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Development of an Educational Management Model for Antimicrobial Stewardship among Medical Students

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ABSTRACT

Antimicrobial resistance is one of the most urgent public health challenges in contemporary medical practice. Medical education has a strategic role in preparing future physicians to use antimicrobials rationally; however, antimicrobial stewardship is often taught in a fragmented manner, with limited integration between theoretical pharmacology, clinical reasoning, simulation, and digital self-directed learning. This article presents the development, feasibility assessment, and effectiveness evaluation of an educational management model for antimicrobial stewardship among medical students. The study applied a research and development approach using the ADDIE framework, consisting of analysis, design, development, implementation, and evaluation, while program evaluation was strengthened through the CIPP logic of context, input, process, and product evaluation. Data were obtained through curriculum review, observation, expert validation, learning trials, pre-test and post-test assessment, clinical simulation observation, and student feedback. The findings show that the developed model integrates problem-based learning, simulation-based learning, project-based learning, OSCE-oriented assessment, and digital online self-directed learning. Expert validation indicated that the module was highly feasible in terms of content, language, technology, and implementation. Implementation involving 40 medical students showed improvement in mean knowledge scores from 64.75 before intervention to 87.75 after intervention, with a significant Wilcoxon test result and very large effect size. Students also demonstrated improved clinical decision-making in indication, antimicrobial selection, dosing, duration, culture interpretation, and professional attitude. The model provides a structured, adaptive, and sustainable educational management framework for strengthening rational antimicrobial use in medical education.

Keywords: ADDIE, antimicrobial resistance, antimicrobial stewardship, CIPP, clinical simulation, digital learning, educational management, medical education.

INTRODUCTION

Antimicrobial resistance (AMR) is no longer a future threat but a current and escalating challenge for health systems, clinical practice, and medical education. AMR occurs when microorganisms such as bacteria, viruses, fungi, and parasites change in ways that make antimicrobial medicines less effective or ineffective. This condition leads to therapeutic failure, prolonged illness, increased mortality, and higher health-care costs. In the clinical context, AMR is closely linked to inappropriate antimicrobial use, including unnecessary prescribing, incorrect drug selection, inadequate dosing, excessive duration, incomplete adherence, and the absence of culture-guided decision-making. Therefore, AMR is not merely a microbiological problem; it is also an educational and managerial problem that involves the way future physicians are trained to think, decide, prescribe, communicate, and evaluate therapy.

The development of antimicrobial stewardship (AMS) education is important because medical students will eventually become physicians who make prescribing decisions in hospitals, primary care, and community settings. Students may already understand that antibiotics should not be used carelessly, but knowledge alone does not guarantee rational clinical behavior. In many medical curricula, antimicrobial learning is distributed across microbiology, pharmacology, internal medicine, pediatrics, infection prevention, and community medicine. This distribution is academically logical, yet it can produce fragmentation when there is no integrated management model that connects knowledge, clinical skill, professional attitude, and behavioral readiness. The problem becomes more serious when students learn antimicrobial principles theoretically but lack structured simulation in selecting and prescribing antimicrobials for real clinical scenarios.

Educational management is needed to transform AMS from a set of disconnected topics into a coherent learning system. Educational management allows institutions to conduct needs analysis, design learning outcomes, organize resources, implement interactive learning activities, and evaluate outcomes continuously. In this study, the educational management model for AMS was developed to answer three practical needs. First, students require high-yield, clinically relevant content on AMR, antimicrobial principles, infection diagnosis, culture interpretation, de-escalation, and prevention of transmission. Second, lecturers need structured modules, assessment rubrics, digital resources, and learning scenarios that can guide teaching consistently. Third, the institution needs a sustainable model that can be inserted into the existing medical curriculum and aligned with national and global efforts to prevent AMR.

The novelty of the model lies in its integration of ADDIE-based development, CIPP-oriented evaluation, and contemporary learning strategies. ADDIE offers a systematic instructional design cycle: analysis, design, development, implementation, and evaluation. CIPP strengthens program evaluation by asking whether the context justifies the model, whether the input is adequate, whether the process is implemented properly, and whether the product achieves the expected results. In addition, the model combines problem-based learning, simulation-based learning, project-based learning, self-directed digital learning, and OSCE-oriented assessment. Such integration is intended to build a complete competence profile: knowledge of AMR, ability to interpret clinical and laboratory evidence, skill in selecting and prescribing antimicrobials rationally, awareness of infection prevention, and professional responsibility in communicating antimicrobial decisions.

The research focused on the development, feasibility, and effectiveness of an AMS educational management model for medical students. The central problem addressed is the absence of a comprehensive and structured model that links curriculum management, clinical learning, simulation, digital resources, and evaluation of rational antimicrobial use. The objectives are to develop the model, assess its feasibility based on expert and user evaluation, and analyze its effectiveness in improving students' knowledge, skills, attitudes, and rational behavior related to antimicrobial use. The expected contribution is both theoretical and practical: theoretically, the study enriches educational management in medical education; practically, it offers a model that can be adapted by medical faculties and clinical education units to strengthen AMR prevention through student learning.

THEORETICAL FRAMEWORK

Educational Management and Competency Development

Educational management refers to the systematic process of planning, organizing, implementing, supervising, and evaluating educational resources to achieve learning objectives effectively and efficiently. Classical management theory views management as a coordinated process of planning, organizing, actuating, and controlling. In education, these functions become a practical framework for curriculum design, instructional coordination, learning implementation, and quality assurance. Terry and Rue (2021) emphasize that management is a distinct process involving planning, organizing, actuating, and controlling in order to achieve established objectives through human and other resources. Mulyasa (2013) sees educational management as professional and continuous management of educational resources, including educators, students, curriculum, facilities, financing, and learning environment. Fattah (2017) similarly stresses systematic and integrated cooperation to achieve educational goals.

In the context of medical education, educational management must be oriented toward competency development. Students need not only cognitive understanding but also clinical reasoning, communication, ethical sensitivity, and professional behavior. A competency-based educational model requires the institution to define learning outcomes clearly, align learning methods with competencies, and evaluate performance using valid assessment instruments. Wullur et al. (2024) state that educational management involves managing educational institutions through planning, organizing, implementation, and supervision to achieve educational goals effectively and efficiently. This view is relevant to AMS education because antimicrobial stewardship requires a deliberate management cycle, not isolated teaching sessions.

Creative and innovative educational management is essential in preparing high-quality human resources. Sumual et al. (2024) argue that creative and innovative educational management supports the preparation of excellent human resources through planned, adaptive, and competency-oriented education. In this study, the statement is directly relevant because AMS education must be managed innovatively to shape future physicians' professional competence in rational antimicrobial use. Furthermore, Umbase (2023) emphasizes that education in the digital era requires improvement of managerial knowledge and skills oriented toward the integration of technology, pedagogy, and content. This supports the inclusion of digital modules, online evaluation, and self-directed learning in the developed model.

Antimicrobial Resistance and Antimicrobial Stewardship

Antimicrobials are medicines used to inhibit or kill microorganisms, including antibiotics, antivirals, antifungals, and antiparasitic agents. Antibiotics remain the most frequently discussed antimicrobial group because inappropriate antibiotic use is a major driver of bacterial resistance. AMR develops through genetic mutation and selection pressure, but its acceleration is strongly influenced by human behavior, prescribing habits, inadequate infection prevention, poor regulation, and incomplete awareness. WHO (2020) and WHO (2024) describe AMR as a global health priority because resistant organisms reduce the effectiveness of standard therapies and increase morbidity and mortality.

Antimicrobial stewardship is a systematic and coordinated approach to ensuring optimal antimicrobial use. The core principles include correct indication, appropriate drug selection, correct dose, correct route, appropriate duration, culture-guided adjustment, de-escalation when possible, infection prevention, surveillance, and patient education. Magiorakos et al. (2021) explain that stewardship aims to improve patient outcomes, minimize side effects, and reduce resistance by optimizing antimicrobial decisions. In medical education, stewardship is more than a clinical guideline; it is a learning framework that trains students to link microbiology, pharmacology, clinical judgment, public health, patient safety, and ethics.

The challenge is that students often learn antimicrobial topics separately. They may memorize drug classifications but remain uncertain when facing clinical cases that require choosing between empirical and definitive therapy, interpreting culture results, or explaining why broad-spectrum therapy should be narrowed. Therefore, AMS learning must be organized as a progressive set of clinical reasoning experiences. Learning should begin with basic AMR concepts, proceed to pathogen recognition and infection diagnosis, then develop toward case-based prescribing, simulation, evaluation, and reflection.

Learning Models in Medical Education

Contemporary medical education increasingly uses active learning strategies. Problem-based learning allows students to analyze clinical problems, identify learning issues, integrate knowledge, and justify decisions. Simulation-based learning provides safe and controlled opportunities to practice clinical decision-making without harming patients. Project-based learning promotes collaborative inquiry and product-oriented learning, such as developing educational materials or stewardship recommendations. Self-directed learning develops learner autonomy and lifelong learning, which is essential because antimicrobial guidelines and resistance patterns change over time.

In AMS education, these strategies complement each other. PBL supports reasoning from symptoms, risk factors, diagnosis, and local resistance patterns toward rational therapy. Simulation trains students in prescribing under time pressure, counseling patients, and explaining de-escalation. Digital self-directed learning enables repeated access to modules, videos, quizzes, discussion forums, and reference materials. OSCE-based assessment provides an objective way to evaluate applied competence. This combination is consistent with the need for a model that connects knowledge, skill, and professional behavior.

Research and Development, ADDIE, and CIPP

Research and Development (R&D) is appropriate for studies that aim to produce and test educational products. In this study, R&D was operationalized through ADDIE. The analysis stage identifies needs, gaps, learner characteristics, curriculum position, and institutional resources. The design stage translates needs into learning outcomes, content structure, learning activities, and assessment strategy. The development stage produces modules, digital media, evaluation instruments, and learning scenarios. The implementation stage tests the model with users. The evaluation stage determines quality, effectiveness, and recommendations for improvement.

The CIPP model strengthens the evaluation dimension. Context evaluation clarifies the need for AMS education in the face of AMR. Input evaluation examines the adequacy of modules, lecturers, digital platforms, and facilities. Process evaluation monitors whether learning activities are implemented as designed. Product evaluation assesses changes in knowledge, skills, attitudes,

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and student satisfaction. The combination of ADDIE and CIPP is useful because it links instructional design with program accountability.

METHOD

This study used a research and development design to develop, validate, implement, and evaluate an educational management model for antimicrobial stewardship among medical students. The development procedure followed the ADDIE model: analysis, design, development, implementation, and evaluation. The model was selected because it provides a practical sequence for designing educational products and allows iterative revision at each stage. The evaluation framework was strengthened by the CIPP logic so that the model could be analyzed from the perspectives of need, resources, process quality, and learning outcomes.

The analysis stage involved review of the medical curriculum, literature study on AMR and AMS education, identification of learning gaps, and exploration of student and lecturer needs. The design stage produced the structure of the AMS module, learning outcomes, teaching methods, assessment strategies, and digital learning flow. The development stage produced the learning module, digital platform interface, clinical cases, pre-test and post-test items, OSCE-oriented assessment, and validation instruments. The implementation stage involved a trial with 40 medical students selected purposively from a relevant semester and who had completed basic modules. The implementation lasted ten days with sixteen hours of contact learning, including self-directed study, interactive sessions, discussion, simulation, and evaluation.

Data consisted of qualitative and quantitative information. Qualitative data were obtained from curriculum review, observation, expert feedback, and student reflections. Quantitative data were obtained from pre-test and post-test scores, expert validation scores, observed clinical performance, and student satisfaction. Expert validation involved assessment of content feasibility, linguistic feasibility, media or technology feasibility, implementation feasibility, and assessment feasibility. Quantitative data were analyzed descriptively and through comparative testing of pre-test and post-test results. Qualitative data were analyzed thematically to identify the strengths, limitations, and improvement needs of the model.

RESULTS AND DISCUSSION

Analysis Stage: Needs, Gaps, and Model Rationale

The analysis stage confirmed that AMS education was urgently needed because AMR is a global and national health problem, and future physicians require competence in rational antimicrobial use. The review showed that students had exposure to microbiology, pharmacology, infection prevention, and clinical medicine, but these topics were not yet managed as a coherent AMS education pathway. Learning tended to emphasize knowledge rather than integrated clinical application. Students needed a model that could help them interpret infection cases, determine whether antimicrobials are indicated, select appropriate agents, determine dose and duration, interpret culture and sensitivity results, and communicate antimicrobial decisions safely.

The analysis also identified that digital learning resources were needed to support flexibility. Medical students face dense academic schedules; therefore, AMS materials should be concise, high-yield, accessible, and repeatedly usable. The digital component was intended to prevent information overload while enabling self-directed learning. The analysis stage therefore generated five major model requirements: an integrated curriculum structure, competency-based learning outcomes, active clinical learning strategies, digital resources, and measurable assessment instruments. See figure 1.

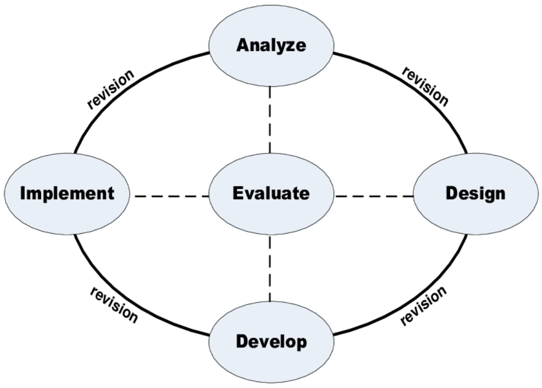

Figure 1. ADDIE development cycle used as the instructional development framework.

Design Stage: Learning Components and Curriculum Alignment

The design stage formulated the educational management model as a system consisting of input, process, output, control, and feedback. Inputs include students, lecturers, clinical cases, digital learning resources, stewardship guidelines, and assessment rubrics. The process includes delivery of essential content, case discussion, clinical simulation, culture interpretation, prescription practice, reflection, and evaluation. The expected output is improved knowledge, clinical decision-making, professional attitude, and rational antimicrobial behavior. The control component ensures that the process follows standards through structured learning instructions, rubrics, module guides, and feedback mechanisms. The feedback component creates a continuous improvement cycle based on student and lecturer responses.

The learning design integrates four methods. First, interactive short lectures and e-learning introduce AMR mechanisms, antimicrobial principles, and stewardship strategies. Second, problem-based learning uses clinical scenarios such as pneumonia, urinary tract infection, sepsis, skin infection, and nosocomial infection to develop clinical reasoning. Third, simulation-based learning trains students to prescribe antimicrobials, interpret culture and antibiogram data, and practice de-escalation. Fourth, digital self-directed learning provides modules, videos, quizzes, and discussion forums that can be accessed independently. Assessment is aligned with learning outcomes through MCQ, short answer questions, OSCE, mini-CEX style observation, portfolio tasks, and reflective activities. See table 1 and figure 2.

Table 1. Alignment of learning outcomes, methods, and assessment

Learning outcome domain	Module competence	Main learning method	Assessment strategy
Biomedical, clinical, and public health reasoning	Explain basic AMR principles, mechanisms, and drivers at individual, hospital, and community levels	Short interactive lecture, self-directed e-learning, guided tutorial discussion	MCQ/SAQ on AMR concepts and online pre-post quizzes
Rational infectious disease management	Apply stewardship principles: indication, drug choice, dose, route, duration, and de-escalation	PBL, small-group discussion, prescription simulation, bedside teaching	OSCE rational antibiotic prescription, case management sheet, mini-CEX style observation

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Critical thinking and evidence-based decision-making	Interpret culture, susceptibility test, and antibiogram to adjust antimicrobial therapy	Interactive workshop with branched cases, antibiogram practice, stewardship team simulation	OSCE culture and antibiogram interpretation, portfolio case analysis, group worksheet
Patient safety and infection prevention	Link infection prevention, vaccination, culture timing, and safe medicine use to AMS	Video demonstration, clinical teaching, role play counseling	PPI-related OSCE checklist, counseling assessment, reflective notes
Communication and professionalism	Communicate antimicrobial decisions and educate patients about adherence and resistance risk	Role play, reflection, feedback session	Communication rubric and professional attitude observation

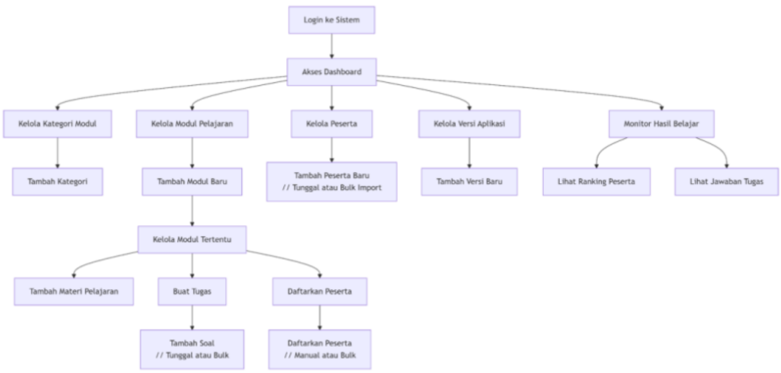

Figure 2. Conceptual structure of AMS educational management based on theoretical review.

Development Stage: Module, Digital Platform, and Expert Validation

The development stage produced the AMS learning module and digital learning resources. The module contains semester learning plans, learning objectives, structured materials, clinical cases, prescribing exercises, self-directed learning instructions, and assessment instruments. The digital platform was designed to support web-based and mobile-based access. It includes user registration, login, dashboard, lesson categories, learning modules, learning materials, assignments, evaluation results, forum discussion, ranking, profile management, and application updates. These features were designed to make the model accessible, interactive, and manageable by lecturers and administrators.

The administrator flow enables lecturers or managers to create module categories, add lessons, upload learning materials, assign tasks, register participants, monitor ranking and answers, and manage application versions. The user flow enables students to register, verify email, log in, enroll in modules, access materials, participate in forums, complete assignments, view evaluation results, see leaderboard ranking, update profiles, and check application updates. These functions strengthen educational management because the learning process can be monitored systematically rather than delivered only as a face-to-face session.

Expert validation indicated that the model was feasible. The content feasibility score reached 3.70 and was categorized as very good. Linguistic feasibility reached 3.63 and was also categorized as very good. Media or technology feasibility reached 3.35 and was categorized as good. Implementation feasibility reached 3.45, located between good and very good. Assessment feasibility reached 3.55 and was categorized as very good. The overall average score was 3.54,

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indicating that the product was highly feasible for implementation after minor refinements. Expert comments emphasized that the model should maintain concise content, strengthen clinical examples, ensure digital usability, and use rubrics consistently. See table 2, and figure 3, 4.

Table 2. Expert validation results for the AMS module and model

Validation indicator	AMS expert	Medical education expert	Media/application expert	Mean	Category
Content feasibility	3.80	3.60	3.70	3.70	Very good
Linguistic feasibility	3.60	3.75	3.55	3.63	Very good
Media/technology feasibility	3.40	3.30	3.35	3.35	Good
Implementation feasibility	3.50	3.40	3.45	3.45	Good-Very good
Assessment feasibility	3.60	3.50	3.55	3.55	Very good
Overall average	3.58	3.51	3.52	3.54	Very feasible

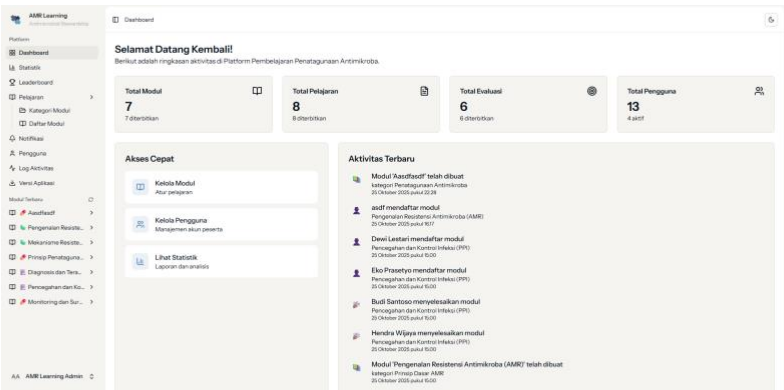

Figure 3. Administrative flow and dashboard functions of the digital AMS learning platform.

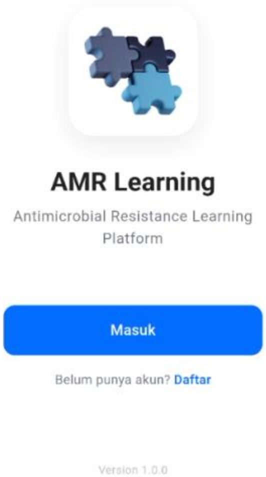

Figure 4. Mobile login interface supporting student access to AMS learning resources.

Implementation Stage: Learning Activities and Trial Process

The implementation stage tested the model in a structured ten-day learning cycle. The first day introduced the module and conducted the pre-test. The next sessions delivered microbiology, antimicrobial concepts, AMR mechanisms, stewardship principles, diagnosis and rational infection therapy, infection prevention and control, monitoring and surveillance, clinical simulation, group presentation, reflection, and post-test. The total contact time was sixteen hours, combined with self-directed learning and digital access. Students were divided into groups and given clinical cases such as pneumonia, urinary tract infection, sepsis, and nosocomial infection. Each group analyzed clinical findings, laboratory data, and stewardship options using problem-based learning steps.

The simulation component required students to identify whether antimicrobial therapy was indicated, select empirical therapy, interpret culture and susceptibility data, revise therapy through de-escalation, determine duration, and consider resistance risk. Students were also assessed on professional attitudes, including caution in antimicrobial selection, awareness of resistance risk, infection prevention, and clinical communication. At the end of the simulation, students provided scientific justification for antimicrobial decisions, reflected on their learning, completed a perception questionnaire, and undertook the post-test. See table 3, and figure 5, 6.

Table 3. Duration and structure of model implementation

Day	Main activity	Duration
Day 1	Module introduction and pre-test	2 hours
Day 2	Microorganism and infection concepts	4 hours
Day 3	Introduction to antimicrobials	4 hours
Day 4	Mechanisms of antimicrobial resistance	4 hours
Day 5	Principles of antimicrobial stewardship	4 hours
Day 6	Diagnosis and rational infection therapy	4 hours
Day 7	Infection prevention and control	2 hours
Day 8	Monitoring and surveillance of antimicrobial use	2 hours
Day 9	Clinical simulation and group case discussion	4 hours
Day 10	Reflection, post-test, and satisfaction evaluation	2 hours

Figure 5. Implementation documentation: classroom-based learning and discussion activity.

Figure 6. Implementation documentation: student access to digital learning materials.

Evaluation Stage: Knowledge Gain, Clinical Competence, and Satisfaction

The evaluation stage showed strong improvement in students' knowledge after using the model. The mean pre-test score was 64.75, while the mean post-test score increased to 87.75. The increase of 23.00 points indicates that the model helped students understand AMR and AMS concepts more effectively. The normality test showed non-normal distribution, so a Wilcoxon test was used. The result indicated a statistically significant difference between pre-test and post-test scores with $p < 0.001$. The effect size was very large, suggesting that the intervention had a substantial educational impact. This finding supports the claim that structured AMS education can produce meaningful cognitive improvement when students are engaged through integrated methods.

Clinical simulation also demonstrated improved stewardship competence. Before implementation, student achievement was relatively low in several clinical aspects: appropriate indication, antimicrobial selection, dose, duration, culture consideration, and professional attitude. After implementation, all aspects improved substantially. Appropriate indication increased from 45% to 85%, appropriate antimicrobial selection from 40% to 80%, correct dose from 35% to 78%, correct duration from 30% to 75%, culture consideration from 38% to 82%, and professional attitude from 50% to 88%. These results suggest that the model affected not only knowledge but also applied clinical reasoning and professional behavior.

Student satisfaction was also high. Ninety-two percent of students were satisfied with the module materials, 88% with case discussion, 95% with clinical simulation, 90% with the digital platform, and 93% with the overall learning experience. Students reported that the model helped them understand AMS more clearly, gave them clinical experiences close to real situations, and increased their confidence in antimicrobial selection and prescription. Areas for improvement included increasing the number of case variations, improving mobile interface stability, and providing more frequent feedback from lecturers. See figure 7, 8, and table 4, 5.

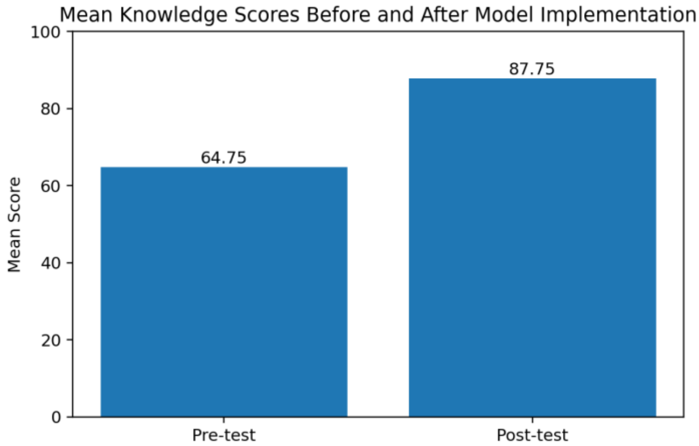

Figure 7. Mean pre-test and post-test scores after model implementation.

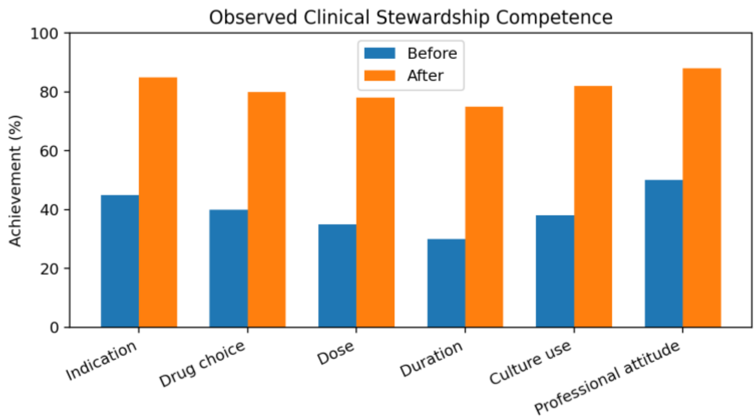

Figure 8. Observed improvement in clinical stewardship competence.

Table 4. Observed clinical competence before and after implementation

Assessment aspect	Before implementation	After implementation
Appropriate indication	45%	85%
Appropriate antimicrobial selection	40%	80%
Correct dose	35%	78%
Correct duration of therapy	30%	75%
Culture and susceptibility consideration	38%	82%
Professional attitude and communication	50%	88%

Table 5. Student satisfaction with the AMS educational management model

Aspect	Satisfied (%)	Adequate (%)	Not satisfied (%)
Module material	92%	8%	0%
Case discussion	88%	10%	2%
Clinical simulation	95%	5%	0%
Digital platform	90%	10%	0%
Overall learning experience	93%	7%	0%

The findings demonstrate that the AMS educational management model is feasible and effective because it responds to a clearly identified educational gap. Students need more than theoretical exposure to antimicrobial topics; they need a managed learning pathway that connects concepts, clinical reasoning, simulation, reflection, and evaluation. The ADDIE framework ensured that the product was not developed arbitrarily. Needs were analyzed, learning outcomes were designed, materials and media were developed, the model was implemented, and outcomes were evaluated. This systematic sequence is consistent with educational management principles that emphasize planning, organizing, implementation, control, and continuous improvement (Terry & Rue, 2021; Fattah, 2017; Wullur et al., 2024).

The analysis stage confirmed the importance of context evaluation. AMR is a complex problem, but medical education can contribute to long-term prevention by shaping clinical decision-making habits before students become independent physicians. Context evaluation under CIPP showed a strong need for AMS education because irrational antimicrobial use remains a major driver of AMR. Input evaluation showed that modules, digital resources, cases, lecturers, and assessment tools were required. Process evaluation demonstrated that the model could be implemented through lectures, PBL, simulation, and digital self-directed learning. Product evaluation showed improved knowledge, clinical competence, and satisfaction. This confirms the usefulness of combining ADDIE with CIPP as both a development and evaluation structure.

The expert validation results indicate that the model has strong content quality. The very good content score suggests that AMR mechanisms, stewardship principles, rational therapy, infection prevention, culture interpretation, and surveillance were considered relevant to medical education. The linguistic score shows that the module was understandable to students. The media score was good rather than very good, which suggests that digital learning media were feasible but still require improvement. This is important because digital technology should support, not complicate, learning. Umbase (2023) emphasizes the need to integrate technology, pedagogy, and content in the digital era. Therefore, future development should improve interface usability, mobile performance, notification systems, and learner analytics.

The implementation findings support the value of active learning. PBL enabled students to analyze clinical cases rather than merely memorize antibiotic names. Simulation-based learning enabled students to practice antimicrobial decisions in a safe environment. Project-based and discussion activities encouraged collaboration. Self-directed digital learning allowed students to revisit content independently. This combination explains the strong increase in knowledge scores and observed clinical competence. The model helped students connect clinical data, laboratory results, guidelines, and patient safety considerations into a rational prescribing decision. Such integration is particularly important because inappropriate prescribing often comes from failure to synthesize information, not only lack of knowledge.

The improvement from 64.75 to 87.75 in mean knowledge scores is educationally meaningful. A 23-point increase shows that students were able to absorb and apply the material. The significant Wilcoxon result and very large effect size provide quantitative support. However, the interpretation should remain balanced because the design used one group without a control group. The improvement can be attributed to the intervention with reasonable confidence, but future research should compare this model with conventional teaching or other instructional models. Nevertheless, the combination of quantitative improvement and qualitative feedback strengthens the conclusion that the model was effective.

The clinical competence results are particularly important because AMS is fundamentally a practice-oriented competence. Knowledge about AMR is valuable only if it influences prescribing behavior. The increase in indication, drug choice, dose, duration, culture use, and professional attitude demonstrates that the model moved learning beyond recall toward applied reasoning. The highest post-implementation percentage was professional attitude and communication, reaching 88%. This indicates that simulation and reflection helped students become more careful, responsible, and aware of resistance risks. The lower but still improved score on therapy duration suggests that duration remains a difficult topic and should receive additional emphasis in future module revisions.

The high satisfaction score suggests that students accepted the model. Satisfaction is not the same as learning effectiveness, but it is important because student acceptance influences engagement and sustainability. Students valued clinical simulation most highly, followed by overall learning experience and module materials. This suggests that AMS education should not be delivered only through lectures. Students need to practice decision-making, receive feedback, and see the relevance of stewardship to actual patient care. The digital platform was also positively evaluated, showing that technology can support AMS learning when used as part of an integrated design.

The model also reflects creative and innovative educational management. Sumual et al. (2024) emphasize that educational management should be planned, adaptive, and oriented toward competency development. This model follows that principle by using needs analysis, active learning, digital technology, and evaluation. Wullur et al. (2024) describe educational management as a process of planning, organizing, implementing, and supervising educational institutions to achieve goals effectively and efficiently. The AMS model operationalizes these functions in a medical education context: planning through curriculum alignment, organizing through lecturer and platform roles, implementation through PBL and simulation, and supervision through assessment and feedback.

From a curriculum perspective, the model contributes to integrating fragmented content. Antimicrobial content is often scattered across courses. The model reorganizes it into a competency pathway that follows the logic of clinical practice: understand infection and resistance, decide whether antimicrobials are indicated, select empiric therapy, interpret culture, de-escalate, determine duration, educate patients, and monitor outcomes. This pathway is valuable because it mirrors the decision-making process that doctors will use in real clinical settings. It also supports the SPICES orientation in medical education by encouraging student-centered, problem-based, integrated, community-oriented, elective, and systematic learning.

The study has practical implications. Medical faculties can adapt the model by inserting AMS modules into microbiology, pharmacology, internal medicine, or integrated clinical blocks. Hospitals can use the model to prepare students for clinical rotations and align prescribing education with infection control and antimicrobial policies. Lecturers can use the module, cases, OSCE rubrics, and digital platform to standardize learning. Students can use digital materials for self-directed learning and repeated practice. Policy makers can use the model as a prototype for broader AMS curriculum development in medical education.

The limitations should also be acknowledged. The trial involved 40 students from one institution and used a one-group pretest-posttest design. This limits generalization and causal inference. The intervention was implemented over ten days, so long-term retention and behavioral transfer into clinical practice were not measured. The digital platform was tested for educational use but needs further evaluation of system stability, scalability, and integration with institutional learning management systems. Future studies should use randomized or quasi-experimental comparison groups, larger samples, multi-institutional trials, longer follow-up, and measurement of actual prescribing performance during clinical rotation.

Interpretation of the Management Cycle

The management cycle embedded in the model can be interpreted as a translation of educational management theory into medical education practice. Planning is reflected in the identification of AMR learning needs, mapping of curriculum gaps, formulation of learning outcomes, and determination of assessment standards. In many programs, antimicrobial learning is present but distributed across subjects without explicit integration. The model addresses this by converting fragmented content into an explicit AMS pathway. This planning process gives educators a roadmap for deciding what students should know, what they should be able to do, and how their achievement should be measured. It also provides students with transparent expectations so that learning is not perceived as a collection of disconnected lectures.

Organizing appears in the distribution of roles among lecturers, clinical educators, digital platform administrators, and students. In the model, lecturers are not only knowledge transmitters; they become facilitators of reasoning, designers of cases, assessors of OSCE performance, and providers of formative feedback. Students are not passive recipients; they become active problem solvers who engage with cases, compare therapy options, interpret laboratory evidence, and evaluate their own decisions. Digital administrators manage materials, assignments, feedback, and ranking features. This role distribution makes the system manageable and reduces dependence on one individual lecturer.

Actuating is represented by the actual learning experience. The model motivates students through authentic clinical problems, simulation, immediate feedback, and digital accessibility. Students are more likely to engage when the relevance of learning is visible. A case of pneumonia, urinary tract infection, or sepsis requires students to connect symptoms, examination findings, local resistance patterns, drug spectrum, patient safety, and follow-up plans. This learning activity activates reasoning in a way that conventional lecture-based delivery cannot fully provide. Actuating also includes the emotional and professional dimensions of learning because students become aware that poor antimicrobial decisions may contribute to resistance and harm future patients.

Controlling is reflected in pre-test, post-test, OSCE, observation sheets, satisfaction surveys, and expert validation. These mechanisms make quality assurance visible. Without control, a curriculum can appear complete on paper but fail to produce competence. The model shows that control should not be punitive; it should be developmental. Students receive feedback, lecturers see which concepts remain weak, and the institution obtains data for curriculum improvement. The evaluation results are returned to planning, creating a cycle of continuous improvement. This is why the model functions not only as a learning module but also as an educational management system.

Implications for Medical Education and AMR Prevention

The first implication concerns curriculum integration. AMR prevention cannot be left only to infectious disease specialists or microbiology lecturers. It requires a shared educational responsibility across the medical curriculum. The model can be positioned in pre-clinical blocks to introduce mechanisms of resistance and antimicrobial classes, then continued in clinical blocks to strengthen prescribing decisions, infection prevention, de-escalation, and patient counseling. This progression allows students to revisit AMS concepts repeatedly at increasing levels of complexity. Such repetition is important because professional competence develops through cumulative exposure, practice, and feedback.

The second implication concerns assessment reform. Traditional written tests can measure knowledge but may fail to assess whether students can prescribe safely in clinical scenarios. The inclusion of OSCE, mini-CEX style observation, portfolio tasks, and case analysis allows the institution to assess applied competence. For example, a student can be asked to interpret a culture result showing resistance to ciprofloxacin and sensitivity to nitrofurantoin, then justify why therapy should be changed. Such assessment directly measures stewardship reasoning. It also teaches students that rational prescribing involves evidence interpretation and patient-specific decision-making, not memorization of drug names.

The third implication concerns digital transformation. Medical students are familiar with mobile access and online learning, but digital technology must be pedagogically meaningful. The digital platform in the model provides access to materials, assignments, discussion forums, evaluation results, and learning progress. This creates continuity between classroom learning and independent study. However, the digital component should continue to be improved. A future version could include adaptive quizzes, analytics dashboards, push reminders, case branching, antibiotic guideline links, and integration with institutional learning management systems. Digital learning should support reflection, practice, and feedback, not simply store PDF files.

The fourth implication concerns professional formation. AMS education shapes not only cognitive competence but also professional identity. Students learn that antimicrobial prescription is a moral and public responsibility. A prescription affects the individual patient, but it also influences microbial ecology, hospital resistance patterns, and future treatment options. By combining clinical simulation with reflection, the model helps students recognize their role as future stewards of antimicrobial effectiveness. This ethical dimension is essential because AMR prevention depends on responsible habits sustained across professional life.

The fifth implication concerns policy. Medical faculties and teaching hospitals need formal policies that require AMS education, specify minimum competencies, allocate teaching time, provide simulation resources, and support faculty development. Without policy support, AMS education may depend on individual enthusiasm and remain vulnerable to staff changes. Institutionalization is necessary to make the model sustainable. This can be done by including AMS competencies in curriculum documents, developing interprofessional collaboration with pharmacy and microbiology departments, and linking student learning with hospital antimicrobial stewardship committees.

Strengths and Areas for Improvement of the Model

A major strength of the model is its balance between systematic development and practical usability. ADDIE ensured that development followed a logical sequence, while the learning activities were designed to be feasible within a medical education context. The ten-day implementation demonstrates that the model can be delivered in a compact format without losing essential content. Another strength is the integration of multiple learning methods. PBL, simulation, project tasks, digital learning, and OSCE address different dimensions of competence. This multimodal design is particularly appropriate for AMS because the subject itself is interdisciplinary.

Another strength is the use of measurable outcomes. The model was not evaluated only through narrative impressions. It used validation scores, pre-test and post-test results, observed clinical competence, and satisfaction data. This strengthens the credibility of the findings and provides a basis for future improvement. The evidence shows that students improved in knowledge and applied skills. The satisfaction results also indicate that the model was acceptable to users. High acceptability matters because even a well-designed curriculum will fail if students perceive it as irrelevant or burdensome.

At the same time, several areas require improvement. First, the digital platform should be developed further to improve interface stability and interactive features. Second, the number of case scenarios should be expanded to include pediatric infections, surgical prophylaxis, tuberculosis, fungal infections, viral infections, sepsis bundles, and local antibiogram variations. Third, lecturers need faculty development to use simulation and OSCE rubrics consistently. Fourth, longitudinal follow-up is needed to determine whether students retain competence and apply it during clinical rotation. Fifth, interprofessional elements should be strengthened because AMS in real practice involves physicians, pharmacists, microbiologists, nurses, infection control teams, and hospital managers.

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Sustainability and Adaptation Strategy

Sustainability is a crucial issue because educational innovations often disappear after the research period ends. The AMS educational management model can be sustained when it is embedded in institutional routines. This means that the module should be included in curriculum planning documents, the digital platform should be maintained by an assigned team, lecturers should have scheduled responsibilities, and evaluation results should be reviewed regularly by the program. Sustainability also requires resource allocation. Even though the model can begin with modest resources, the institution should gradually invest in case banks, simulation materials, digital maintenance, and faculty training. A model that depends solely on one developer or one enthusiastic lecturer will be difficult to maintain.

Adaptation is also necessary because AMR patterns and treatment guidelines change. The model must not be treated as a fixed textbook. Instead, it should be a living curriculum that can be updated based on new guidelines, local antibiogram data, hospital policy, and student feedback. Annual review can be conducted through a small AMS curriculum committee consisting of educators, clinicians, microbiologists, pharmacists, and student representatives. The committee can revise cases, update drug choices, add local data, and adjust assessments. This mechanism keeps the model clinically relevant and prevents outdated prescribing information from being taught.

The model can also be adapted for different levels of medical training. For early-year students, the emphasis can be placed on basic microbiology, mechanisms of resistance, public health impact, and ethical awareness. For clinical students, the emphasis can shift to diagnosis, empirical therapy, definitive therapy, de-escalation, surgical prophylaxis, and patient communication. For internship or residency settings, the model can be expanded into interprofessional stewardship rounds and hospital-based audit feedback. In this way, the model functions as a flexible educational framework rather than a one-time course.

Finally, the model supports wider public health goals. Medical education is one entry point for AMR prevention because future prescribing behavior is shaped before students become independent doctors. When students learn to prescribe antimicrobials rationally, communicate with patients who request unnecessary antibiotics, and respect culture-guided therapy, they contribute to a broader culture of responsible antimicrobial use. Therefore, the educational value of the model extends beyond student achievement. It supports the health system by preparing physicians who understand that every antimicrobial decision has clinical, ethical, and epidemiological consequences.

Proposed Educational Management Model

Based on the findings, the proposed model can be described as an integrated AMS educational management cycle. The first component is context and needs analysis. The institution identifies AMR challenges, curriculum gaps, student characteristics, lecturer readiness, and clinical learning needs. The second component is curriculum design, consisting of learning outcomes, AMS topics, case scenarios, digital learning materials, and assessment rubrics. The third component is resource organization, including lecturer teams, clinical supervisors, digital administrators, simulation resources, case banks, and assessment instruments. The fourth component is learning implementation, combining interactive lectures, PBL, simulation, project-based activity, self-directed digital learning, and reflection. The fifth component is evaluation and control, using pre-post tests, OSCE, portfolios, satisfaction surveys, and feedback loops. The sixth component is continuous improvement, where evaluation results are used to revise modules, cases, media, and assessment instruments.

This model is not only an instructional product but also a management system. It requires leadership commitment, lecturer collaboration, technological support, and institutional policy. The model can be implemented gradually. In the first phase, the institution can introduce the module and digital resources. In the second phase, PBL and simulation can be integrated into existing blocks. In the third phase, OSCE and portfolio assessment can be formalized. In the fourth phase, institutional data can be collected to evaluate student competence and curriculum impact. With this staged approach, the model becomes sustainable and adaptable. See table 6.

Table 6. Proposed model components and implementation functions

Model component	Management function	Implementation strategy	Expected outcome
Context and needs analysis	Planning	Review AMR burden, curriculum gaps, student needs, and institutional resources	Clear problem basis and competency priorities
Curriculum and module design	Planning and organizing	Develop learning outcomes, cases, module sequence, digital content, and rubrics	Integrated AMS curriculum structure
Resource organization	Organizing	Assign lecturer roles, digital administration, simulation resources, and assessment team	Efficient and coordinated implementation
Learning implementation	Actuating	Use PBL, simulation, self-directed digital learning, role play, and reflection	Improved knowledge, reasoning, skill, and professional attitude
Evaluation and control	Controlling	Use pre-post tests, OSCE, observation, portfolio, and satisfaction survey	Evidence-based quality assurance
Continuous improvement	Feedback loop	Revise content, cases, media, and assessment based on results	Adaptive and sustainable AMS education

CONCLUSION

The developed educational management model for antimicrobial stewardship is feasible, relevant, and effective for strengthening AMS competence among medical students. The model was developed through a systematic ADDIE process and evaluated using CIPP-oriented logic. It integrates curriculum management, problem-based learning, simulation-based learning, project-based learning, digital self-directed learning, and competency-oriented assessment. Expert validation showed that the model was highly feasible, especially in terms of content, language, implementation, and assessment, while the media component was feasible and should continue to be refined. Implementation results showed a significant improvement in student knowledge, with mean scores increasing from 64.75 to 87.75. Clinical competence also improved across indication, drug selection, dose, duration, culture interpretation, and professional attitude. Student satisfaction was high, particularly for clinical simulation and overall learning experience. These findings indicate that AMS education is more effective when managed as an integrated learning system rather than delivered as fragmented theoretical content. The model offers theoretical contribution to educational management by demonstrating how planning, organizing, implementation, evaluation, and feedback can be translated into a medical education innovation. Practically, it provides a model that medical faculties can adapt to strengthen rational antimicrobial use and contribute to AMR prevention. Future work should expand the model through multi-institutional trials, control-group designs, longer follow-up, digital platform refinement, and assessment of prescribing behavior during clinical practice.

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