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Exploring an Artificial Intelligence - Driven Teaching Model for the Environmental Engineering Microbiology Course

Shasha LIU

School of Environmental and Chemical Engineering, Zhaoqing University, Guangdong Provincial Key Laboratory of Suburban Eco-environment and Low-carbon Agriculture, Zhaoqing 526061, China

Abstract Artificial intelligence (AI) technology, with its powerful capabilities in data analysis, intelligent interaction, and personalized learning support, is creating new opportunities for the reform of education and teaching. Through the integration of online and offline blended teaching methods, this study utilizes a learning platform to analyze multi-source student learning data, assess knowledge mastery, and dynamically generate personalized learning paths. Abstract concepts are visualized via 3D modeling and dynamic simulation to enhance students' comprehension of microbiological knowledge. Knowledge mapping is employed to systematically organize course concepts and establish dynamic connections, aiding students in navigating complex and abstract knowledge structures. By leveraging an interactive learning platform, a multi-evaluation system incorporating dynamic assessment, teacher feedback, and student self-evaluation is established. This system evaluates learning outcomes through automated grading and intelligent analysis, while also delivering adaptive teaching resources tailored to individual student differences, so as to meet personalized learning need and stimulate students' interest and motivation. This study offers innovative insights for the curriculum reform of Environmental Engineering Microbiology in the context of emerging engineering education.

Key words Artificial intelligence (AI), Environmental Engineering Microbiology, Teaching mode, Personalized learning, Knowledge mapping

0 Introduction

As a vital foundational course for environmental engineering majors, Environmental Engineering Microbiology establishes an applied and interdisciplinary framework aimed at water pollution control, waste gas treatment, soil bioremediation, and solid waste resource utilization. It achieves this by combining core microbiological topics, such as morphology, growth metabolism, and genetics, with knowledge from environmental science, engineering, ecology, and chemistry, thereby revealing the fundamental principles and action mechanisms of microbes in these applications. However, the microscopic, dynamic, and complex nature of its research focus has often been poorly served by traditional pedagogy, which impedes effective teaching and comprehension. Leveraging advantages in data analysis, intelligent interaction, and personalized learning, Artificial Intelligence (AI) provides fresh perspectives for reforming education and teaching. Integrating AI technology into the teaching of Environmental Engineering Microbiology can effectively address issues in curriculum development and enhance both the quality and effectiveness of instruction[1].

Recent years have witnessed growing research on the application of AI in microbiology education. For instance, the Microbiology teaching team at Yunnan Agricultural University has pioneered the transition from traditional instruction to smart education by developing an integrated AI-driven course, creating a large AI model-based virtual teaching assistant, establishing a shared virtual teaching and research platform, and continuously incorporating high-quality virtual simulation experiments. Similarly, Sun Li *et al.*[3] fostered student engagement and innovative thinking through knowledge mapping, virtual experimental platforms, and the integration of research findings, paving a new path for course digitalization. Nevertheless, further exploration is needed on how to effectively integrate AI technology into Environmental Engineering Microbiology and construct innovative teaching models.

In the context of increasingly complex environmental problems and the accelerating intelligent transformation of environmental protection technologies, reforming the pedagogy of Environmental Engineering Microbiology has become imperative. Based on an analysis of the existing teaching model's deficiencies, this paper formulates a student-centered, AI-supported framework. It investigates the development of a hybrid teaching model that integrates online and offline elements, facilitates personalized content customization, enables intelligent management of the teaching process, and ensures accurate evaluation of learning outcomes. The objective is to improve both the quality and effectiveness of instruction, thereby providing crucial support for cultivating environmental engineering professionals equipped to meet the demands of the times.

1 Analysis on the teaching status and problems of Environmental Engineering Microbiology

This course utilizes *Environmental Engineering Microbiology* (5^{th} *Edition.*) edited by Zhou Qunying as its core textbook. Given the interdisciplinary nature, broad coverage, and complex knowledge system of the subject, students are expected not only to master fundamental concepts but also to integrate and apply multidisciplinary knowledge effectively. The essential microbiology princi-

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Shasha LIU, doctoral degree, research fields: environmental behavior and ecological effects of new pollutants.

ples taught in the course are directly applied to environmental pollution control engineering. For instance, during wastewater treatment, microbial metabolic processes are harnessed to break down organic pollutants into low-toxic or non-toxic substances, thereby purifying the water[4]. These demands place higher requirements on students' learning and problem-solving abilities. However, certain limitations persist in the current teaching methodology of Environmental Engineering Microbiology.

1.1 Rigid teaching methods and ineffective knowledge transfer The prevailing teaching in Environmental Engineering Microbiology is characterized by teacher-centered instruction delivered primarily via PowerPoint. In this model, instructors systematically present textbook content while students assume a passive role, absorbing information with little interaction. This approach fosters low classroom participation and does little to motivate students or encourage proactive learning. The inherently abstract nature of topics such as the cellular structures of viruses, prokaryotes, and eukaryotes makes them difficult to convey through verbal description and static images alone. A case in point is the "aerobic biofilm process": although instructors show structural diagrams in slides, students often cannot form a mental model of the biofilm's spatial configuration, hindering their ability to understand the underlying purification mechanism. Under this traditional model, students depend heavily on teacher exposition, which is not conducive to cultivating self-directed learning skills and ultimately leads to a lack of innovative thinking and problem-solving abilities.

1.2 Fixed and undifferentiated teaching content and uniform pace of instruction making it difficult to meet students' personalized learning needs Students exhibit significant individual differences in their foundational knowledge and learning capacities. Some have already grasped basic microbiological theories in high school, while others lack this background. Similarly, while some students can quickly assimilate new information, others struggle to keep pace with the course. The traditional teaching model, with its homogeneous content and uniform pace, fails to accommodate these diverse learning needs. This one-size-fits-all approach dampens student enthusiasm and leads to suboptimal learning outcomes. For instance, "microbial metabolism", a theoretical foundation for "pollutant treatment using microorganisms", is taught according to the fixed sequence of textbook chapters. Students with weaker comprehension are pushed into applied theories before fully understanding the link between metabolic pathways and pollutant degradation, preventing them from constructing a coherent theoretical framework. Conversely, students who quickly master the basics may wish to advance to applied concepts earlier, but the rigid schedule prevents their applied thinking from being challenged in a timely manner.

1.3 Delayed teaching feedback prevents the timely resolution of student learning issues In traditional teaching, feedback mainly relies on after-class assignments and final exam scores. However, this feedback mechanism suffers from significant delays and lacks specificity, making it difficult for instructors to monitor each student's progress in real time. As a result, student queries cannot be addressed promptly, leading to disjointed knowledge acquisition and preventing the formation of a coherent cognitive framework. This ultimately hampers deep theoretical understanding and reduces the efficiency of self-directed learning.

2 Exploration of teaching modes of AI-driven Environmental Engineering Microbiology

2.1 Dividing the teaching into "online preview" and "offline teaching" The teaching of Environmental Engineering Microbiology is structured into two interconnected phases: online pre-class preparation and offline in-class instruction. Teachers utilize the Superstat Learning App (developed by Beijing Chaoxing Digital Library Information Technology Co., Ltd.), platform to publish chapter-specific learning objectives and assign pre-class tasks, requiring students to share their understanding and questions in the discussion forum. The platform collects and analyzes multi-source data, including learning progress, quiz performance, and assignment quality, to assess students' mastery of knowledge points and dynamically generate personalized learning paths. Based on students' in-class performance and overall learning status, tailored review materials and extended learning resources are provided. For students struggling with certain concepts, the system pushes explanatory videos and foundational exercises to consolidate knowledge and prepare them for new content. For advanced learners, it recommends cutting-edge academic research and complex engineering cases related to the course, thereby broadening their perspectives and stimulating interest. During the offline classroom sessions, multimedia tools are employed to deliver targeted instruction on key and difficult concepts, informed by data feedback from the online phase. In addition, group collaborative learning activities are organized to prompt in-depth thinking and discussion, fostering students' teamwork and communication skills.

2.2 Transforming abstract theory into intuitive visual content to realize interactive teaching AI technology can transform abstract theories into intuitive visual content through methods such as 3D modeling and dynamic simulation, helping students develop a spatial understanding and grasp complex concepts more easily. For example, using DeepSeek to create 3D animated demonstrations of bacterial cell structures allows students to drag and rotate the model with a mouse, observing the spatial arrangement of the cell wall, cell membrane, cytoplasm, and nucleoid. This converts abstract knowledge into tangible content, enabling students to gain deeper insight into the microscopic world of bacteria. During interactive discussion sessions, instructors can post topics such as "the relationship between the chemical composition and structure of bacterial cell walls and Gram staining" on the Superstar Learning App platform, synchronized with the class progress. Students first observe the structural differences between Gram-positive and Gram-negative bacterial cell walls, then watch an animation dynamically illustrating the entire Gram staining process. Through group discussions on the mechanism of Gram

staining, the AI platform evaluates the accuracy of their responses and provides real-time feedback.

2.3 Establishing a complete theoretical knowledge system Teachers utilize the Superstar Learning App platform to construct a conceptual knowledge map for the course, centered on the theme of Microorganisms and Environmental Management. The map is organized into three main modules: Fundamentals of Microbiology, Microbial Ecology, and Pollution Control, each containing several sub-nodes interconnected with logical relationships indicated by lines. Students are divided into small groups, with each group assigned one sub-module of the knowledge map. Building on theoretical knowledge acquired in class and assisted by the AI teaching assistant, each group supplements and refines its assigned sub-nodes. This process guides students to discuss and identify logical gaps within the map, ultimately helping them establish a comprehensive theoretical knowledge framework.

2.4 Establishing diversified theoretical learning evaluation system Relying on the Superstar Learning App (developed by Beijing Chaoxing Digital Library Information Technology Co., Ltd.), a combined evaluation system integrating dynamic AI assessments, teacher feedback, and student self-evaluations has been established. The platform's automatic grading and analytical functions are utilized to evaluate the accuracy of students' exercises and homework answers. Based on data such as students' learning behaviors, classroom performance, and group collaboration, their learning attitudes, progress, knowledge mastery, and teamwork skills are assessed. By analyzing the duration and frequency of students' engagement with instructional videos, their learning motivation can be understood. Furthermore, the level of participation and critical thinking skills are evaluated by examining the quantity and quality of students' contributions in classroom discussions. At the end of each chapter, the Superstar Learning App is used to automatically generate personalized tests focusing on conceptual understanding questions for students with a weaker foundation, and comprehensive application questions for those with a solid foundation. These tests are then automatically graded and analyzed. Based on the evaluation results, teachers can stay informed about students' learning progress and adjust their teaching strategies accordingly. For students who are progressing slowly, teachers can provide guidance on learning methods and suggestions for adjusting their study plans. For those having difficulty understanding specific knowledge points, relevant review materials and instructional videos can be provided. On the Superstar Learning App platform, students complete self-assessments and, based on the generated list of learning objectives (for example, "able to analyze the impact of environmental factors on microbial growth"), evaluate their own knowledge mastery and ask questions requiring assistance from the teacher.

3 Conclusions

In the teaching of Environmental Engineering Microbiology, it is recommended to solve the problem of inherent deficiencies such as rigid teaching methods, an undifferentiated content system, and delayed feedback. This has been achieved through the integration of in-class exercises, personalized learning diagnostics with dynamic content delivery, and real-time intelligent Q&A. This AI-driven reform exploration breaks the limitations of traditional lecture-based instruction, transforms abstract microbiological knowledge into intuitive teaching scenarios, and thereby enhances students' learning interest. Through dynamic learning analytics, student performance and needs are closely monitored. Teaching resources, tailored to individual differences, are then distributed to meet personalized needs, ensure students master the complete theoretical knowledge framework of the course, and thereby enhance learning outcomes. In addition, the learning activities module (including thematic discussions and group tasks) within the Superstar Learning App enhances teacher-student interaction, encouraging students to participate more actively in the learning process. By discussing the applications of microorganisms in environmental engineering and sharing their own insights, students broaden their intellectual horizons and develop capacities for self-directed learning, communication, and collaboration. However, the process of AI-driven teaching reform has encountered several impediments. For instance, some instructors lack proficiency in AI technology, while some students, accustomed to traditional pedagogical models, have been slow to adapt to the AI-driven approach. Therefore, it is imperative to enhance teacher training to elevate their competency in applying AI technologies. Additionally, staying abreast of AI advancements is crucial for the timely integration of novel technologies and applications into teaching practices, thereby fostering continuous innovation in teaching methodologies and improving educational quality. Furthermore, increased guidance and support for students are essential to facilitate their acclimatization to the new teaching paradigm and to help them master the methods of self-directed and collaborative learning.

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