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A Systematic Approach To Promote Environmental Engineering Students' Learning in Environmental Molecular Microbiology

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INTRODUCTION

Environmental engineering is a multidisciplinary program that combines biological and chemical sciences with principles of engineering (1, 2). Ultimately, the goal of this discipline is to protect and preserve natural resources and human health by contributing to a sustainable environment. Environmental Molecular Microbiology (EMM) is a core course cluster for students majoring in environmental engineering which allows them to understand the molecular mechanisms underlying microbial processes in environmental engineering systems, e.g., wastewater treatment plants and in situ bioremediation sites (3–5). Courses in EMM cover fundamental principles, techniques, and applications of molecular microbiology in environmental engineering processes and help students gain insights into complex microbial processes at the molecular, cellular, community, and system levels. However, environmental engineering students generally have not taken any molecular microbiology courses prior to entering college, and many of them have a difficult time learning EMM. One major reason for this is that molecular microbiology addresses the invisible molecular basis of bioprocesses rather than visible engineering systems (6). Developing a systematic approach to deliver EMM courses progressively can help make it easier. Additionally, there are many teaching methods that have been proven to promote students' learning and critical thinking, thereby improving student performance. These methods include the case study teaching method (7), computer-assisted tools (8), preassessment and in-class questions (9), and the argument-and-plan method (10). For example, case studies have been identified as being more effective than classroom discussions and textbook reading in promoting learning of biological concepts and development of written and oral communication skills (7). In this article, we describe a systematic approach we designed to make environmental engineering students more comfortable with EMM. This approach is divided into three stages: (i) prerequisite course and course evaluation, (ii) course cluster teaching, and (iii) feedback and improvement (Fig. 1).

PROCEDURE

Prerequisite course and course evaluation

The main teaching objectives at this stage are to (i) introduce the basic concepts of molecular microbiology, (ii) introduce the connection between environmental engineering and molecular microbiology, and (iii) identify students' potential difficulties in learning EMM. This stage has two parts: a prerequisite course, Environmental Molecular Microbiology: Case Studies, and course evaluation analyses. Before taking the EMM courses, many students may have learned that microorganisms can be used to remove pollutants from wastewater, to digest and stabilize sludge, and to remediate polluted soil and groundwater. However, most students do not yet understand the molecular principles underlying these microbial processes. A major difficulty for environmental engineering students taking EMM courses is understanding how EMM can be applied to environmental engineering systems. To address this problem, EMM Case Studies was developed and introduced as a prerequisite course. In this course, 8 of the 36 teaching hours are used to briefly introduce the basics of molecular microbiology, followed by 12 practical case studies (2 teaching hours each) to show how EMM knowledge can be applied to solve environmental engineering problems (see Appendix 1 for the syllabus of the prerequisite course). In addition, we embedded the course evaluation in the prerequisite course. The survey questions were designed to cover the basic content of molecular microbiology, as well as to identify the students' challenges and intentions when taking EMM courses (see Appendix 2 for the course evaluation). To simplify the survey, we provided the basic components and modules of molecular microbiology knowledge for most

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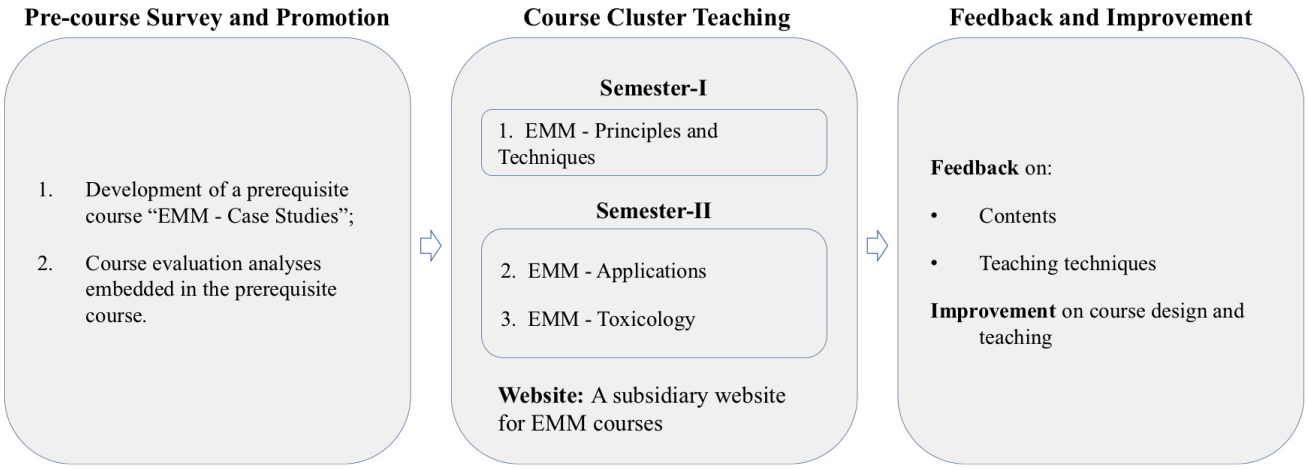

FIGURE 1. A systematic three-stage approach to promote environmental engineering students' learning in the EMM courses.

survey questions. This allowed respondents to organize reasonable answers based on their understanding of molecular microbiology rather than having to rely on memorized knowledge. The survey data indicated that the prerequisite course effectively encouraged environmental engineering students to take EMM courses (Fig. 2).

Course cluster teaching

A good teaching approach should start by identifying what students need rather than what they like. The student-centered learning objective at this stage is to learn concepts and understand the molecular mechanisms underlying environmental engineering processes. Based on the practical requirements of understanding and applying EMM in environmental engineering, together with the course evaluation, we developed a comprehensive teaching plan, including the following three different courses: (i) EMM Principles and Techniques, (ii) EMM Applications, and (iii) EMM Toxicology. The three courses were delivered in two different semesters (Fig. 1): EMM Principles and Techniques in semester I and EMM Applications and also EMM Toxicology in semester II. We employed a variety of teaching techniques, including lectures, animations, videos, and small-group discussions, to enhance students' learning throughout these EMM courses. A teaching website (with intranet access, see Appendix 3) was also established as an EMM course subsidiary website, providing a platform to share information on the course syllabus, instructions, and teaching documents or files. In addition, laboratory experiments and field trips were arranged after theoretical teaching sections of EMM Principles and Techniques to give students hands-on experience and show them how EMM can be applied to environmental engineering topics and systems (see Appendix 1 for EMM syllabus details). All students are required to complete biosafety level 1 (BSL1) and BSL2 safety training prior to their laboratory experiments and follow the University's safety guidelines for student field trip studies. Feedback revealed that respiratory electron transport chains and corresponding energy metabolisms for pollutant removal in functional microorganisms have generally been difficult for students to understand (see Appendix 4 for survey feedback from students taking the EMM Principles and Techniques course). Therefore, in each

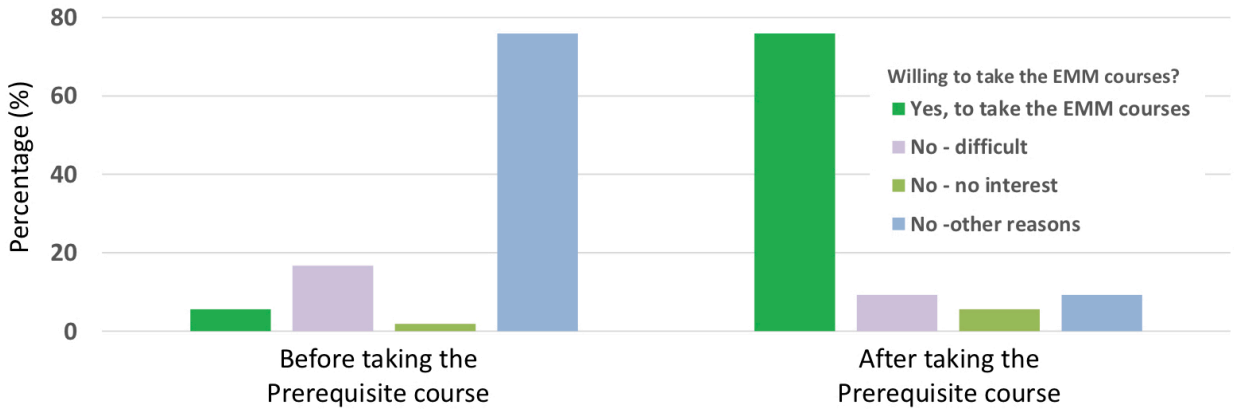

FIGURE 2. Anonymous survey summaries of students willing to take the EMM) courses (54 respondents) before and after taking the prerequisite course. See supplemental materials for raw survey data (Appendix 2).

EMM course, 4 to 8 teaching hours focus on the identified difficulties. Additionally, in the EMM courses, particularly EMM Principles and Techniques, each class begins with background theories and related concepts and continues with biotechnology development for environmental applications. With DNA sequencing, for example, to help students understand the teaching content, we first ask the question, "How does DNA sequencing change our understanding of wastewater treatment?" We then introduce the basics of de novo DNA synthesis and its development from Sanger sequencing to next-generation sequencing technologies, as well as their underlying molecular principles. The class concludes with a case study on the use of high-throughput sequencing in analyzing the composition and function of a sludge microbial community. This allows students to connect the invisible molecules with large-scale wastewater treatment tanks.

Feedback and improvement

During these courses, environmental engineering students begin to realize the importance of gaining EMM knowledge. Nonetheless, many areas of difficulty need to be identified and addressed, and skills need to be developed to enhance students' learning of EMM. Analysis of teaching feedback from previous courses, collected via anonymous paper and online surveys, is a simple yet critical way to continuously improve the quality of the courses. Although online surveys may be easier to conduct, we tend to favor paper surveys because the answer rates are higher than those of online surveys (P. Juneau, unpublished data). Furthermore, an interactive discussion between course instructors and students on course content, teaching techniques, and the teaching styles of instructors is also encouraged. This feedback can then be sent to specific instructors for course improvement and used for optimization of overall course planning. Major criteria for the improvement of course teaching and learning include (i) whether the course motivates students to learn EMM and understand molecular mechanisms underlying environmental engineering systems and (ii) whether the students are equipped with comprehensive EMM knowledge to support their future success in environmental engineering.

CONCLUSION

It is critical for environmental engineering students to learn EMM in order to understand biological environmental engineering processes. Here, we described a systematic approach to help environmental engineering students learn EMM. Overall, student feedback on this approach has been positive, as reflected in teaching evaluation reports, laboratory performance, and conversations with students. We notice that the students not only gained solid EMM knowledge but also were highly motivated to study and think about environmental engineering questions as they related to EMM.

SUPPLEMENTAL MATERIALS

Appendix 1: Syllabi for prerequisite course (EMM Case Studies) and EMM courses (EMM Principles and Techniques and EMM Toxicology)
Appendix 2: Responses to pre- and postassessment anonymous surveys
Appendix 3: Home page of a course subsidiary website with intranet access
Appendix 4: Responses to an anonymous survey of major difficult teaching points in the EMM Principles and Techniques course

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