



Perspective

Building Antimicrobial Reasoning Before Prescribing: Reframing the Role of Preclinical Microbiology Education

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Abstract

Antimicrobial resistance (AMR) is usually addressed through surveillance, prescribing policy, stewardship programs, infection prevention, and drug development. Less attention is given to an earlier educational question: how future doctors first learn to connect microorganisms, antibiotics, and resistance. In some preclinical medical curricula, microbiology provides essential knowledge of microbial structure, virulence, antimicrobial mechanisms, laboratory diagnosis, and resistance pathways, but opportunities to use this knowledge for antimicrobial reasoning may be limited. Students may therefore recall resistance mechanisms yet remain less prepared to interpret culture and susceptibility reports, consider local resistance patterns, or explain when therapy should be escalated, narrowed, optimized, or discontinued. This Perspective argues that AMR education should begin before students prescribe. Preclinical microbiology should preserve its scientific foundation while more deliberately linking microbial mechanisms to clinical scenarios, stewardship principles, microbiology report interpretation, and assessment design. Implementation should be adapted to local standards, supported by faculty development, and evaluated prospectively.

Keywords: antimicrobial resistance; preclinical microbiology; antimicrobial stewardship; medical education; clinical reasoning

1. Background

Antimicrobial resistance (AMR) is often discussed as a problem of surveillance, prescribing policy, stewardship, and drug development [1]. These components remain essential. However, one part of the response to AMR receives comparatively less attention: how future doctors first learn to think about microorganisms, antibiotics, and resistance.

Curricular organization varies; microbiology may be taught in a discrete block or integrated across organ-system and disease-based courses. In either structure, students require a strong foundation in microbial structure, pathogenesis, host–pathogen interactions, antimicrobial agents, laboratory diagnosis, and resistance mechanisms. Although these topics are essential, a gap arises when they remain isolated areas of knowledge rather than foundations for clinical reasoning. For example, β -lactamase production, susceptibility testing, and local resistance patterns may be taught as scientific concepts without being explicitly connected to treatment failure, antibiotic de-escalation, or empirical antibiotic selection. The concern is therefore not whether microbiology or AMR is present in the curriculum, but whether students have sufficient opportunities to apply this knowledge to antimicrobial decision-making.



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The central concern is whether preclinical microbiology prepares students only to recall mechanisms of infection and resistance, or also to apply this knowledge when interpreting microbiology results and thinking about antimicrobial use.

2. Why This Matters

Antibiotic prescribing is among the most common and consequential decisions in clinical practice. Even under supervision, junior doctors are often expected to identify infection, interpret laboratory findings, and help guide early treatment. Doing this well requires more than memorizing pathogens and drug classes; it requires linking the likely organism, the patient's clinical condition, local resistance patterns, and the harms of unnecessary broad-spectrum therapy.

The WHO Global Action Plan on AMR emphasizes awareness, education, surveillance, infection prevention, and optimized antimicrobial use, but undergraduate medical education remains an important point at which these priorities must be translated into future prescribing behaviour [2].

This issue is particularly relevant in rapidly developing healthcare systems, including Saudi Arabia, where newly graduated physicians may enter a busy clinical environment early in their careers and encounter frequent and time-sensitive infection-related decisions. Without undergraduate training that links microbiological mechanisms to prescribing decisions, they may understand AMR in theory without fully recognizing it as an everyday clinical challenge.

A multicenter study of medical students reported variable perceptions and knowledge of antimicrobial stewardship, supporting the need for more consistent education in antimicrobial prescribing and stewardship [3].

This approach is aligned with the WHO competency framework for health workers' education and training on AMR, which emphasizes that pre-service education should equip future health professionals with the knowledge, skills, and attitudes needed to address antimicrobial resistance [4].

3. Where the Gaps Begin: Insight from Preclinical Teaching

3.1. Knowledge-Rich, Decision-Poor Learning

Preclinical microbiology remains heavily weighted towards knowledge acquisition. The concern is not knowledge acquisition itself, but whether curricula also provide opportunities to apply that knowledge. Students learn bacterial classification, virulence factors, mechanisms of antimicrobial action, resistance pathways, sterilization, infection control, and laboratory diagnosis. These foundations are essential and should be preserved. When they remain separate learning objectives, however, students may have limited practice in using them to interpret culture results, revise antibiotics, or narrow coverage after laboratory confirmation.

Available survey evidence is geographically specific rather than global. In a 2014 survey of 142 Liaison Committee on Medical Education-accredited U.S. medical schools, 104 (73%) responded; 55/104 (53%) reported a single microbiology block or course and 47/104 (45%) integrated microbiology into other curricula. Among 94 schools that identified a course director, 48% were led by microbiologists alone, 23% were co-led by a microbiologist and a clinician, and 20% were led by a clinician alone [5]. These findings document substantial structural and leadership heterogeneity and demonstrate why educational needs cannot be inferred from curricular organization alone. The relevant question is whether, within either structure, students have sufficient opportunities to apply microbiological knowledge to antimicrobial decisions.

As a result, students may understand how resistance occurs, but not necessarily how it should influence treatment choices.

3.2. *Fragmented Integration with Clinical Context*

Preclinical curricula may include clinically relevant topics such as sepsis, infection control, and perioperative infections. A gap arises when these topics are presented as separate teaching units rather than being longitudinally connected with foundational microbiological principles.

In practice, clinical reasoning requires the simultaneous consideration of the pathogen, the host, and the therapy. When these elements are taught in parallel rather than in combination, students may not fully recognize their interdependence.

3.3. *Antimicrobial Resistance as a Concept, Not a Practice*

AMR is typically introduced through mechanisms such as enzyme production, efflux pumps, and genetic mutations. Although this scientific foundation is important, it can reduce AMR to an abstract concept if it is not linked to clinical practice.

What is often missing is the practical dimension of AMR: choosing empirical therapy when the pathogen is uncertain, interpreting culture and susceptibility reports, deciding when to escalate or de-escalate treatment, and using local antibiogram data to guide safer antimicrobial decisions. Without such exposure, AMR may remain a theoretical concept rather than a framework for clinical judgement.

3.4. *Assessment Drives Learning: But What Are We Testing?*

Assessment strategies play a decisive role in shaping how students study. Because students often prioritize what is assessed, examination design strongly influences whether microbiology is learned as factual content or as applied clinical reasoning. In many preclinical settings, MCQs dominate evaluation methods.

Recall-based questions can assess essential foundational knowledge, including organism identification, resistance mechanisms, and laboratory methods. However, when assessment relies predominantly on such items, students have fewer opportunities to interpret clinical vignettes, connect resistance mechanisms to antimicrobial choice, or determine how microbiology reports should guide management. In practical terms, assessment reform should shift from simple recall items to clinically contextualized questions with appropriate difficulty and strong discrimination (Table 1).

Table 1. From recall-based assessment to clinically contextualized AMR learning in preclinical microbiology.

Current Assessment Tendency	Preferred Direction for AMR Learning
Recall of organism names	Interpretation of likely pathogen in clinical scenarios
Resistance mechanism taught as isolated facts	Resistance mechanism linked to antibiotic selection
Culture techniques assessed as laboratory knowledge	Culture and susceptibility reports used to guide escalation or de-escalation
Recall-based MCQs with weak discrimination	Case-based MCQs with appropriate difficulty and stronger discrimination
Bloom’s taxonomy level assigned without sufficient clinical context	Cognitive level supported by item design, and clinical reasoning and contextual cues

Students usually study according to what the examination rewards. If decision-making is not assessed, it is rarely prioritized.

4. From Classroom to Clerkship

The consequences of these educational gaps become apparent during clinical training. Students entering clerkships may demonstrate strong theoretical knowledge yet feel uncertain when faced with real prescribing decisions.

This may manifest as:

- over-reliance on broad-spectrum antibiotics
- delayed de-escalation
- limited confidence in interpreting microbiology reports

More importantly, without early exposure to stewardship principles, prescribing habits may develop reactively rather than reflectively.

5. Moving Forward: Practical Directions for Reform

Addressing these gaps does not require abandoning foundational teaching; it requires reframing the connection between this knowledge and clinical decision-making. Previous reviews of antimicrobial stewardship training in medical education suggest that educational interventions are feasible, but their design, timing, and evaluation remain variable [6].

5.1. Integrate Microbiology with Clinical Reasoning

Microbiology and clinical reasoning should be connected deliberately. Brief clinically relevant scenarios may be embedded within existing preclinical sessions without creating a separate course. For example, a session on beta-lactamase production can be introduced through a short case of antibiotic treatment failure, prompting students to consider why the previously appropriate therapeutic choice is now no longer effective. Similarly, a session on culture and antimicrobial susceptibility testing could ask students to decide whether to escalate, de-escalate, or continue. A local antibiogram can also be used to show how empirical antibiotic choices should be informed by resistance patterns rather than by memorized drug lists alone.

These changes do not require additional teaching hours. They can be incorporated into existing preclinical lectures as short case triggers, discussion prompts, or vignette-based questions. Such changes can help students recognize that microbiology is not only material for examination, but also a practical tool for interpreting infection, anticipating resistance, and revising safer antibiotic therapy decisions.

To make AMR teaching more practical and adaptable across preclinical settings, Table 2 summarizes key AMR-focused educational strategies, suggested classroom activities, and possible assessment methods that can be incorporated into microbiology courses.

Table 2. Practical approaches for integrating antimicrobial resistance into preclinical microbiology education.

Tips	AMR-Focused Strategy	Suggested Teaching Activity	Assessment Approach
1. Start AMR teaching early in the curriculum	Introduce AMR as a core microbiology and patient-safety issue	Begin the block with a treatment failure case caused by resistant bacteria	Short-answer question asking students to explain why first-line therapy failed
2. Link resistance mechanisms to clinical consequences	Help students connect beta-lactamases, efflux pumps, target modification, and biofilm formation with treatment difficulty	Use examples such as ESBL-producing <i>E. coli</i> , MRSA, carbapenem-resistant <i>Klebsiella pneumoniae</i> , or multidrug-resistant <i>Pseudomonas aeruginosa</i>	Case-based MCQs requiring students to identify the resistance mechanism

Table 2. Cont.

	Tips	AMR-Focused Strategy	Suggested Teaching Activity	Assessment Approach
3.	Use real or simulated antibiograms	Teach students to interpret antibiograms	Provide a simplified hospital antibiogram and ask students to choose appropriate antibiotics for common infections	Interpretation of antibiogram data with justification of antibiotic choice
4.	Teach culture and susceptibility reports as learning tools	Help students understand how laboratory results influence patient management	Use reports showing S, I (susceptible, increased exposure), and R	Interpret the report using patient context and local guidance
5.	Emphasize antimicrobial stewardship principles	Introduce rational antibiotic use, de-escalation, and avoidance of unnecessary prescriptions	Discuss broad-spectrum antibiotics are started followed by narrowed after culture results	Problem-solving question on when to start, stop, switch, or de-escalate antibiotics
6.	Highlight infection prevention and control	Show that AMR control is not limited to antibiotic selection	Discuss hand hygiene, isolation precautions, device-associated infections, and hospital transmission of resistant organisms	Scenario-based question on preventing the spread of resistant organisms (e.g., MRSA, CRE, or VRE)
7.	Include “One Health” examples	Discuss links between human health, animal use of antibiotics, agriculture, and the environment	Discuss how antibiotic use in animals or environmental contamination can contribute to resistant organisms	Short reflective question on One Health approaches to reducing AMR
8.	Use problem-based or team-based learning	Encourage students to apply microbiology knowledge collaboratively	Assign small groups to manage an AMR case from presentation to laboratory diagnosis and stewardship decision	Group presentation or structured case analysis
9.	Align assessment with AMR competencies	Ensure that exams test application, not only factual recall	Include questions requiring interpretation of culture reports, antibiograms, and clinical scenarios	Blueprinted AMR questions mapped to knowledge, interpretation, and decision-making skills
10.	Encourage critical thinking about antibiotic misuse	Help students recognize inappropriate prescribing and its consequences	Provide examples of viral infections treated unnecessarily with antibiotics or incomplete antibiotic courses	Ask students to identify prescribing errors and suggest corrections
11.	Reinforce AMR longitudinally across the curriculum	Prevent AMR from being taught as a single isolated lecture	Revisit AMR in pathology, pharmacology, infectious diseases, pediatrics, surgery, and community medicine	Use recurring AMR-related clinical vignettes across multiple courses

A Worked EUCAST-Linked Teaching Paradigm

EUCAST resources provide one concrete bridge between mechanism, laboratory interpretation, and clinical reasoning where EUCAST is the locally applicable standard. Educators can use a simulated or de-identified microbiology report together with the current breakpoint table, dosage/exposure notes, and definitions of S, I, and R [7]. Students should understand that I denotes “Susceptible, increased exposure” and must not be interpreted as an intermediate or resistant category. The objective is not to memorize numerical

breakpoints or prescribe independently, but to understand how a laboratory category informs, and does not replace consideration of infection site, illness severity, dose and exposure, organ function, allergies, local resistance data, and institutional guidance. Because breakpoint tables are updated, teaching materials should use the current version and the standard adopted by the local laboratory. Table 3 illustrates a worked learning sequence.

Table 3. Worked paradigm linking microbiological knowledge, EUCAST interpretation, and clinical reasoning.

Learning Stage	Illustrative Activity	Expected Reasoning
1. Clinical trigger	A simulated patient with suspected urinary infection begins empirical therapy according to local guidance; urine culture later grows <i>Escherichia coli</i> .	Identify the provisional diagnosis, purpose of empirical therapy, and information still needed.
2. Mechanism to phenotype	Relate β -lactamase-mediated resistance to possible discordance between the initial regimen and the susceptibility report.	Explain how a resistance mechanism can alter the probability of treatment success.
3. Interpret the report	Use a current EUCAST-formatted report to distinguish S, I (susceptible, increased exposure), and R.	Interpret the reported category and any exposure implication without equating I with resistance.
4. Integrate context	Consider infection site, severity, response, allergies, renal function, dose/exposure, local antibiogram, and institutional guidance.	Justify whether therapy should be continued, optimized, narrowed, or changed; recognize that a breakpoint table alone does not prescribe treatment.
5. Assess and reflect	Provide a brief written justification and identify which elements may change if the organism, site, patient factors, local policy, or breakpoint version changes.	Demonstrate transferable reasoning rather than memorization of a numerical breakpoint.

5.2. Introduce Stewardship Early—Not Later

Antimicrobial stewardship should begin before the clinical years. Although preclinical students do not yet prescribe antibiotics, this is when they start shaping their understanding of appropriate antimicrobial use. If stewardship is introduced only during clinical training, antibiotics may be learned first as drug lists, mechanisms, or exam content rather than as decisions with important consequences for patients and populations. A UK mapping study provides a more specific illustration. Of 24 responding undergraduate medical programs, 23 (95.8%) reported explicit antimicrobial-stewardship teaching, but only 16/23 (69.5%) included all recommended stewardship principles [8]. These findings demonstrate high uptake but incomplete coverage among the responding UK medical programs; comparable estimates from other regions remain limited.

Within preclinical curricula, stewardship can be introduced in a developmentally appropriate way. The goal is not to teach prescribing guidelines too early, but to help students understand the rationale for responsible antimicrobial use. When learning about antimicrobial classes, students can consider why broad-spectrum therapy is not always the best choice. Discussion of resistance mechanisms can also show how unnecessary antibiotic exposure selects for resistant organisms. Likewise, teaching on culture and susceptibility

testing can help students see why laboratory results should guide escalation, de-escalation, or discontinuation of therapy.

5.3. Use Cases to Bridge Theory and Practice

Case-based learning can make AMR more visible in preclinical microbiology. Brief clinical scenarios in preclinical curricula can help students apply microbiological concepts as they learn them rather than treat them as isolated facts. For example, cases involving sepsis, hospital-acquired infection, or multidrug-resistant organisms can prompt students to identify the likely pathogen, interpret culture results, and decide whether escalation or de-escalation of therapy is appropriate.

The purpose is not to make preclinical students manage patients independently, but to help them understand how microbiological knowledge supports clinical reasoning. Evidence from case-based approaches outside AMR is encouraging but not definitive. An optional preclinical elective enrolled 170 students over four years; in one course iteration, a quasi-experimental comparison involving 29 participant respondents and 35 non-participant respondents identified differences in selected self-assessed clinical-reasoning skills. Objective and long-term outcomes were not established [9].

5.4. Rethink Assessment Design

If students are expected to think clinically, assessment must go beyond factual recall. In preclinical microbiology, MCQs should emphasize application to antimicrobial decision-making through:

- clinical vignettes
- problem-solving scenarios
- interpretation of microbiology reports

For example, instead of asking students to identify a resistance mechanism, a question could ask how that mechanism should influence antibiotic selection, escalation, or de-escalation. A recall-based item on extended-spectrum β -lactamase production could be reframed as a vignette in which initial therapy fails and the student must interpret susceptibility results to justify the next microbiologically appropriate action.

Aligning assessment with these competencies is likely to be one of the strongest drivers of change. When application and clinical reasoning are assessed, students are more likely to value microbiology not only as examinable content but also as a foundation for safe and responsible antimicrobial use.

5.5. Implementation, Faculty Development, and Evaluation

These changes may be accommodated within existing teaching time, but they still require resources. Preparing authentic cases, selecting appropriate microbiology reports and antibiograms, calibrating their clinical complexity, and developing application-level assessment items all require protected preparation time. Faculty whose primary training is in basic science may also need support when facilitating discussions involving clinical uncertainty. Co-design with clinical microbiologists, infectious diseases clinicians, antimicrobial pharmacists, and assessment specialists can help ensure that cases remain both microbiologically sound and clinically realistic. Focused faculty-development sessions could address case facilitation, feedback, and assessment-item writing. A multicenter European interview study identified time, culture, motivation, teaching, assessment, and infrastructure among the interconnected barriers to implementing longitudinal clinical-reasoning curricula [10].

The recommendations presented here have not yet been tested together as a complete educational intervention. A sensible starting point would be a pilot within a single microbiology block or course. Evaluation should consider the preparation time required, the

experiences of students and faculty, and whether the intended educational activities are delivered consistently. Case-based MCQs and structured interpretation of microbiology reports could provide initial objective measures of student performance. If the approach proves feasible, subsequent studies could examine knowledge retention, performance during clinical clerkships, and, eventually, prescribing-related outcomes. Self-reported confidence may also be informative, but it should not be the principal measure of effectiveness. This distinction is important because a systematic review of 119 faculty-development studies found that most studies focused on faculty-level outcomes, whereas effects on learners and institutions were less frequently examined [11].

6. Conclusions

AMR is not only a clinical and public health challenge; it is also an educational challenge. Preclinical microbiology provides the scientific basis for understanding infection and resistance, but this knowledge must be more deliberately connected to antimicrobial use, microbiology report interpretation, and stewardship principles. The goal is not to reduce basic science, but to prepare future doctors to use it when reasoning about infection. Because the available curricular evidence is geographically limited and the proposed package has not yet been tested as a single intervention, its feasibility and educational effects require prospective, preferably multi-institutional evaluation.

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