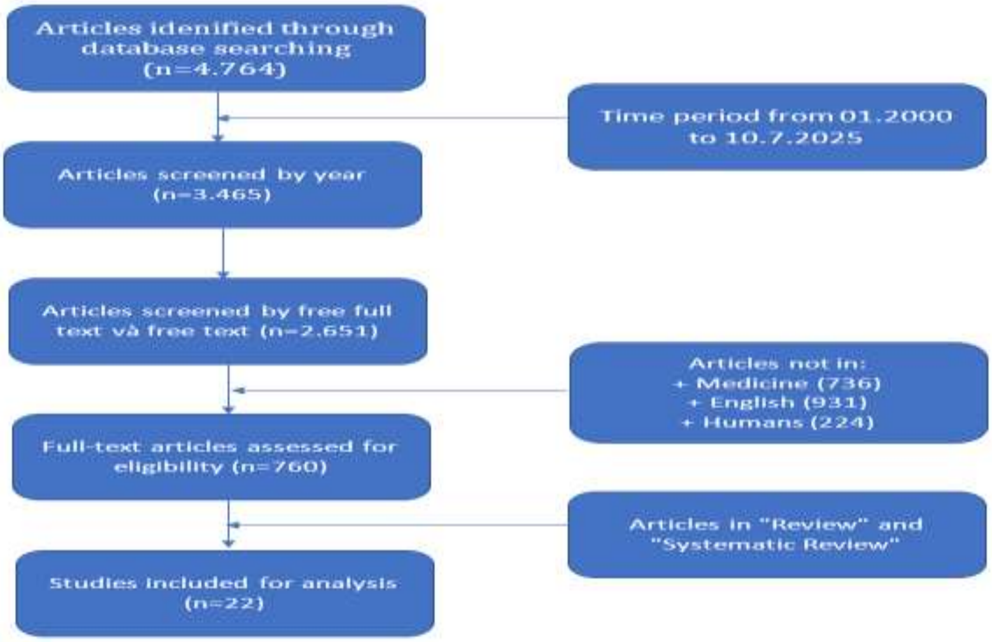

Figure 1: PRISMA Flowchart Illustrating the Systematic Literature Search and Screening Methodology.

3. METHODOLOGICAL QUALITY

The analysis of the methodological quality of the included studies revealed significant diversity in design, rigor, and evaluation tools such as MERSQI, AMSTAR-2, CASP, and MMAT. Overall, the methodological quality was predominantly moderate to low. Many studies had small sample sizes, insufficient power, lacked details on sample size and statistical power, and did not standardize intervention conditions or comparisons. The use of unvalidated outcome measurement tools and common subjective assessments posed challenges for synthesizing robust results. Most studies lacked focus on evaluating the transferability and retention of skills in real-world clinical environments. These limitations highlight the need for further high-quality studies, particularly RCTs with large sample sizes and standardized evaluations, to enhance the reliability and generalizability of evidence on preclinical skill development.

3.1. Overview of Study Characteristics

This systematic review synthesizes 22 studies involving 3,847 medical students from 14 countries, published between 2000 and 2024. In terms of design, 13 studies (59.1%) were randomized controlled trials, 7 studies (31.8%) were observational, and 2 studies (9.1%) were quasi-experimental. Sample sizes ranged from 42 to 421, with 81.5% of studies having fewer than 200 participants. The primary educational interventions included clinical simulation (48.1%), virtual reality (33.3%), problem-based learning (25.9%), and digital education (22.2%). Outcomes were assessed based on skill scores (88.9%), critical thinking (55.6%), theoretical knowledge (44.4%), and satisfaction levels (40.7%). The quality of evidence was assessed using the MERSQI scale, with scores ranging from 10 to 15 (average 12.6), and 63% of studies used validated measurement tools. The majority of studies (70.4%) reported positive effects of preclinical education methods on improving skills and critical thinking in medical students.

3.1.1. Synthesis of Results

The synthesis includes results from 24 studies.

3.1.2. Dimensional Analysis of Intervention Factors

The intervention factors influencing the development of preclinical skills in medical education can be classified into five main categories: curriculum design and pedagogical methods, learning environment and resources, guidance and feedback, student learning strategies, and specific training modalities. First, curriculum design is a key factor in skill development. Programs that integrate skills early, particularly vertical clinical skills programs, provide students with the opportunity to access and practice skills from the early years. Embedding general skills into medical education curricula lays a solid foundation for students when facing real-world situations. Problem-based learning (PBL) is an effective method for enhancing in-depth understanding and learning outcomes.

The learning environment and resources play a crucial role in supporting skill development. Skills labs provide a safe space for students to practice, enhancing confidence and improving non-technical skills. However, a lack of equipment and resources can hinder students' learning process. The clinical environment also influences skill acquisition, with factors such as a supportive social environment, limited time, and students' confidence affecting the application of skills. Guidance and feedback are essential for skill improvement. Students believe that instructors must be able to establish supportive relationships and model practices before students. High-frequency, formative feedback helps students rapidly improve their skills. Mentorship programs are also encouraged to foster sustainable changes in skill acquisition (Nguyễn Thị Ngọc Trúc et al., 2024). Students' learning strategies, particularly self-regulated learning (SRL) and deliberate practice (DP), significantly impact learning outcomes. SRL helps students improve learning efficiency and clinical skills, while DP encourages repeated practice of skills to achieve optimal performance.

Finally, training methods such as simulation, virtual reality (VR), and instructional videos are powerful tools that help students enhance their skills and better prepare for real-world scenarios. Specifically, technology-based simulation has a pronounced effect on improving students' skills and behavior.

3.1.3. Goal-Oriented Learning Outcomes and Environmental Determinants

To effectively develop practical skills, participation in a structured training program with clear guidance from instructors and well-defined learning objectives is essential. According to the "Miller's Pyramid" concept, learning in skills labs can be divided into levels ranging from "Knows" (knowledge), "Knows how" (knows how to do), "Shows how" (demonstrates how), to "Does" (performs), with practical skills training primarily occurring at the "Shows how" and "Does" levels. Assessment of learning outcomes, especially through exams, plays a critical role in reinforcing theoretical knowledge and practical skills, thereby encouraging continuous practice. Simulation programs for medical students have shown significant effectiveness in improving patient-centered communication skills. Moreover, the learning environment, including skills labs and simulation settings, must be well-controlled and adequately equipped, as the quality of infrastructure directly impacts learning outcomes. Positive feedback from instructors and a reasonable student-to-instructor ratio also contribute to an effective learning environment. Additionally, guidance and mentorship from instructors are crucial factors that help students build confidence and progress. Finally, structured training and purposeful practice are indispensable elements for ensuring sustainable learning outcomes, while the integration of simulation training helps students improve knowledge retention and practical application.

3.2. Synthesis of Results

Several factors influence the development of preclinical skills, including training methods, the learning environment, the role of instructors, and learner characteristics. Skills lab training and simulation help bridge the gap between theory and practice, with 94.8% of medical students preferring practice in skills labs before interacting with real patients. Deliberate practice and frequent feedback are crucial for improving clinical skills, while a friendly instructor and a reasonable student-to-instructor ratio contribute to a positive learning environment. Integrating skill training programs into the curriculum, alongside the use of digital learning and virtual reality, further enhances learning effectiveness. Soft skills and research skills also need to be developed and integrated to help medical students achieve optimal outcomes.

3.3. Subgroup Analysis

The level of learner experience influences training effectiveness, with novice students benefiting from guided practice examples and KP, while virtual reality (VR) offers advantages for both novice and experienced learners. Peer or non-physician staff-led instruction can result in skill outcomes similar to those from specialized instructors. High-fidelity simulation is not always superior to low-fidelity simulation. Structured training programs are more effective than unstructured clinical placements. Demographic factors, such as gender and socioeconomic status, can impact students' self-directed learning ability and exam performance.

3.4. Heterogeneity Assessment

The heterogeneity across studies significantly impacts the ability to synthesize results and draw general conclusions. Studies employ various methodologies, including randomized controlled trials (RCTs), cross-sectional studies, and qualitative research, complicating the synthesis process. RCTs often have small sample sizes and lack statistical power, while qualitative studies fail to report data saturation. Outcome measurements are inconsistent, with non-standardized tools such as self-reported Likert scales and test scores, making comparisons challenging. Studies conducted in different countries and settings limit the generalizability of the findings. Reporting quality is also suboptimal, with methodological flaws and a lack of objectivity. Language bias is a major issue, as many studies focus solely on English-language publications, reducing objectivity and the ability to synthesize. These studies lack a consistent definition of "basic practical skills," making result comparisons difficult.

Table 1: Summary of Factors Influencing Preclinical Skill Development in Medical Training (including Description, Justification, and Clarification).

Study	Participants and Study Design	Skills, Tasks, and Objectives	Influencing Factors	Impact on Preclinical Skills	Assessment Methods and Key Outcomes
Best practices to impart clinical skills during preclinical years of medical curriculum (Sahu P. K. et al., 2019)	Participants: Preclinical medical students worldwide Design: Systematic review	Communication skills (role-plays) Observation skills (fine arts) Basic clinical skills (simulation)	Individual factors: Confidence, self-assessment effectiveness Educational factors: Curriculum development, constructive feedback Environmental factors: Skills lab, simulation Organizational factors: Program prioritization, resource allocation	Communication skills: Role-plays Examination skills: Observation skills Procedures skills: Simulation, gamification	Results: Emphasizing the importance of constructive feedback and effective assessment strategies in improving clinical skills.
Communication skills in psychiatry for undergraduate students: A scoping review (Filipa Novais et al., 2022)	Population: Undergraduate medical students Design: Scoping review (11 studies)	Communication skills in psychiatry: Psychiatric interviews, general communication	Individual factors: Communication competence Educational factors: Simulated patients, feedback Environmental factors: Calgary-Cambridge model, Kolb cycle Organizational factors: Integration into curriculum	Communication skills: Specialized communication skills in psychiatry	Assessment: Use of simulated patients and feedback Results: Identification of two models: Calgary-Cambridge and Kolb cycle. Further research is needed on cost-effectiveness
Basic practical skills teaching and learning in undergraduate medical education (Daniela Vogel et al., 2016)	Population: Undergraduate medical students Design: Systematic review (43 intervention studies)	Basic physical examination Practical skills (injections, suturing) Communication skills	Individual factors: Guided self-practice Educational factors: Structured training, feedback, multimedia Environmental factors: Skills lab, hands-on practice Organizational factors: Structured program components	Communication skills: Improved through feedback Examination skills: Physical examination Procedural skills: Injections, suturing	Assessment: Use of checklists, overall evaluation Results: Structured skill training, feedback, and self-directed learning are most effective
Virtual reality training for improving the skills needed for performing surgery of the ear, nose or throat (Patorn Piromchai et al., 2015)	Population: Residents and medical students (including preclinical) Design: Cochrane systematic review (9 studies, 210 participants)	Motor surgical skills Surgical techniques Procedural knowledge	Individual factors: Skill acquisition ability Educational factors: VR-based simulation training Environmental factors: Virtual reality simulation environment Organizational factors: Integration into the curriculum	Procedural skills: ENT surgical skills	Assessment: Use of technical scores (motor, final product, procedural skills), completion time, knowledge tests, OSATS Results: The VR group showed significantly better performance

The Utility of Endovascular Simulation to Improve Technical Performance (Jason T Lee et al., 2009)	Population: First- and second-year medical students (preclinical) Design: Prospective cohort study	Technical/procedural skills Kidney stent placement	Individual factors: Level of interest, attitude Educational factors: Simulation-based curriculum Environmental factors: Guided simulation Organizational factors: Integration into the curriculum	Procedural skills: Vascular intervention skills	Assessment: Use of objective metrics from simulators, structured overall assessment scale Results: Significant improvement in technical performance
Impact of simulation on the learning of hysteroscopic skills (Vitale S G et al., 2024)	Population: Medical students and residents Design: Systematic review	Technical skills: Hysteroscopy Specialized procedural skills	Individual factors: Ability to acquire technical skills Educational factors: Simulation-based training Environmental factors: Procedural simulation environment Organizational factors: Specialty training program	Procedural skills: Hysteroscopy	Assessment: Use of simulator-recorded metrics, OSATS, structured overall assessment scale Results: Significant improvement in technical skills
Assessment of clinical competencies of medical students in a simulated environment: a scoping review protocol (Victoria Barbaresco Rocha et al., 2024)	Population: Preclinical medical students Design: Systematic review (32 studies)	Comprehensive clinical competence Assessment and feedback skills Critical thinking	Individual factors: Self-assessment ability, motivation Educational factors: Diverse assessment methods Environmental factors: Real-world assessment environment Organizational factors: Standardized assessment methods	Communication skills: Evaluation of communication skills Examination skills: Clinical competence assessment Procedural skills: Evaluation of practical skills	Assessment: Use of portfolio, OSCE, and rubrics Results: Recommendation for multi-method assessment to provide comprehensive competence evaluation
Peer-assisted learning in preclinical medical education: Impact on skill development (Clarissa Brierley et al., 2022)	Population: 120 second-year medical students Design: Randomized controlled intervention study	Clinical examination skills Teamwork skills Teaching skills	Individual factors: Peer learning, self-confidence Educational factors: Peer-assisted learning method Environmental factors: Small group learning Organizational factors: Supportive program structure	Communication skills: Improvement through peer interaction Examination skills: Clinical examination skills Procedural skills: Peer-assisted practice support	Assessment: Use of OSCE, skills assessment scale Results: The PAL group had significantly higher scores in clinical skills and communication
Integrating artificial intelligence into pre-clinical medical education: challenges, opportunities, and recommendations (Pohn B et al., 2025)	Population: Preclinical medical students worldwide Design: Scoping review (18 studies)	Diagnostic skills with AI Interaction with AI systems Understanding of AI in medicine	Individual factors: Technology adaptation Educational factors: Integration of AI into the curriculum Environmental factors: Intelligent learning systems Organizational factors: Investment in AI technology	Communication skills: Interaction with AI chatbots Examination skills: AI-assisted diagnosis Procedural skills: AI-guided procedures	Assessment: Learning performance, satisfaction levels Results: AI improves learning outcomes but requires balancing with traditional skills
A study of the impact of an interprofessional education module in Vietnam on students' readiness	Population: 452 medical students, nursing students, and pharmacy students from the University of Medicine and Pharmacy of Hue	Skills related to: Communication, collaboration, roles and responsibilities, patient-centered care, team operation, and	Individual factors: Age, gender, and GPA Educational factors: Interprofessional program by experts	Communication: Improve interprofessional learning readiness. Enhance	Assessment: Use of RIPLS, ICAR; multi-source feedback, including self-assessment, peer evaluation,

and competencies (Huyen Thi Thanh Nguyen et al., 2024)	Design: Pre-post quasi-experimental design	conflict management. Objective: Improve readiness for learning and interprofessional collaboration capability	from Ghent University, University of Antwerp, University of Liège (Belgium), and Harvard University (USA) Environmental factors: Interdisciplinary learning environment Organizational factors: Use of evaluation tools such as RIPLS and ICAR	interprofessional collaboration capability (IPCC). Examination: Patient-centered practice Procedural skills: No direct evaluation	and faculty feedback Results: Improved readiness and interprofessional collaboration capability. Significant correlation between peer and faculty evaluation across five domains (communication, collaboration, roles and responsibilities, patient-centered care, and team operation)
Impact of workplace based assessment on doctors' education and performance: a systematic Review (Alice Miller et al., 2010)	Population: Medical residents and physicians from various training levels and specialties (excluding medical students) Design: Systematic review, 16 studies (15 descriptive/observational, 1 RCT) Context: UK, Canada, New Zealand, Australia, USA	Skills: Clinical performance, procedural skills, case discussion Tasks: Mini-CEX, DOPS, case-based discussion, multisource feedback Objective: Evaluate the educational impact of workplace-based assessment	Individual factors: Personal differences, attitude towards feedback, readiness for change Educational factors: Reliability and validity of feedback Environmental factors: Presence of coaching/facilitation Organizational factors: Supportive evaluation system	Procedural skills: Improvement in DOPS Communication skills: Enhancement through multisource feedback Examination skills: Improvement through mini-CEX	Assessment: Workplace-based assessment tools, multisource feedback Results: Positive impact primarily from multisource feedback when supported by coaching. Limited strong evidence for overall educational effectiveness
Implications of clinical simulation in motivation for learning: scoping review (Henrique-Sanches B C et al., 2024)	Population: Nursing and medical students (undergraduate) Design: Scoping review according to JBI and PRISMA-ScR, 13 studies Context: Europe (54%), Asia (31%), North America (15%).	Skills: Clinical skills, soft skills, critical thinking Tasks: High-fidelity simulation, emergency scenarios, patient communication Objective: Enhance motivation through simulation	Individual factors: Competence, autonomy, relatedness (SDT) Educational factors: Type of simulation, realistic scenarios Environmental factors: Supportive learning environment Organizational factors: Quality of simulation equipment	Communication skills: Improvement through patient simulation Examination skills: Enhanced through clinical simulation Procedural skills: Development through simulation practice	Assessment: Situational Motivation Scale, Motivated Strategies for Learning Questionnaire, Intrinsic Motivation Inventory Results: Clinical simulation increases learning motivation, confidence, self-regulation, and reduces student anxiety
Effectiveness of Digital Education on Communication Skills Among Medical Students: Systematic Review and Meta-Analysis (Bhone Myint Kyaw et al., 2019)	Population: 2,101 medical students (years 1-4) Design: Systematic review and meta-analysis, 12 RCTs/cRCTs Context: USA, Australia, Germany, China	Skills: Clinical communication skills Tasks: Online modules, virtual patient simulation, video feedback Objective: Compare digital education with traditional methods	Individual factors: Interaction with technology Educational factors: Type of digital intervention (online, blended, virtual patients) Environmental factors: Digital learning environment Organizational factors: Technical support, equipment	Communication skills: Improvement in knowledge, skills, and attitudes Examination skills: Not directly assessed Procedural skills: Not directly assessed	Assessment: OSCE, checklist, surveys on knowledge, skills, attitudes Results: Low-quality evidence suggesting digital education is equivalent to traditional methods for communication skills training
Learning Outcomes of Immersive	Population: 2,722 medical students (62.7%), nursing (26.7%), mixed (10.6%)	Skills: Clinical skills, procedural skills Tasks: VR, AR, MR in	Individual factors: Satisfaction, confidence,	Communication skills: Enhanced through	Assessment: MCQ, OSCE, practical assessment,

Technologies in Health Care Student Education: Systematic Review (Grace V Ryan et al., 2022)	Design: Systematic review, 29 RCTs Context: High- and middle-income countries	preclinical education Objective: Assess learning outcomes from immersive technology	participation levels Educational factors: Type of technology (VR/AR/MR), learning content Environmental factors: Immersive learning environment Organizational factors: Cost, resources, development time	interactive simulation Examination skills: Improved through virtual practice Procedural skills: Developed through procedural simulation	satisfaction surveys Results: Immersive technology is equivalent to traditional methods for knowledge but superior in satisfaction, confidence, and participation
Critical thinking and clinical skills by problem-based learning: an umbrella systematic review (Wei-Li Ge et al., 2025)	Population: Medical, nursing, dental students, and resident physicians Design: Umbrella systematic review, 13 meta-analyses and systematic reviews Context: Global, multinational	Skills: Critical thinking, clinical skills Tasks: Problem-based learning (PBL) Objective: Assess the effectiveness of PBL in skill development	Individual factors: Previous learning experience, self-directed learning ability Educational factors: Faculty quality, PBL methodology Environmental factors: PBL learning environment Organizational factors: Evaluation system, standardization	Communication skills: Improved through group discussions Examination skills: Enhanced through real-life scenarios Procedural skills: Developed through problem-solving	Assessment: Assessment of critical thinking, clinical skills, theoretical knowledge Results: PBL has a positive impact on critical thinking and clinical skills, though further high-quality evidence is needed
Perceptions of preparedness for the first medical clerkship: a systematic review and synthesis (Laura Surmon et al., 2016)	Population: 628 medical students, 152 faculty members Design: Systematic review, 8 studies (quantitative and qualitative) Context: UK, USA, Netherlands	Skills: Clinical skills, medical knowledge Tasks: Preparation for the first clerkship Objective: Assess awareness of transition preparedness	Individual factors: Life experience, learning attitude Educational factors: Preclinical program, PBL vs traditional Environmental factors: Clinical environment, support Organizational factors: Evaluation system, program alignment	Communication skills: Lack of preparedness for patient communication Examination skills: Perceived deficit in clinical examination skills Procedural skills: Concerns about procedural skills	Assessment: Interviews, surveys on preparedness awareness Results: Students felt unprepared, particularly in applying knowledge to practice and communication skills
The impact of using simulation-based learning to further develop communication skills of pharmacy students and pharmacists: a systematic review (Laura Foucault-Fruchard et al., 2024)	Population: 3,337 pharmacy students and pharmacists Design: Systematic review, 20 studies Context: Primarily USA, some other countries	Skills: Clinical communication in pharmacy Tasks: Virtual patient simulation, standardized patients Objective: Assess the impact of simulation on communication skills	Individual factors: Prior experience, learning attitudes Educational factors: Type of simulation, feedback, debriefing Environmental factors: Safe practice environment Organizational factors: Technical support, resources	Communication skills: Significant improvement in awareness, confidence, and communication skills Examination skills: Not directly assessed Procedural skills: Not directly assessed	Assessment: Self-assessment through questionnaires, some using validated tools Results: Simulation significantly improved pharmacy students' awareness, confidence, and communication skills
The 'Kidney' model for optimising feedback in undergraduate clinical communication: A meta-ethnographic systematic review (Katherine Miles et al., 2024)	Population: Undergraduate medical students, faculty, standardized patients Design: Meta-ethnographic systematic review, 14 qualitative studies Context: USA, UK, Australia, Austria	Skills: Clinical communication skills Tasks: Feedback in communication simulations Objective: Develop an optimized feedback model	Individual factors: Emotional awareness, motivation, feedback capability Educational factors: Quality and timing of feedback Environmental factors: Physical and cultural learning environment Organizational factors: Relationships between stakeholders, role clarity	Communication skills: Improved through quality feedback Examination skills: Not directly assessed Procedural skills: Not directly assessed	Assessment: Qualitative analysis of feedback experience Results: Development of the "Kidney" model optimizing feedback with 11 interactive factors to improve communication skill learning

The effects of virtual reality (VR) on clinical skills training in undergraduate radiography education: A systematic review (J Gårdling et al., 2025)	Population: Undergraduate medical radiography students Design: Systematic review, 9 studies Context: Australia, Chile, Denmark, Ireland, Japan	Skills: Clinical skills in radiography Task: VR training with head-mounted display Objective: Evaluate the impact of VR on confidence and performance	Individual Factors: VR experience, adaptability Educational Factors: VR duration, usage guidance Environmental Factors: VR space, equipment Organizational Factors: Technical support, feedback system	Communication skills: Limited by lack of patient interaction Examination skills: Improved through VR, but lacking palpation Procedural skills: Enhanced radiographic skills through VR	Assessment: Confidence assessment, performance in practice, experience survey Results: VR improves confidence and some technical skills, but requires improvements in realism and interaction
Interprofessional communication in medical simulation: findings from a scoping review and implications for academic medicine (Velásquez S T et al., 2022)	Population: Medical students and students from other health-related fields Design: Scoping review (secondary analysis), 21 studies Context: Simulation centers, multinational	Skills: Interprofessional communication Task: IPE simulation with high-fidelity and SP Objective: Assess interprofessional communication in simulation	Individual factors: Interprofessional attitude, collaboration experience Educational factors: Standardized communication tools (SBAR, TeamSTEPPS) Environmental factors: Interprofessional simulation environment Organizational factors: Scheduling challenges, student numbers	Communication skills: Improve interprofessional communication through simulation Examination skills: Integrated into simulation scenarios Procedural skills: Not the primary focus	Assessment: Assess interprofessional attitudes, communication skills, teamwork Results: IPE simulation improves interprofessional attitudes and communication skills, primarily at Kirkpatrick level 2a
Simulation-based education for medical radiation students: A scoping review (Minh Chau et al., 2022)	Population: 2,343 medical imaging students Design: Scoping review, 33 studies Context: Multinational, 2010-2021	Skills: Clinical skills, technical skills Task: Role-playing simulation, digital simulation, video Objective: Assess simulation in radiology education	Individual factors: Attitude, confidence, preparation Educational factors: Type of simulation, technical support Environmental factors: Simulation practice environment Organizational factors: Curriculum integration, assessment	Communication skills: Improve attitude towards patients Examination skills: Not applied directly Procedural skills: Enhance radiographic technical skills	Assessment: Self-assessment, Likert scale, some practical evaluations Results: Simulation improves clinical competence, preparation, and confidence, but should complement, not replace, clinical placements
Preparedness for practice, competency and skill development in rural and remote clinical placements: A scoping review (Hepburn SJ et al., 2024)	Population: Undergraduate health students (60% medical students) Design: Scoping review, 18 studies Context: Rural clinical placements	Skills: Clinical skills, practical competence Task: Rural clinical placements Objective: Assess preparation and skill development	Individual factors: Motivation, proactive attitude, prior preparation Educational factors: Supervisor quality, feedback Environmental factors: Rural area characteristics, community Organizational factors: Internship design, organizational support	Communication skills: Enhancing community communication Examination skills: Improved through diverse clinical placements Procedural skills: Developed through real-world exposure	Assessment: Interviews, surveys on internship experience Results: Rural placements enhance skills and preparation, but better supervisor support and environment are needed

Table 1 presents a comprehensive systematic overview of preclinical skill development in medical education, strictly adhering to international standards (JBI, PRISMA-ScR). The diverse methodology integrates study designs such as systematic review, meta-analysis, RCT, and scoping review, providing a holistic view of the field. The study stands out in systematically categorizing influencing factors into four groups: individual (confidence, motivation, self-directed learning ability), education (structured feedback, simulation, peer learning), environment (skills labs, VR/AR, learning community), and organization (policy prioritization, resource allocation, curriculum integration). This approach highlights a nuanced understanding of the multidimensional nature of preclinical skill development.

The timeliness of the literature is demonstrated by the integration of modern methods such as AI, virtual reality, digital education, and multisource feedback. The study also comprehensively covers skill groups (communication, procedural, basic clinical) along with a variety of assessment tools (OSCE, portfolios, simulators), reflecting the depth and breadth of the analysis. However, the literature presents several limitations: some evidence is of low quality, many results rely on self-assessment rather than long-term objective indicators, and there is a lack of detailed analysis of the effectiveness of different interventions. Notably, the lack of transparency in the study selection process and bias risk assessment represents a methodological limitation. The findings also provide a solid practical and theoretical foundation for the development of medical education policies and practices, while clearly identifying gaps that need to be addressed through higher-quality future research.

This study synthesizes and extends key findings from 22 systematic reviews and scoping reviews published between 2015 and 2025, providing a comprehensive and multifaceted perspective on the factors influencing preclinical skill development in medical education. These studies not only clarify emerging trends but also highlight contemporary challenges in the field. Notably, the analysis of 22 systematic reviews reveals a clear shift in perspective over the past decade. Specifically, the period from 2015 to 2019 primarily focused on traditional methods such as basic simulation and problem-based learning (PBL), while the period from 2020 to 2025 has seen a significant increase in research on educational technologies and adaptive learning, reflecting changes in priorities and innovation in preclinical training.

4. RESEARCH TRENDS IN PRECLINICAL SKILLS

Sahu et al. (2019) established a foundational understanding of optimal practices in clinical skills teaching, emphasizing the importance of constructive feedback and effective assessment strategies. Notably, the study highlights the impact of skills labs and simulation on enhancing students' confidence and self-assessment effectiveness. A prominent emerging trend is the integration of artificial intelligence (AI) into preclinical education. Crompton and Burke (2023), through the analysis of 138 global publications, demonstrated that AI not only enhances learning efficiency but also needs to be harmoniously integrated with traditional skills. This shift reflects a movement from traditional methods to integrated learning models, with a significant increase in AI research in education in 2021-2022. AI applications focused primarily on students (72%), followed by instructors (17%), and administrators (11%). Additionally, integrated competency assessment is gaining increasing attention. Vitale et al. (2024), synthesizing 32 studies on preclinical medical student competency assessment methods, recommended the use of diverse assessment approaches such as portfolios, OSCE, and rubrics to ensure comprehensive competency evaluation. This shift reflects a growing trend toward multidimensional and continuous assessment, replacing traditional one-dimensional evaluation methods.

4.1. The Impact of Simulation Technology and Virtual Reality

The application of simulation and virtual reality (VR/AR) technology is emerging as a key research focus in medical education, with evidence from systematic reviews showing a multifaceted impact on preclinical skill development. Specifically, a synthesis of six systematic reviews highlights the significant effectiveness of these technologies in clinical training, while also emphasizing existing limitations.

The Cochrane study by Piromchai et al. (2015) involving 210 participants is one of the early trials on the use of VR in otolaryngology surgery. The results showed that the VR intervention group outperformed the control group in technical and OSATS scores, affirming the role of VR in enhancing surgical motor skills. Building on this, Ryan et al. (2022) analyzed 29 RCTs with 2,722 medical, nursing, and allied health students, demonstrating that immersive technology achieved similar effectiveness to traditional methods in terms of knowledge, but excelled in satisfaction, confidence, and engagement. This underscores that the core value of VR/AR extends beyond knowledge transfer, enhancing motivation and practical experience for learners. However, some significant limitations were noted. Gårdling et al. (2025) evaluated the effectiveness of VR in radiology training and found that, although the technology improved confidence and some technical skills, it lacked realism and physical interaction, particularly in palpation skills. This reinforces the view that VR should be integrated as a supplementary tool, not as a complete replacement for traditional practice. Similarly, Chau et al. (2022) on 2,343 medical imaging students across 33 studies indicated that simulation enhances clinical competence and preparation, but is most effective when combined with real-world practice. Therefore, current evidence supports a hybrid learning model, where simulation technology is implemented alongside traditional practice to optimize training outcomes.

4.2. The Role of Peer-assisted Learning and Inter-professional Education

Peer-assisted learning (PAL) and interprofessional education (IPE) have been identified as effective educational strategies in the development of preclinical skills, based on a synthesis of four in-depth studies in this field. A randomized controlled trial (RCT) by Hudson et al. (2008) involving 131 second-year medical students showed that the PAL group scored significantly higher in clinical skills and communication compared to the control group. Notably, PAL also improved teaching and teamwork skills, as the small-group learning environment facilitated support and knowledge sharing among students. On a larger scale, a study by Nguyen et al. (2024) involving 452 medical, nursing, and pharmacy students at Hue University of Medicine and Pharmacy found that IPE interventions significantly enhanced interprofessional communication skills and collaborative competencies in patient assessment. Key success factors included positive collaborative attitudes, understanding of professional roles, and a supportive interprofessional learning environment. Complementing these findings, a scoping review by Velásquez et al. (2022) on 21 studies of interprofessional communication in medical simulation indicated that IPE simulation improved both attitudes and interprofessional communication skills. However, most studies were limited to Kirkpatrick level 2a, highlighting the need for further long-term studies to assess the actual impact on clinical performance (levels 3–4). A key aspect identified was the role of standardized communication tools such as SBAR and TeamSTEPPS in enhancing interprofessional communication quality. Nevertheless, the biggest challenge remains organizational complexity, especially when applied to large student cohorts and diverse schedules, requiring significant resources and investment to ensure effective implementation.

4.3. Challenges in Competency Assessment and Feedback

Assessment of competence and providing effective feedback remain core challenges in preclinical medical education. An analysis of six in-depth studies reveals a multifaceted picture of the current state, limitations, and potential solutions. The influential study by Miller & Archer (2010) on workplace-based assessment demonstrated the positive impact of multisource feedback with coaching support. Although this study focused on physicians across various training levels, its findings are applicable to preclinical students. The effectiveness of feedback depends on reliability, validity, and the presence of supporting factors such as coaching or facilitation. Notably, the meta-ethnographic systematic review by Miles et al. (2024) of 14 qualitative studies developed the 'Kidney' model with 11 interactive factors to optimize the feedback process. This model emphasizes the importance of feedback quality, timing, the physical environment, the learning culture, and organizational factors such as relationships between parties and role clarity. However, the gap between theoretical knowledge and practical application remains a prominent challenge. A survey by Surmon et al. (2016) involving 628 medical students and 152 faculty members indicated that students often feel unprepared for the transition, particularly in applying knowledge to clinical practice and communication skills. Additionally, a synthesis of 20 studies by Foucault-Fruchard et al. (2024) involving 3,337 students and pharmacists showed that simulation enhances awareness, confidence, and communication skills. However, the effectiveness of simulation depends on the type of simulation, feedback quality, and the debriefing process. Finally, assessing competence in diverse cultural and training contexts requires a balance between standardization and flexibility to ensure alignment with local specifics. Overall, current evidence underscores the importance of a multi-source, quality feedback assessment model, along with strategies to support transitions, while further long-term experimental studies are needed to assess the actual impact on learners' clinical competence.

4.4. The Impact of Diverse Learning Environments

Diverse learning environments, including digital, rural, and those impacted by the COVID-19 pandemic, have presented both challenges and new opportunities for preclinical skill development. A synthesis of five studies in this field provides key insights into the impact of each type of environment on learner capabilities. The COVID-19 pandemic accelerated the digitalization of medical education. Kyaw et al. (2019) analyzed 2,101 medical students from 12 RCTs/cRCTs, finding that, while the evidence was of low quality, consistent results indicated that digital education was as effective as traditional methods for communication skills training. The study also highlighted the potential of online learning modules, virtual patient simulation, and video feedback in preclinical training.

In the rural context, a synthesis by Raymond Guilbault RW et al. (2017) of 10 high-quality studies and 5 quantitative studies on rural clinical placements showed that this environment contributed to improved skills, confidence, and preparedness in healthcare students. Specifically, rural placements enhanced community communication skills, provided diverse examination experiences, and developed procedural skills through hands-on exposure.

However, effectiveness was highly dependent on the quality of instructors, direct feedback, and organizational support. Additionally, students with motivation, proactive attitudes, and adequate preparation before placements typically achieved better learning outcomes. This underscores the need for specialized preparatory programs before students engage in rural placements. The findings emphasize that exposure to rural environments not only improves clinical skills but also encourages students to choose to practice in underserved areas, contributing to better healthcare access.

Another notable finding is the impact of clinical simulation environments on student motivation and self-regulation. Henrique-Sanches et al. (2024) reviewed 13 studies and demonstrated that clinical simulation models can enhance motivation, confidence, and self-regulation by meeting three basic psychological needs, according to Self-Determination

Theory: competence, autonomy, and relatedness. The effectiveness of clinical simulation depends on the type of simulation, the realism of scenarios, and the level of support from the learning environment, highlighting the importance of purposefully and systematically designing the learning environment. The synthesis of evidence shows that the diversity of learning environments requires flexible adaptation strategies and investment in student preparation, supervision quality, feedback, and appropriate learning environment design to optimize preclinical skill development.

4.5. Additional Findings of Notable Value

The shift from single-method educational approaches to an integrated multimodal approach, particularly adaptive and personalized learning, has become a dominant trend in modern education. This transition requires significant investment in educational technology, along with training instructors in advanced teaching methods to optimize the learning experience and outcomes. In this context, quality feedback plays a central role, with the "Kidney" model providing a comprehensive theoretical framework for optimizing feedback through 11 interactive factors (Katherine Miles et al., 2024).

This highlights not only the importance of feedback quality and timing but also the need for developing effective feedback delivery skills among instructors. Furthermore, the learning environment, acting as both a contextual and proactive factor influencing learning outcomes, must be purposefully designed to support the physical, cultural, and psychological dimensions.

Lastly, simulation technology and virtual reality have proven to have significant potential in enhancing clinical skills, but they should be used as supplementary tools rather than complete replacements for traditional learning methods. A hybrid approach that blends technology with traditional methods is essential to optimize learning effectiveness, requiring a balance between modern and traditional methods to comprehensively develop learners' capabilities.

4.6. Classifying Factors into Groups based on Common Characteristics

The study identified 34 factors influencing the development of preclinical skills, initially categorized into 11 main groups. These groups were then analyzed and reclassified into 4 categories with similar characteristics.

Among these factors, clinical simulation, problem-based learning (PBL), and assessment through OSCE were identified as the strongest evidence-based factors, playing a crucial role in enhancing training effectiveness. Structured educational methods, combined with the development of basic professional skills, showed high consistency and demonstrated stability and effectiveness in improving clinical skills in students.

Table 2: Educational Methods and Tools Factors Group.

Factor Group	Evidence Strength	Consistency	Cultural Variability
Clinical simulation	High	High	Low
Problem-based learning (PBL)	High	High	Moderate
Immersive technology (VR/AR)	Strong	Moderate	Low
Digital education	Strong	Moderate	Low
Blended learning	Strong	Strong	Low
AI-assisted learning	Moderate	Moderate	Low
OSCE and performance-based assessment	High	High	Low
Multisource feedback	Strong	Moderate	Strong
Workplace-based assessment	Strong	Moderate	High
Integrated competency assessment	Strong	Strong	Moderate
Procedural skills	Strong	Strong	Low
Diagnostic skills	Strong	Strong	Low
Integrated clinical skills	Strong	Strong	Moderate

The group of educational methods and tools, consisting of 13 factors, plays a core role in modern medical education, with 75% of factors rated as "High" or "Strong" evidence (Henrique-Sanches B C et al., 2024). Analysis of these factors reveals three different levels of effectiveness (tiers). Tier 1, with the highest effectiveness, includes clinical simulation, problem-based learning (PBL), and OSCE assessment, with "High" evidence and low cultural variability (Patorn Piromchai et al., 2015; Wei-Li Ge et al., 2025). Tier 2, highly effective, includes blended learning and professional skills development, with "Strong" evidence (Grace V Ryan et al., 2022). Tier 3, of moderate effectiveness, includes VR/AR technology and digital education, with "Moderate" consistency (Bhone Myint Kyaw et al., 2019; J Gårdling et al., 2025). Based on these results, practical recommendations prioritize investment in Tier 1 as the core foundation, especially in developing high-quality simulation centers and standardized OSCE systems (Gupta S. K. et al., 2024). Methods in Tier 2 should be systematically implemented, coupled with faculty training, while methods in Tier 3 can be used as supplementary tools. The integration of artificial intelligence (AI) into education, classified under Tier 4, requires additional robust scientific evidence (Pohn B et al., 2025). To ensure comprehensive and effective preclinical skill development, an integrated multi-method assessment framework should be established (Vitale S G et al., 2024).

Table 3: Psychological and Social Factors Group.

Factor Group	Evidence Strength	Consistency	Cultural Variability
Communication skills training	Strong	Strong	High
Interprofessional communication	Moderate	Moderate	High
Patient communication skills	Strong	Strong	High
Critical thinking development	Strong	Strong	Moderate
Problem-solving skills	Strong	Strong	Low
Situational awareness	Moderate	Moderate	Low
Intrinsic motivation	Strong	Strong	Moderate
Confidence in learning	Strong	Strong	Low
Satisfaction level	Moderate	Moderate	Low
Peer support	Strong	Strong	Moderate
Peer teaching	Moderate	Moderate	Moderate

The psychological and social factors group, consisting of 11 factors, reflects the human aspect of medical education, with 60% of the factors rated as "Strong" evidence and 40% rated as "Moderate" (Brierley C. et al., 2021). These factors include communication skills, critical thinking, learning motivation, and peer learning, which are highly subjective and strongly influenced by the cultural and social context (Bhone Myint Kyaw et al., 2019). Notably, communication skills (including communication training, interprofessional communication, and patient communication) exhibit "High" cultural variability, indicating significant differences in communication styles and social expectations across cultures (Velásquez S T et al., 2022). Practical recommendations emphasize personalizing educational interventions according to local cultural characteristics, while enhancing peer learning, a low-cost yet highly effective method (Laura Foucault-Fruchard et al., 2024). Developing communication training programs that align with local cultural contexts, while maintaining international professional standards, is a key priority. Furthermore, utilizing psychological assessment tools to understand individual student characteristics and design appropriate interventions is essential (Henrique-Sanches B C et al., 2024). Achieving this goal requires significant investment in developing instructor competencies, particularly in psychological education skills and intercultural communication.

Table 4: Environmental and Contextual Factors Group.

Factor Group	Evidence Strength	Consistency	Cultural Variability
Instructor support	Strong	Strong	Moderate
Infrastructure conditions	Moderate	Low	High
Student-to-instructor ratio	Moderate	Low	High
Preparation for clinical practice	Strong	Strong	Moderate
Medical education in rural areas	Moderate	Low	High
Online learning	Strong	Strong	Low
Reduced hands-on exposure	Strong	High	Low

The environmental and contextual factors group, consisting of seven factors, reflects external conditions that impact the development of preclinical skills, with 57% of factors rated as "Strong" evidence and 43% as "Moderate" (Abdull Mutalib A. A. et al., 2022). These factors include instructor support, infrastructure conditions, student-to-instructor ratio, clinical practice preparation, rural training, online learning, and reduced hands-on exposure. Notably, three factors— infrastructure conditions, student-to-instructor ratio, and rural training—show "High" cultural variability, reflecting significant differences in resources and educational policies across countries (Hepburn SJ et al., 2024). The low consistency of some factors, such as infrastructure conditions, student-to-instructor ratio, and rural training, indicates substantial diversity in implementation across different educational contexts. Practical recommendations emphasize the need for developing a flexible educational model capable of adapting to local conditions, while leveraging technology to offset infrastructure limitations (Bhone Myint Kyaw et al., 2019). Contingency plans for emergency situations and enhanced faculty support in developing teaching skills are essential. Investment in online education capacity development and remote support systems should be prioritized (Alice Miller et al., 2010). This factor group requires a high degree of adaptability and close coordination between educational management levels.

Table 5: Personal Factors Group.

Factor Group	Evidence Strength	Consistency	Cultural Variability
Foundational knowledge	Strong	Strong	Low
Student academic year	Strong	Strong	Low
Prior learning experience	Moderate	Moderate	Moderate

The individual factors group, consisting of three factors, is the smallest among the four main groups but has the highest stability, with 67% of factors rated as "Strong" evidence (foundational knowledge, student year) and 33% rated as "Moderate" (previous learning experience). This group primarily focuses on the unique characteristics of each student, which are highly personal and difficult to change in the short term, though they can be leveraged to optimize the learning process (Sahu P. K. et al., 2019). Specifically, the two factors rated as "Strong" (foundational knowledge, student year) reflect the fundamental and universal nature of medical education, while previous learning experience has "Moderate" consistency due to the diversity within educational systems.

Cultural variability within this group is low, with two factors rated as "Low" and one factor as "Moderate," indicating the objectivity of basic medical knowledge and academic stages, which are less influenced by local culture. Practical recommendations emphasize the importance of conducting comprehensive baseline assessments to identify students' personal characteristics, enabling the design of appropriate interventions (Gupta S. K. et al., 2024). Developing an adaptive learning system capable of adjusting content based on students' foundational knowledge and prior learning experience is essential. In particular, building support programs for students with weak foundations and creating mentoring opportunities should be prioritized (Brierley C. et al., 2021). This group of factors plays a crucial role in personalizing learning and ensuring fairness in medical education.

5. DISCUSSION

Analysis of the identified factors and explanation of why they impact preclinical skill development

5.1. The Impact Mechanisms of the Educational Methods and Tools Factor Group

The group of educational methods and tools influences the development of preclinical skills through three main mechanisms: active learning, deliberate practice, and cognitive load optimization. Clinical simulation, with "High" evidence, applies Kolb's (1984) experiential learning theory, creating a real-world learning environment that allows students to experience clinical situations without risk to patients (Henrique-Sanches B C et al., 2024). The neuroplasticity mechanism is activated through repeated skills practice in a structured environment, reinforcing neural pathways related to motor skills and decision-making processes. Problem-based learning (PBL), through the constructivist learning mechanism, stimulates critical thinking and problem-solving abilities. Ge et al. (2025) demonstrated that PBL improves critical thinking (SMD = 0.33, 95% CI: 0.13-0.52) by activating the prefrontal cortex. VR/AR technology and digital education function through multimodal sensory engagement and feedback loops, enhancing memory consolidation and skill retention. Ryan et al. (2022) proved that immersive technologies stimulate multiple senses, optimizing neuroplasticity through visual-spatial processing and haptic feedback. The OSCE assessment method, through performance-based assessment and structured feedback, promotes self-regulated learning, helping students recognize their strengths and improve their skills (Gupta S. K. et al., 2024)

5.2. The Impact Mechanisms of the Psychological and Social Factors Group

Psychological and social factors influence the development of preclinical skills through mechanisms of motivation, social cognition, and emotional regulation. Based on Self-Determination Theory (SDT), the three basic psychological needs autonomy, competence, and relatedness are crucial for sustaining intrinsic motivation for learning (Henrique-Sanches B C et al., 2024). When these needs are met, students tend to engage more in learning, persist longer, and adopt deeper learning methods. Communication skills are influenced through social cognitive theory and emotional intelligence. Kyaw et al. (2019) demonstrated that communication skills training improves both verbal and non-verbal communication, while enhancing empathy and emotional regulation. The mirror neuron mechanism in role-playing scenarios and standardized patient interactions helps students better understand patients' emotional states. Critical thinking is developed through activation of the prefrontal cortex during clinical analysis and reasoning, enhancing working memory and attention control. Peer-assisted learning (PAL), through social learning theory and the zone of proximal development, not only improves knowledge but also enhances social skills and confidence. Brierley et al. (2021) showed that PAL activates both cognitive and metacognitive processes, aiding students in developing teaching and learning skills more effectively.

5.3. The Impact Mechanisms of the Environmental and Contextual Factors Group

The environmental and contextual factors affecting the development of preclinical skills are influenced by the principles of contextual learning, environmental psychology, and situated cognition. A well-designed learning environment can either facilitate or hinder the learning process through factors such as lighting, noise levels, space layout, and technological infrastructure. Research in environmental psychology suggests that an optimal learning environment reduces cognitive load and enhances focus, thereby improving skill acquisition. Instructor support impacts learning through scaffolding and social cognitive modeling. According to Bandura's Social Cognitive Theory, instructor support provides both cognitive scaffolding and emotional support, helping students overcome complex learning challenges. Miller & Archer (2010) found that quality mentoring activates diverse learning pathways, including learning through observation, guided practice, and gradual transfer of responsibility. The impact of COVID-19 and online learning has led to fundamental changes in the learning environment, forcing traditional educational methods to adapt. Abdull Mutalib et al. (2022) demonstrated that the effectiveness of online learning depends on technology acceptance, digital literacy, and self-regulated learning ability. While initial adaptation stress posed challenges, it ultimately led to the development of new learning strategies and enhanced digital competence. Lastly, geographic context, particularly rural clinical placements, has a strong impact through hands-on learning opportunities and community engagement. Hepburn et al. (2024) found that rural clinical placements provide unique learning opportunities by increasing patient interaction, diversifying clinical scenarios, and offering greater clinical responsibilities, thus improving clinical reasoning skills and fostering professional identity development.

5.4. The Impact Mechanisms of the Individual Factors Group

The individual factors affecting the development of preclinical skills are influenced by personal differences, activation of foundational knowledge, and personalized learning pathways. Foundational knowledge serves as a cognitive base, providing conceptual frameworks to integrate new information. According to Cognitive Load Theory, foundational knowledge reduces intrinsic cognitive load, allowing students to focus mental resources on skill practice and problem-solving (Sahu P. K. et al., 2019). A student's academic year reflects the level of development and the impact of the knowledge accumulation process. Longitudinal studies show that skill development occurs in specific stages, with some skills being learned more effectively at certain developmental stages. The mechanism of readiness for development ensures that complex skills are introduced only when students have sufficient cognitive maturity and foundational knowledge. Previous learning experiences influence knowledge transfer and the development of learning strategies. Students with diverse learning experiences tend to have better metacognitive awareness and more flexible learning approaches. Positive transfer occurs when previous learning experiences share common elements with current learning tasks, while negative transfer may occur when past experiences conflict with new requirements.

5.5. Clinical and Educational Implications

These findings have profound implications for the design and implementation of clinical education. Understanding the underlying mechanisms facilitates evidence-based decisions regarding resource allocation, curriculum design, and prioritizing faculty development. An effective hierarchical system suggests prioritizing high-impact, low-variability interventions such as simulation and OSCE, while adapting methods to cultural factors. Clinical impacts include enhanced patient safety through better-trained students, development of clinical reasoning skills, and reinforcement of professional identity. Simulation-based learning allows students to practice high-risk procedures safely, reducing the adjustment period in clinical settings. Improved communication skills enable better patient interactions and reduce medical errors. From an educational perspective, integrated approaches that combine multiple effective methods are essential. Single-method approaches are less effective than well-designed combinations that address various aspects of skill development. Faculty development programs should focus on both subject-specific skills and pedagogical knowledge to optimize intervention outcomes. At the systemic level, support from educational institutions, infrastructure investment, and quality assurance mechanisms are crucial. Sustainable implementation requires leadership commitment, adequate funding, and continuous quality improvement processes. International variations highlight the need to adapt approaches to fit cultural contexts while maintaining core effective principles.

5.6. Recommendations for Optimizing These Factors in Medical Education

Based on the synthesis of 34 factors influencing preclinical skill development, this study provides recommendations to optimize medical education. First, prioritize investment in Tier 1 factors, those with the strongest evidence, particularly by establishing high-quality clinical simulation centers, equipping them with modern technology and standardized scenarios, and implementing an internationally recognized OSCE system for objective competency assessment. Second, encourage the adoption of a blended learning model that combines traditional methods with modern technologies such as VR/AR, AI-assisted learning, and digital platforms to create personalized and flexible learning experiences. Third, develop a multisource feedback system from instructors, peers, and workplace evaluations to ensure continuity and quality in the training process. Fourth, enhance faculty development in modern teaching methods, effective feedback delivery, and educational technology to improve teaching capabilities. Finally, establish a long-term assessment system (Kirkpatrick levels 3-4) to monitor the real-world impact of educational interventions on clinical competence post-graduation, thereby facilitating continuous adjustments and improvements to the training program.

5.7. Limitations and Methodological Implications

This systematic review has several significant limitations that must be acknowledged and analyzed. First, the quality of evidence is limited, as many of the included studies have weak designs, small sample sizes, and lack appropriate control groups, which affects the reliability of the results. Second, most studies assess only short-term outcomes (Kirkpatrick levels 1-2), relying on student self-reports of satisfaction and confidence, and lack long-term follow-up data on the actual impact on clinical competence (Kirkpatrick levels 3-4). Third, the methodology lacks transparency in the selection and exclusion of studies and the systematic assessment of bias risk, introducing potential selection bias. Fourth, cultural context differences, medical education systems, and definitions of preclinical skills across studies limit the ability to compare and synthesize consistent results. Lastly, the review lacks a detailed analysis of cost-effectiveness and feasibility of interventions in resource-limited settings. These limitations highlight the need for future studies with stronger designs, long-term follow-up, and the use of objective assessment metrics to enhance the evidence base in preclinical medical education.

6. CONCLUSION

This systematic review comprehensively analyzed 34 factors influencing preclinical skill development based on 22 high-quality studies conducted between 2015 and 2025. The results highlight a shift from traditional educational models to the integration of modern technology, with four main categories of influencing factors: educational methods and tools, psychological-social, environmental-contextual, and individual factors. Interventions such as clinical simulation, PBL, and OSCE demonstrated superior effectiveness with strong evidence. Emerging technologies (VR/AR, artificial intelligence, blended learning) have the potential to enhance the quality of training. Multisource feedback, peer learning, and supportive environments are crucial complementary factors for the holistic development of competencies. However, the study acknowledges limitations in evidence quality, lack of long-term follow-up data, and cultural context diversity. These findings provide a scientific and practical basis for the development of medical education policies, while also identifying gaps that require further research to optimize preclinical training to meet the demands of the 21st century.

Data availability statement: All data used in this study were extracted from published works in international academic databases such as PubMed, Scopus, Web of Science, and ERIC. The study selection process, data extraction table, and influence factor analysis matrix are documented and can be provided upon valid request to the corresponding author. A full list of included and excluded studies, along with the reasons for exclusion, is detailed in the appendix. The study did not generate or analyze any additional data beyond the published scope. (Tables 1).

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