DOI: https://doi.org/10.4038/seajme.v19i2.677

Review Article

Educational Strategies in Microbiology: Impact on Clinical Competence of Residents

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Abstract

Introduction: Microbiology is foundational to diagnosing and treating infectious diseases, yet many medical students experience it as abstract, fragmented, and removed from clinical realities. Although educational strategies have evolved over the past two decades to address this, the real-world impact of microbiology training on clinical behaviour—particularly in residency—remains underexplored. This review synthesizes research on microbiology teaching methods and evaluates whether and how these approaches correlate with clinical performance, particularly in areas such as diagnostic accuracy, antimicrobial prescribing, and infection control practices among residents.

Methods: We conducted a narrative review of peer-reviewed literature from 2005 to 2025, using PubMed, ERIC, and Scopus. We included studies that evaluated microbiology education interventions with a focus on clinical behaviour or outcomes during postgraduate training. Articles assessing only learner satisfaction or preclinical exam performance were excluded unless linked to downstream clinical effects.

Results: Educational strategies such as vertical integration, case-based learning, and simulation show improved knowledge application. However, most studies stop at short-term cognitive outcomes. Only a minority assess real clinical behaviours or patient-related outcomes. Evidence linking microbiology pedagogy to clinical prescribing or diagnostic decision-making is promising but still limited.

Conclusion: To close the gap between preclinical education and patient care, microbiology must move beyond memorization to immersive, practice-linked learning. Future studies should prioritize longitudinal outcomes, particularly those reflecting clinical application and health system impact.

Keywords: Microbiology education, clinical competence, problem-based learning, simulation training, internship and residency/education, program evaluation

Introduction

Medical microbiology plays a foundational role in undergraduate medical education. It equips future physicians with the knowledge required to accurately diagnose, treat, and prevent infectious diseases—skills that are increasingly essential in the face of rising anti-microbial resistance (AMR), emerging infectious threats, and the growing complexity of diagnostic tools in modern clinical settings (Ajulo & Awosile, 2024).

Despite its importance, many students perceive microbiology as a dense and memorization-heavy subject, often disconnected from the realities of clinical care (Nichat *et al.,* 2023). Learners frequently report difficulty applying foundational microbiological concepts to real-world decision-making tasks such as selecting appropriate diagnostic tests, interpreting lab results, or initiating evidence-

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based antimicrobial therapy (Silverberg *et al.,* 2017 , Azevedo *et al.,* 2018). This disconnect can contribute to suboptimal test utilization, antibiotic overuse, and inadequate management of infectious diseases during residency and clinical practice (Silverberg *et al.,* 2017).

In response, educators have adopted a range of innovative strategies aimed at making microbiology more engaging and clinically applicable. These include flipped classrooms, simulation-based learning, digital platforms, case-based integration, and vertically integrated curricula that weave microbiological principles into clinical rotations (Nichat *et al.,* 2023, Rajan *et al.,* 2016, Singhal, 2017, Kulasegaram *et al.,* 2013). Initial studies suggest these methods enhance student engagement, conceptual understanding, and performance in knowledge-based assessments (Singhal, 2017, Romancenco *et al.,* 2024). However, a key question remains largely unanswered: do these educational innovations improve actual clinical performance—particularly during the early postgraduate years when interns and residents are frequently involved in antimicrobial prescribing, infection control, and diagnostic decision-making? (Garzón-Orjuela *et al.,* 2023) While many interventions have been evaluated at the level of learner satisfaction and knowledge acquisition, relatively few have assessed their impact on clinical behaviour or patient outcomes (Azevedo *et al.,* 2018, Ishizuka *et al.,* 2023). There remains a substantial gap in our understanding of whether and how microbiology education influences behaviours such as diagnostic reasoning, test ordering, or antibiotic prescribing in clinical settings (Azevedo *et al.,* 2018, Garzón-Orjuela *et al.,* 2023).

This narrative review synthesizes current literature on microbiology education in undergraduate medical training and explores its relationship to clinical performance during residency. By framing the analysis through established educational models like Miller's Pyramid of Clinical Competence and Kirkpatrick's Model of Evaluation, this review aims to highlight successes, identify gaps, and outline future directions needed to more effectively align microbiology teaching with real-world clinical care (Garzón-Orjuela *et al.,* 2023, Ishizuka *et al.,* 2023).

Methods

We conducted a narrative literature review spanning January 2005 to April 2025. Searches were performed in PubMed, ERIC, and Scopus using combinations of the following keywords: "medical microbiology education," "clinical performance," "residency," "infectious diseases," "antimicrobial stewardship," "simulation," and "vertical integration."

Inclusion criteria

- Peer-reviewed studies in English
- Research connecting microbiology teaching strategies to clinical behaviour or outcomes in internship or residency

Exclusion criteria

- Studies focused only on preclinical test scores or student satisfaction without links to real-world application

The review prioritized studies that used educational evaluation models (e.g., Kirkpatrick's levels or Miller's Pyramid) to assess learning and performance.

Results

Educational Strategies in Microbiology

Over the last two decades, teaching methods have shifted toward more clinically relevant and applied approaches:

- *Vertical Integration:*
  This model embeds microbiology within clinical clerkships and longitudinal curricula, allowing learners to revisit concepts in relevant contexts. Studies show improved knowledge retention and better diagnostic performance on Objective Structured Clinical Examinations (OSCEs) when

microbiology is taught alongside clinical rotations (Rajan *et al.,* 2016; Kulasegaram *et al.,* 2013).

- *Case-Based Learning (CBL):*
  CBL encourages students to reason through clinical cases involving infectious diseases, helping them form connections between pathogens, host responses, and diagnostic choices. CBL has been linked to improved clinical reasoning scores and pathogen-pattern recognition (Singhal, 2017).

- *Simulation-Based Microbiology Scenarios:*
  Simulation training allows learners to apply microbiological knowledge in time-pressured, high-fidelity scenarios such as sepsis or infection control emergencies. Participants show faster decision-making and improved outcomes in simulated environments (Romancenco *et al.,* 2024).

- *Antimicrobial Stewardship Modules:*
  E-learning modules and dashboard tools focused on antimicrobial use have led to improved prescribing behaviour among interns, with increased adherence to guidelines and institutional antibiograms (Silverberg *et al.,* 2017; Garzón-Orjuela *et al.,* 2023).

- *Interactive Digital Tools:*
  Gamified quizzes and virtual labs reinforce microbiology concepts and promote independent learning. While they improve short-term performance, their effect on clinical decision-making is limited (Ishizuka *et al.,* 2023).

- *Problem-Based Learning (PBL):*
  PBL methods, when used with a microbiology emphasis, help bridge theoretical knowledge with systems-based diagnostic frameworks. Some evidence suggests improved integration into clinical thinking (Isada & Isada, 2017).

Table 1 shows the summary of educational strategies in Microbiology and associated clinical outcomes**.**

Table 1: Summary of Microbiology Education Strategies and Associated Clinical Outcomes

Strategy	Purpose	Reported Outcome	Clinical Relevance	Supporting Evidence
Vertical Integration (e.g., microbiology in clinical clerkships)	Reinforce microbiology in clinical contexts to support long-term retention	Improved OSCE scores in infectious disease stations	Enhances diagnostic accuracy and appropriate test selection	Rajan *et al.,*2016
Case-Based Learning (CBL)	Promote applied learning through patient scenarios	Better clinical reasoning & pathogen -pattern recognition	Strengthens decision-making in infectious disease workups	Singhal, 2017
Simulation-Based Microbiology Scenarios	Provide realistic, time-pressured ID scenarios for skills application	Increased confidence, faster response times, and improved diagnostic accuracy in sepsis/ID OSCEs	Improves emergency ID management and clinical preparedness	Romancenco *et al.,*2024
Antimicrobial Stewardship Modules	Teach appropriate prescribing and resistance mechanisms	Reduced unnecessary antibiotic prescriptions by interns	Supports institutional stewardship efforts and rational antimicrobial use	Garzón-Orjuela *et al.,*2023
Interactive Digital Tools (e.g., gamified quizzes, virtual labs)	Increase engagement and knowledge retention through tech-based learning	Higher microbiology scores and more frequent application of concepts	Boosts early exposure and supports self-directed learning	Ishizuka *et al.,*2023

Problem-Based Learning (PBL) with Microbiology Emphasis	Facilitate multidisciplinary diagnostic reasoning	Better transition of knowledge from classroom to clinic	Supports integrated thinking and case-based microbial decision-making	Isada & Isada, 2017
Flipped Classroom with Lab Integration	Encourage active participation and pre-session preparation	Improved student satisfaction and better scores on applied microbiology quizzes	Reinforces host-pathogen interaction and microbiological reasoning	Nichat A *et al.,*2023
Embedded Stewardship Dashboards	Deliver real-time decision support training for prescribing	Increased adherence to empirical antibiotic guidelines in simulations	Reinforces clinical use of local antibiograms and stewardship policies	Silverberg *et al.,*2017
Micro learning & Podcasts	Offer flexible, spaced learning formats	Self-reported boosts in clinical readiness for ID rotations	May reduce cognitive overload and increase retention	Cook *et al.,* 2008
Interprofessional Education (IPE) with Pharmacists & Microbiologists	Expose students to collaborative ID care	Improved communication and team-based decision-making	Promotes real-world interdisciplinary dynamics in infection management	Medina-Presentado *et al.,* 2016

Aligning Educational Strategies with Performance Models

Frameworks like Miller's Pyramid (Knows → Knows How → Shows How → Does) and Kirkpatrick's Evaluation Model allow mapping of educational strategies to actual performance:

- Vertical Integration, CBL, and Simulation support performance in simulated settings but have only moderate evidence linking them to actual behaviour change.
- Antimicrobial stewardship training is among the few interventions shown to improve prescribing habits (Silverberg *et al.,* 2017; Garzón-Orjuela *et al.,* 2023).
- Digital tools and microlearning remain under-investigated for clinical impact (Ishizuka *et al.,* 2023; Cook *et al.,* 2008).

Table 2 illustrates the alignment of microbiology teaching strategies with Miller's Pyramid of Clinical Competence.

Table 3 presents the application of Kirkpatrick's Model of Educational Evaluation to microbiology teaching strategies.

Clinical Outcomes: What the Evidence Shows

Few studies assess the downstream clinical effects of microbiology education. However:

- Interns trained with stewardship-focused modules demonstrated fewer inappropriate antibiotic prescriptions (Silverberg *et al.,* 2017).
- Vertical integration models correlated with better OSCE scores in ID scenarios, especially in diagnostic decision-making (Rajan *et al.,* 2016).
- A 2022 systematic review found that fewer than 10% of microbiology education studies evaluated real-world clinical outcomes (Garzón-Orjuela *et al.,* 2023).

Table 2: Alignment of Microbiology Teaching Strategies with Miller's Pyramid of Clinical Competence

Teaching Strategy	Knows *(Factual Knowledge)*	Knows How *(Applies Knowledge)*	Shows How *(Demonstrates in Simulated Setting)*	Does *(Performs in Real Practice)*
Traditional Didactic Lectures	☑Solid foundation of microbiological facts	✖Limited application without contextual teaching	✖Passive learning; does not support simulation	✖No demonstrated link to clinical behaviour
Vertical Integration *(e.g., microbiology during clerkships)*	☑Reinforces concepts within clinical contexts	☑Encourages application in real-time decision-making	☑Supports interactive discussions during clinical rounds	⚠ Partial: Clinical behaviour depends on supervision and institutional tracking (Rajan *et al.,*2016)
Case-Based Learning (CBL)	☑Uses patient cases to build foundational understanding	☑Supports pattern recognition and test selection	☑Often evaluated through paper cases and MCQs	✖Rarely followed into clinical practice behaviours (Singhal ,2017)
Simulation-Based Microbiology OSCEs	☑Solidifies core knowledge in pre-briefing	☑Encourages application of diagnostic pathways	☑Demonstrates competence in infection-based OSCEs	⚠ Limited: Effectiveness depends on integration into actual patient care (Romancenco *et al.,*2024)
Antimicrobial Stewardship Modules *(including digital modules)*	☑Covers antibiotic mechanisms and microbial resistance	☑Links pathogen identification with treatment planning	☑Used in prescribing simulations and decision trees	☑Demonstrated reduction in inappropriate prescriptions (Garzón-Orjuela *et al.,*2023, Silverberg *et al.,*2017)
Interactive Digital Tools *(e.g., gamified quizzes, virtual labs)*	☑Strengthens knowledge of pathogenesis and classification	⚠ Some tools simulate applied learning	✖Focuses on engagement more than skill demonstration	✖No direct evidence of impact on clinical behaviour (Ishizuka *et al.,*2023)
Problem-Based Learning (PBL)	☑Encourages deep learning through clinical scenarios	☑Fosters differential diagnosis and critical reasoning	⚠ Variable: Simulation use depends on institution	✖Rarely tracked to post-clerkship or residency performance (Isada and Isada, 2017)
Microlearning Modules *(e.g., podcasts, short videos)*	☑Supports spaced repetition and retention	✖Often consumed passively, with limited applied tasks	✖Not used in formal simulation or assessments	✖No evidence of impact on clinical performance (Cook *et al.,* 2008)
Interprofessional Education (IPE) with Microbiology Focus	☑Broadens understanding of microbiological and pharmacological roles	☑Enhances collaboration in therapeutic decision-making	☑Team simulations are feasible in ID scenarios	⚠ Anecdotal improvements reported, but limited formal tracking (Medina-Presentado *et al.,* 2016)

☑ = Strong evidence or alignment; ⚠= Moderate or conditional alignment; ✖ = Weak or no evidence at that level

Table 3: Kirkpatrick's Model of Educational Evaluation Applied to Microbiology Strategies

Teaching Strategy	**Level 1: Reaction** ***(Learner Engagement / Satisfaction)***	**Level 2: Learning** ***(Knowledge or Skill Development)***	**Level 3: Behaviour** ***(Application in Clinical Practice)***	**Level 4: Results** ***(Impact on Patient Care/ System Outcomes)***
Didactic Lectures (Traditional)	⚠ Engagement is often mixed; some students find lectures overwhelming or disconnected	☑ Effectively builds foundational factual knowledge	✖ Rarely facilitates real-world clinical application	✖ No evidence linking lectures to improved patient outcomes
Vertical Integration ***(e.g., integrated into clinical rotations)***	☑ Well-received, especially when content is linked to clinical cases	☑ Enhances long-term retention and transfer of microbiological knowledge	⚠ Some evidence of improved reasoning and diagnostic decision-making during rounds	⚠ Potential impact on test selection and antimicrobial use, but more data needed
Case-Based Learning (CBL)	☑ Frequently rated as engaging and clinically relevant by learners	☑ Strengthens diagnostic reasoning and application of microbiology	⚠Anecdotal reports suggest improved use of clinical reasoning in clerkships	✖ No direct evidence demonstrating patient-level benefits
Simulation-Based Microbiology OSCEs	☑ High learner satisfaction due to immersive, realistic experience	☑Demonstrates learner competence in applying microbiology to clinical scenarios	☑Improves confidence, diagnostic accuracy, and sepsis management in simulations	⚠May indirectly influence patient care through improved readiness and isolation protocol adherence
Antimicrobial Stewardship Curriculum ***(e.g., e-learning, dashboards)***	☑ Highly engaging when interactive or case-based	☑ Increases understanding of resistance mechanisms and appropriate prescribing	☑ Proven improvements in real-world prescribing behaviour among interns	☑ Associated with fewer inappropriate antibiotic starts and better guideline adherence
Interactive Digital Tools ***(e.g., gamified quizzes, virtual labs)***	☑ High engagement, especially in self-directed and low-stakes settings	☑ Improves test scores and factual retention	✖ Rarely translates into clinical behaviour change	✖ No documented effects on patient outcomes to date
Flipped Classroom (Microbiology Focus)	☑ Encourages student accountability, discussion, and active participation	☑ Enhances retention and integration of complex concepts	⚠ Clinical application depends heavily on implementation quality and instructor engagement	✖ System-level impact not yet evaluated
Problem-Based Learning (PBL)	☑ Well-liked for its emphasis on clinical relevance and autonomy	☑ Promotes systems thinking and self-guided learning	⚠ Behavioural change varies depending on curriculum design	✖ Limited outcome-level research specific to microbiology education
Microlearning ***(e.g., podcasts, quick video modules)***	☑ Widely appreciated for flexibility and accessibility	⚠ Effective for review & repetition, but less robust for in-depth mastery	✖ No evidence of behaviour changes in clinical practice	✖ Not associated with improved clinical or system outcomes
Interprofessional Education (IPE) ***(e.g., collaboration with pharmacy/ micro teams)***	☑ Promotes teamwork, communication, and role clarity	☑ Builds shared understanding of ID management principles	☑ Enhances team-based decision-making in simulated or collaborative environments	⚠ May reduce prescribing errors, but outcome data remains preliminary

☑ = Strong evidence or alignment; ⚠= Moderate or conditional alignment; ✖ = Weak or no evidence at that level

Challenges in Measuring Impact

Barriers include:

1. Curriculum Fragmentation: Many medical programs still isolate microbiology from clinical learning, limiting transferability (Azevedo *et al.,* 2018).

2. System Complexity: Clinical decisions are influenced by senior physicians, time constraints, and institutional culture (Garzón-Orjuela *et al.,* 2023).

3. Limited Tracking: Most medical schools do not follow microbiology knowledge through internship into patient care (Azevedo *et al.,* 2018).

Future Research Directions

To build stronger links between microbiology teaching and clinical performance, future studies should:

1. Conduct longitudinal cohort studies- To evaluate whether foundational microbiology education during preclinical years has a sustained influence on diagnostic reasoning, test ordering, and antimicrobial prescribing during internship and residency.

2. Develop clinical microbiology OSCEs- To go beyond rote memorization by assessing students' ability to apply microbiological concepts in realistic, case-based scenarios reflective of infectious disease management.

3. Implement audit and feedback systems- To monitor and evaluate clinical behaviours—such as antibiotic selection or diagnostic test utilization—based on learners' educational background and training exposure.

4. Include microbiologists in curriculum design teams- To ensure that microbiology content remains clinically relevant, accurately aligned with real-world infectious disease practice, and integrated with current diagnostic tools and stewardship priorities.

5. Integrate embedded simulations into curricula- To allow learners to practice applying microbiological knowledge in complex clinical environments using electronic medical records, lab results, and prescribing tasks, thus bridging the gap between theory and clinical performance.

Conclusion

Microbiology education has evolved considerably in recent years, shifting from passive, lecture-based formats to more interactive and clinically integrated approaches. While these innovations have enhanced learner engagement and conceptual understanding, a critical gap persists: there remains limited evidence that these strategies translate into improved clinical performance. As healthcare systems confront mounting challenges such as antimicrobial resistance and the emergence of novel pathogens, reinforcing the bridge between microbiology education and infectious disease management is more urgent than ever. Moving forward, educational research must go beyond assessing what learners know—and begin rigorously evaluating how well they perform in real-world clinical environments.

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