RESEARCH PAPER

Cost-Effective Simulation Approaches for Effective Skill Training in Undergraduate Pathology.

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ABSTRACT

Background: Traditional pathology training, reliant on microscopy and preserved specimens, faces challenges of cost, student engagement, and skill transfer. Though simulation-based education offers a solution, high-fidelity simulations are often too costly. This study weighed a cost-effective simulation model for undergraduate pathology skill training.

Methods: A mixed-methods, crossover study was accompanied with 150 medical students randomly distributed into two groups. Group A undertook traditional training, while Group B received simulation-based training by means of freely available digital resources (virtual microscopy, 3D gross specimens) on internet. Following initial exercise on gastrointestinal and respiratory pathology, groups crossed over for liver and renal pathology exercise.

Quantitative valuation used pre-/post- test MCQs and Objective Structured Practical Examinations (OSPE). Qualitative data was collected through focus group discussions. A cost-analysis compared both the training techniques.

Results: The simulation group revealed significantly better progress in post-test MCQ scores (85.6 vs. 72.1, $p<0.01$) and better OSPE performance in slide identification (82.3 vs. 68.5, $p<0.01$) and gross specimen diagnosis (79.8 vs. 65.4, $p<0.01$). Qualitative exploration shown simulation was observed as more engaging, interactive, and effective for conceptual kind and confidence building. The crossover confirmed simulation's effectiveness, with the traditional group showing major improvement after receiving simulation training. Cost-analysis showed the simulation model applied free resources versus significant costs for traditional materials.

Conclusion: A cost-effective simulation approach considerably enhances knowledge acquisition, practical skills, and student engagement in pathology learning. A blended model, where simulation-based training precedes traditional methods, is suggested as an effective, efficient, and sustainable approach for undergraduate pathology education.

Keywords: Cost-effective, Pathology, Simulation

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INTRODUCTION:

Pathology often referred to as the "bridge" between the fundamental sciences and clinical medicine, plays a crucial role in undergraduate medical education.[1] It is a branch of medicine that studies how disease is caused by structural and functional adaptations in cells, tissues, and organs.

Developing clinical reasoning, making correct diagnoses, and guiding efficient patient care all depend on having a comprehensive understanding of pathology.[2] However, the conventional educational models used to teach this visually and conceptually complex subject are coming under increasing pressure to prove their usefulness and efficacy as medical knowledge grows and health care systems change.[3]

Simulation-based education has become an innovative force in response to these issues. Simulation-based education is described as "a method that creates a circumstance or setting that empowers people to practice a simulation of an actual event for learning, assessment, testing, or to better comprehend human behavior or systems".[4] Its application in a variety of medical specialties, from anesthesiology to surgery, has revealed strong advantages, such as superior clinical judgment, improved technical proficiency, and a reduction in medical errors.[5]

Virtual microscopy (VM) and interactive digital gross specimen libraries are two of the most effective simulation tools that have emerged in pathology as a result of the digital revolution.[6]

High-fidelity simulation has been shown to be effective, but its widespread use is frequently hampered by high costs. Because of this financial restriction, there is a pressing need to investigate and validate affordable simulation models without forfeiting learning objectives.[7]

Therefore, by examining the efficacy of a low-cost simulation approach for skill training in undergraduate pathology, this study fills a substantial gap in the literature. This study tries to ascertain

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whether such a model can function as a feasible and better substitute for conventional techniques by utilizing openly accessible digital resources.[8,9,10]
In addition to comparing the acquisition of knowledge and skills, it also purposes to evaluate student satisfaction and perform a formal cost-effectiveness analysis.

Aim: To evaluate the effectiveness of a cost-effective simulation approach for skill training in undergraduate pathology.

Objectives:

1. Compare knowledge and skill acquisition between traditional and simulation-based pathology training.
2. Assess student satisfaction and confidence with low-cost simulations.
3. Conduct a cost-effectiveness analysis of simulation vs. traditional methods.

METHODS:

This study employed a mixed-methods, quasi-experimental crossover design to comprehensively evaluate an educational intervention for teaching pathology to 150 second-year medical undergraduates. Participants were randomly allocated into two groups of 75.

The research occurred over 12 weeks in two phases. In Phase 1, Group A was taught respiratory and gastrointestinal pathology using the traditional method (glass slides, physical microscopes, and gross specimens), while Group B used the simulation-based method (virtual slides and digital gross specimens on tablets). Following a post-test, the groups crossed over in Phase 2 to learn new topics (liver and renal pathology) with the opposite instructional method.

Quantitative data collection involved a validated multiple-choice question (MCQ) test, administered as pre- and post-tests, and Objective Structured Practical Examinations (OSPEs) scored by blinded examiners. This assessed cognitive knowledge and practical skills. Qualitative data were gathered through four focus group discussions (FGDs) to explore student experiences, engagement, and preferences. Thematic analysis was applied to the qualitative data.

Quantitative data were analysed using SPSS with descriptive statistics, paired t-tests (within-group), and independent samples t-tests (between-group). A cost-effectiveness analysis compared the direct costs of both methods. This robust crossover design controlled for inter-participant variability, enhancing the internal validity of the findings by allowing each participant to act as their own control.

RESULTS:

QUALITATIVE FINDINGS (Focus group discussions):

Theme 1: Participation and Education:

- Interactive and enjoyable learning is the sub-theme (mainly simulation group B).
- **As an illustration**:
- "It didn't seem like a chore. It was like exploring as you zoomed in and out of the tablet's virtual slides. Since it was fascinating to observe the changes at various magnifications, I stayed longer than was necessary.
- **Example**: Sub-theme 1.2: Passive and Monotonous Experience (Mostly Traditional Group A)
- "After an hour, everything starts to look the same during a traditional microscopy session."
- "I became aware of how passive traditional learning was after attempting the simulation.

We were simply instructed to "go and see." There wasn't much conversation.

Theme 2: Conceptualization and Understanding Depth

- **Sub-theme 2.1**: Developing Three-D Sensitivity (Mostly Simulation Group B)
- **As an illustration**:

"I finally understood where the caseous necrosis is occurring in relation to the bronchi and pleura after seeing the digital lung model with TB tubercles." I never got that context from Traditional Specimen. "I always had trouble getting my bearings on a glass slide." I found what I was looking for on the virtual slides with overlays and arrows [annotations].

Applied Learning is the sub-theme 2.2.

- **As an illustration:** We received two appendixes from the digital platform: one with modifications and one without. The neutrophils invading the muscularis propria had to be discovered in an appendix on a virtual slide and diagnose the condition ourselves. Instead of merely learning the answer, it seemed as though we were working through a puzzle.

Theme 3: Self-assurance and Developing Skills

Sub-theme 3.1: Repetition Builds Confidence (Mostly Simulation Group B) • Illustration:

"If I wanted to, I could review the digital gastric adenocarcinoma slide ten times." There was nobody waiting for the microscope.

- **Sub-theme 3.2**: Hesitancy and Anxiety (Mostly Traditional Group A)
- **As an illustration:** "Handling the glass slides always made me anxious." What happens if I drop it? What happens if the next person is waiting and I am unable to locate the lesion? It was difficult to focus because of that anxiety.

Theme 4: Future Preference and Comparative Assessment - Post-crossover focus group discussions (FGDs) (Students after experiencing both methods)

- **A Blended Model (Sub-theme 4.1)**
- **As an illustration:**

"The simulations are excellent for fostering confidence and learning." However, in a pathology lab, the microscope is the gold standard. We must be at ease with it. I believe that after learning the concepts through simulations, we should use the microscope to validate and experience the real world.

"Now that I know what I'm looking for, I appreciate the traditional method more." It was like attempting to read

a map in the dark when you first started using the microscope. The lights were first activated by the simulation.

- **Sub-theme 4.2:**
- **For simulation:** More complex and varied cases are requested, along with the inclusion of self- assessment tests.
- **For Traditional:** Requests for smaller group sizes to cut down on waiting times and structured guidance during microscopy sessions (such as annotated reference images at each station).
- **Blended method of teaching** (Simulation followed by Traditional method)

QUANTITATIVE FINDINGS:

Knowledge Assessment (MCQ Test): (Table 1)

Group	Pre-Test Mean (SD)	Post-Test Mean (SD)	p-value
A (Traditional)	**58.2 (6.4)**	**72.1 (7.3)**	**0.03**
B (Simulation)	**59.5 (5.8)**	**85.6 (6.9)**	**<0.01**

Independent t-test (Group A vs. B post-test):

- $t = 4.21$, $p < 0.01$ (significant improvement in Group B).

Knowledge Assessment (MCQ Test): Crossover (Table 2)

Group	Pre-Test Mean (SD)	Post-Test Mean (SD)	p-value
A (**After Simulation Training**)	72.1 (7.3)	84.3 (6.5)	**< 0.01**
B (**After Traditional Training**)	85.6 (6.9)	87.2 (6.1)	0.18

- **Independent t-test (Group A vs. B Post-Crossover):**
- **t = 2.15, p = 0.03** (The difference, though smaller, remains statistically significant).
- **Group A (Traditional → Simulation):** Showed a **highly significant jump (12.2 points, p < 0.01)** after receiving simulation training.
- **Group B (Simulation → Traditional):** Showed a small, **non-significant increase (1.6 points, p=0.18)** after traditional training.
- After the crossover, Group B's mean score was still higher than Group A's, and this difference was still statistically significant (p=0.03), though the gap had narrowed from 13.5 points to 2.9 points.

Skill Assessment (OSPE Scores) (Table 3)

OSPE Station	Group A Mean (SD)	Group B Mean (SD)	p-value
Slide Identification	68.5 (8.2)	**82.3** (7.6)	**<0.01**
Gross Specimen Diagnosis	65.4 (9.1)	**79.8** (8.4)	**<0.01**

- **Slide Identification:** Mean difference of 13.8 points (82.3 - 68.5) with $p < 0.01$
- **Gross Specimen diagnosis:**

Mean difference of 14.4 points (79.8 - 65.4) with $p < 0.01$

- The simulation-based training group (B) performed

significantly better on both practical skill stations compared to the traditional training group (A).

- The p-values authorize that these differences are very unlikely to be due to random chance.

OSPE (GIT & Respiratory Pathology):

- Station 1: Gross Specimen - Appendicitis vs. Normal Appendix (Marks: 12) Station 2: Histopathology Slide - Acute Appendicitis (Marks: 13)

Station 3: Gross Specimen - Lung Carcinoma vs. TB Lung (Marks: 12) Station 4: Histopathology Slide - Gastric Carcinoma (Marks: 13)

Total Marks: 50

Skill Assessment (OSPE Scores) Crossover (Table 4)

OSPE Station	Group A Mean (SD)	Group B Mean (SD)	p-value
Slide Identification	80.1 (7.8)	83.5 (7.1)	0.02
Gross Specimen Diagnosis	78.2 (8.5)	80.9 (8.0)	0.09

- **Slide Identification:** The performance gap between groups lessened considerably but remained statistically significant (p=0.02). Group A's skills enhanced markedly after simulation training.
- **Gross Specimen Diagnosis:** The performance gap closed completely and turn out to be statistically non-significant (p=0.09). After both groups had experienced both training modes, their practical skills in gross diagnosis were same.
- **OSPE (Liver Pathology & Renal Pathology)**
- Station 1: Gross Specimen – Normal Liver vs. Liver Cirrhosis (Marks: 12) Station 2: Histopathology Slide – Fatty Liver (Marks: 13)

Station 3: Gross Specimen – Hydronephrosis vs. Adult Polycystic kidney disease (Marks: 12)

Station 4: Histopathology Slide – Chronic Pyelonephritis (Marks: 13)

Total Marks: 50

The crossover results demonstrate that a sequential, blended learning model is the most effective strategy for pathology education. Group A's significant performance improvement after switching to simulation (the "Catch-Up Effect") confirms the method's efficacy. Conversely, Group B's minimal gains after traditional training (the "Ceiling Effect") suggest simulation had already maximized their learning. Crucially, the initial practical skill gap between groups was eliminated post-crossover, proving simulation can efficiently bring all students to a high competency level.

A detailed cost-analysis strongly supports this model. The traditional approach involves substantial, recurring costs for acquiring and maintaining gross specimens (₹10,000–₹15,000 each) and glass slides (₹250–₹500 per slide), alongside expensive microscopes. In contrast, the simulation method utilizes free, high-quality digital resources from repositories like the University of Leeds and the National University of Singapore, with free visualization software. The initial hardware investment is offset by the elimination of ongoing procurement and maintenance expenses, making simulation both academically superior and economically prudent, especially for resource-constrained institutions.

Discussion: This study demonstrates that an affordable, simulation-based method is a superior foundational tool for teaching pathology, advocating for a strategic redesign of traditional pedagogy. Quantitative results robustly confirmed its efficacy. In the initial phase, the simulation group (Group B) significantly outperformed the traditional group (Group A) on both the MCQ post-test (85.6 vs. 72.1, $p<0.01$) and the OSPE (by over 13 points, $p<0.01$).

The crossover design provided strong internal validation. Group A's performance sharply improved by 12.2 points ($p<0.01$) after receiving simulation training, while Group B showed only a negligible gain after traditional training, indicating simulation had already maximized their learning.

Qualitative findings explained these results. Students described simulation as "interactive and fun," fostering deep engagement and active learning, in contrast to the "passive and monotonous" traditional experience. The digital tools enhanced conceptual understanding by providing essential anatomical context and a low-stakes environment for repeated, anxiety-free practice, which built confidence and reduced cognitive load.

The converging evidence supports a sequential blended learning model: simulation first to build foundational competence, followed by traditional methods to confirm learning and provide real-world familiarity. This model was validated by post-crossover OSPE results, which showed the initial large skill gap was closed.

Crucially, the model is highly cost-effective, utilizing free digital resources and software, making high-quality pathology education scalable and sustainable, especially for resource-constrained institutions.

Limitations of the study: Our statements cannot be generalized because it was a single-institution design, and it was not evaluated for long-term knowledge and skill retention. Longitudinal follow-up with multi-institutional studies is advised for the future. As wished by the students, the positive feedback for the simulation also suggests future directions, including the creation of more varied digital case libraries and the assimilation of integrated formative assessment quizzes.

CONCLUSION: This study provides robust evidence that an affordable, simulation-based approach revolutionizes undergraduate pathology training. Utilizing free digital resources leads to superior learning outcomes, enhanced student engagement, and greater confidence compared to traditional methods alone. The crucial insight from the crossover analysis is that the most effective strategy is not a choice between simulation and tradition, but their deliberate integration. Therefore, we recommend a Sequential Blended Learning Model: Use digital simulations as the primary tool for building core knowledge and diagnostic skills, ensuring efficient and deep foundational learning. Follow simulation with traditional microscopy and gross specimens to validate digital learning, bridge the gap to real-world practice, and provide concrete experience. This research-backed, cost-effective model is a practical and powerful guide for equipping future doctors with the diagnostic skills essential for clinical practice.

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