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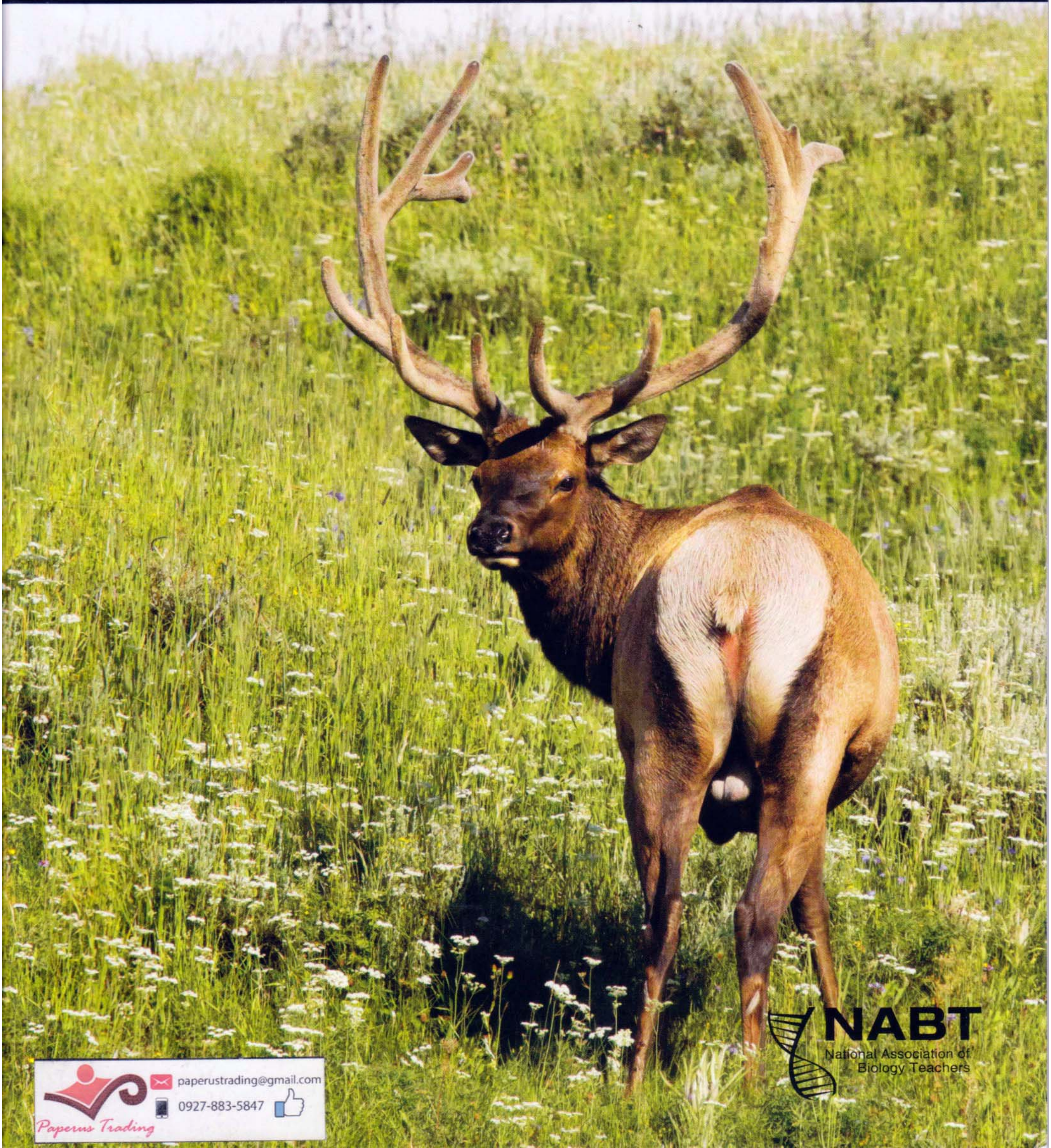

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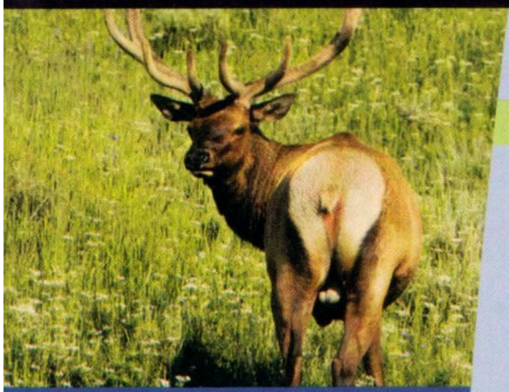

About Our Cover

Elk (*Cervus canadensis;* also called wapiti, the Shawnee word for white-rumped deer), one of the largest members of the deer family, were once widely distributed throughout North America. Although extirpated from much of their eastern and southern range as a result of overhunting and habitat loss, healthy populations of elk can be found in the western United States and Canada.

Yellowstone National Park has abundant data on its complex ecosystem and makes a fascinating study on trophic cascades. The evidence of fluctuations in behavior and population size based on the dynamics between elk, wolf, aspen, willow, and other populations continues to fuel debate regarding the ecological implications of human actions and interventions.

Historical evidence suggests that the reduction of predators in Yellowstone during the early 20th century contributed to an increase in elk populations. Although the park took steps to manage elk numbers, the increased browsing pressure on woody species suppressed populations such as aspen and willow. However, there are indicators that the introduction of gray wolves into the park in 1995 has since contributed to a significant decline in elk populations and a subsequent increase in aspen and willow recruitment.

This photograph of a bull elk was taken in Yellowstone National Park by Bob Remedi, a full-time faculty member in the Biology Division at College of Lake County, where he teaches Environmental Biology, Anatomy and Physiology, Natural History of Southwestern Virginia, and professional development classes for faculty. For this image, he used a Canon 7D Mark II set at ISO 1000 and F14, with a Canon EF 100–400 zoom and a Canon 1.4× teleconverter.

Contents

In our August 2019 issue, we incorrectly spelled the editor's name for our classroom media reviews. The correct spelling is Jeffrey D. Sack. We apologize for this error.

FEATURE ARTICLE

Learning from Competition: An Outcome-Based Introductory Activity for First-Year Biotechnology Undergraduates

XIAOYAN ZHANG, RUIFANG YE, FENGXIAN HU, YITAO ZHENG, SHUHONG GAO, YINGPING ZHUANG, QIYAO WANG, YUNPENG BAI

Abstract

In recent years, accreditation standards for international engineering education have led to a dramatic rise in the use of outcome-based education at universities. In this system, enticing new undergraduate students to science and engineering, although challenging, is the first important step toward building students' career competencies. An ongoing effort to attract students to biotechnology was initiated 13 years ago in the School of Biotechnology at the East China University of Science and Technology in Shanghai. We describe the design and organization of the Microbe Competition, a program attracting a total of nearly 6,500 students as of 2018. In the competition, students need to pass the microbiology knowledge test, provide a practical experiment proposal related to the topic of competition, and finish the experiment under the supervision of teachers before getting final prizes. The competition develops students' competencies in acquiring and applying knowledge, problem solving, teamwork, communication, and experimental skills. By investigating students' feedback, we have been continuously improving the quality of competition to attract more students from the biotechnology major. We hope that by sharing our experience, we can help educators at other universities organize similar introductory activities on their own campuses.

Key Words: *First-year undergraduate; interdisciplinary; discovery learning; biotechnology.*

○ Introduction

Since the Accreditation Board for Engineering Technology (ABET) released Engineering Criteria 2000, engineering programs focusing on outcome-based education (OBE) have been established in many countries to help students develop important competencies for their career success (Lucena et al., 2008; Passow, 2012). China signed the Washington Accord (International Engineering Alliance) as a full member in 2016, a milestone in accepting and spreading the OBE philosophy in the world's largest system of higher education (Washington Accord Signatories, 2017). Engineering students are required, by the end of their educational experience, to accomplish predetermined goals and obtain the corresponding competencies. All teaching activities, such as curriculum organization, student instruction, and performance assessment, are designed to make sure this learning ultimately happens, and these activities are continuously improved (Prideaux, 2007; Male, 2010). The first step to realizing the goals of engineering education is to inspire new university students to take an interest in engineering topics. This is done through effective introductory courses and, more importantly, by meeting the requirements of OBE in the introductory course itself.

> *"A well-defined competition is a strong incentive to students and acts as an effective complement to the introductory courses."*

Unfortunately, traditional introductory courses are subject oriented and knowledge based, so new students lack direct, hands-on experience (Wright, 1996). However, domestic and international subject competitions at different levels have been demonstrated to effectively discover young talents and inspire them to learn and apply knowledge in solving complex problems (Staziński, 1988; Khalil et al., 2015). Well-known examples include the worldwide annual International Mathematical, Physics, Chemistry, and Biology Olympiads (IMO, IPhO, IChO, and IBO, respectively; see IMO, 2017; IPhO, 2017; IChO, 2017; IBO, 2017); the Association for Computing Machinery International Collegiate Programming Contest (ACM-ICPC; see ACM-ICPC, 2017); and the Robot World Cup (RoboCup; see RoboCup, 2017). In biological chemistry, the international protein-folding competition, Critical Assessment of Protein Structure Prediction (CASP; see CASP, 2017), has pushed the rapid development of computational biology, generating innovative computational tools to solve the complex structures of biomolecules, and a group of talented scientists has emerged (see Baker & Sali, 2001; CASP, 2017).

Inspired by these successful international competitions, we believe that a well-designed competition is a good complement to current introductory courses because it provides an opportunity

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for interaction between students and teachers. In biotechnology, the microbe is the research focus for green biomanufacturing. More importantly, microbes are fun for students to learn about. Therefore, to inspire new students to take an interest in biotechnology, we have been holding an annual Microbe Competition (MC), an institutional introductory activity for first-year undergraduate students at East China University of Science and Technology, since 2005. Using the OBE philosophy as our guide, we designed the competition process, developed student evaluation methods, and have adjusted the competition topics continually in response to students' feedback. Through years of practice, the competition has earned a good reputation across the university. In this article, we describe the development of the MC in its first 12 years (hereafter denoted MC1–MC12), its strengths and challenges, and its benefits for students and teachers, with the hope of enabling educators at other universities to reap similar benefits by organizing events like this on their own campuses.

○ Design & Development of the Microbe Competition

Workflow of the MC

In a typical year, the MC starts in April and ends in the last week of August (which falls in the second semester of the first-year university student), progressing through three stages: preliminary, semifinal, and final (Figure 1). The competition is held after the formal biotechnology introductory course in the first semester, which ensures that the participating students have basic knowledge about the major. There are approximately 500, 180, and 42 participants, respectively, at each stage. First-year undergraduates from the School of Biotechnology and students of any year from other schools are eligible for the preliminary. In the preliminary, we emphasize the importance of fundamental knowledge of biology and engineering, focusing on the ability to acquire and apply knowledge. Students usually prepare for the preliminary by actively searching for and learning new information about microbiology from the Internet, textbooks, and/or research papers in the library. At this stage, students are assessed using a written test with 100 multiple-choice questions, including 36 picture questions. After evaluating students' scores, we select 180 qualified students for the semifinal.

In the semifinal, students are required to form three-person teams. At this stage, we focus on problem-solving, teamwork, and communication abilities. Each team needs to search the literature, design an experimental research proposal on the competition's topic, and give an oral presentation defending their proposal. Based on the feasibility of students' research proposals and their performance in the oral presentation, 30–42 students (10–14 teams) eventually enter the final stage.

In the final, 14 teams carry out their proposed experiments, analyze data, draw conclusions, and write a report within five to seven days. On the first day of the final, students are trained to learn the basic experimental skills in microbiology. During the competition, eight teachers and five graduate students supervise students and help solve their problems so that they can finish the experiment smoothly and safely. According to the quality of the reports and students' performance in the experiment and the oral presentation, we award one first prize, two second prizes, and three third prizes; thus, a total of six teams receive awards.

Through the competition process, students are encouraged to demonstrate their ideas by designing and conducting hands-on experiments, and to draw meaningful conclusions through data processing and analysis. More importantly, they need to work cooperatively as a whole team and display their results effectively using oral and written skills.

To attract more students to participate in the contest, each participant can obtain course credits according to their performance in the contest: 0.1 credits for the preliminary, 0.4 for the semifinal, and 1.0 for advancing to the final. In order to enhance the competition's impact for new undergraduates, we use posters and campus radio to advertise the event, and release competition news via online social networks before the contest. Because 500 students participate in the preliminary every year, we developed a computer-based examination and evaluation system to reduce cost. The total cost of the MC, comprising funds for the experiments, the prizes, and subsidies for senior graduate assistants, is estimated to be ~$2000 (U.S.) per year.

The majority of participants are first-year undergraduates who attained only fundamental biology knowledge in high school and who may not have much specific knowledge about microbiology. Thus, we designed preliminary test questions with appropriate difficulty and made them interesting for students. First, we controlled the difficulty of the test by selecting 80% easy questions from textbooks and 20% difficult questions from research literature. Second, in order to make the test engaging and even funny, we designed interesting picture questions (Figure 2). Statistics from 6500 participants from all 12 years of the competition show that the average score and

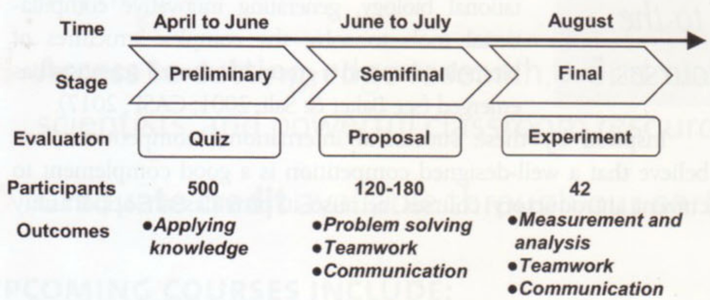

Figure 1. Content design and organization of the preliminary round of the Microbe Competition.

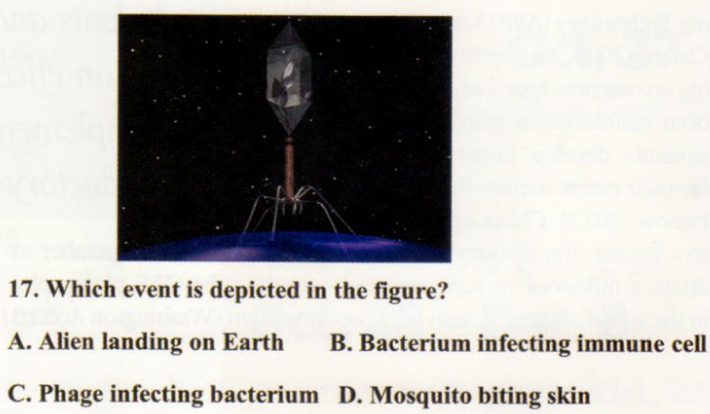

Figure 2. One picture question in the quiz of the preliminary shows the process of a phage infecting a bacterium.

the highest score in the preliminary round were 68 and 88 out of 100, respectively, demonstrating that the test is moderately difficult and is suitable for first-year undergraduates.

Design & Evolution of Competition Topics

A good competition topic can entice students to learn from their discoveries (Řezanka et al., 2013). The first step for utilizing microbes as "cell factories" in biotechnology is to find new microbes in nature with various forms and functions. Thus, we focus on this topic for every MC, inspiring students to apply their knowledge and skills about microorganisms to find microbes in nature. Within this framework, we continuously change topics and goals in response to feedback from students (Table 1).

For example, the topic of the competition's first three years, "Finding More Microbes in Nature," was simple, and the students who found the most microbes were the winners. Students prepared different types of media to isolate and culture microorganisms. In the end, they observed various kinds of microbes with different colors and morphologies, including bacteria, yeasts, actinomycetes, and fungi (Figure 3). To find more microbes, some students obtained mold and yeast from moldy bread and rotten fruit, and one team even brought in some mushrooms from a local farm in their final defense.

After MC3, we changed the topic to "Finding Good or Bad Microbes," on the basis of students' feedback and their ability as demonstrated in previous contests (Table 1). We gave students room to exercise their creativity and imagination, thus keeping the contest interesting. This was an open topic, and we let students themselves define why microbes are "good" or "bad." The topic greatly stimulated students' imaginations, and they presented many interesting results in the final stage. For example, for "bad" microbes, students asked and answered some interesting questions, including

- "What kind of microbes dominate in a cup of cola or green tea after it is left out overnight?"
- "How many microbes are in the classroom switchboard, and can they become a route of disease transmission?"
- "Do microbes grow in an opened bottle of eye drops at room temperature, and, if so, does it affect their use?"

Table 1. Competition topics from MC1 to MC12.

Seasons	Topic	Content	Experimental Skills
MC1–MC3	Finding More Microbes	Isolating microbes from the natural environment (as many as possible)	Medium preparation and sterilization, isolation and identification of microbes
MC4–MC10	Finding Good or Bad Microbes	Isolating microbes and demonstrating their functions	Medium preparation and sterilization, isolation and identification of microbes, bioreaction and characterization
MC11–MC12	Painting with Microbes	Drawing a picture with given microbes	Medium preparation and sterilization, isolation and inoculation of microbes

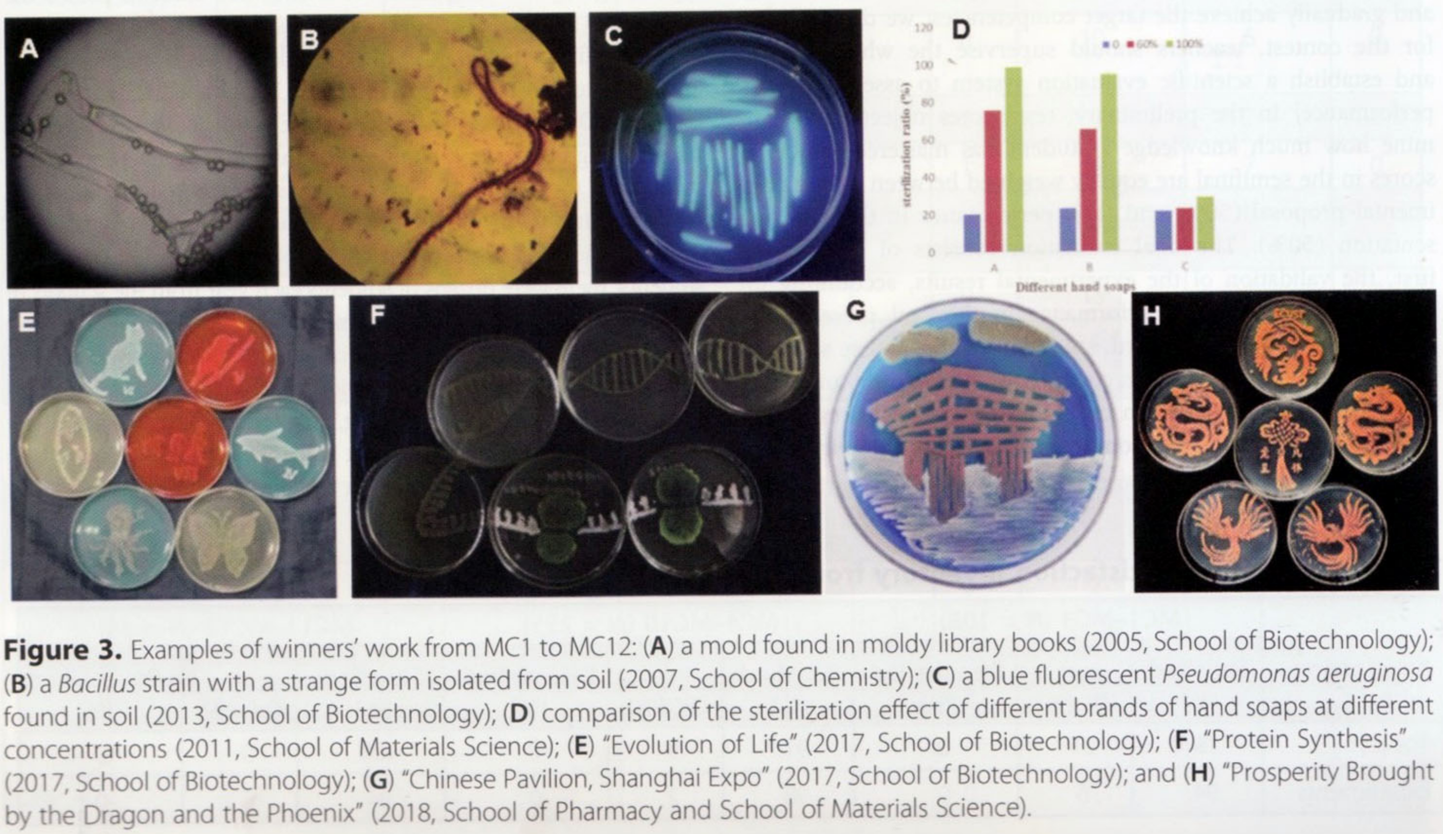

Figure 3. Examples of winners' work from MC1 to MC12: (**A**) a mold found in moldy library books (2005, School of Biotechnology); (**B**) a *Bacillus* strain with a strange form isolated from soil (2007, School of Chemistry); (**C**) a blue fluorescent *Pseudomonas aeruginosa* found in soil (2013, School of Biotechnology); (**D**) comparison of the sterilization effect of different brands of hand soaps at different concentrations (2011, School of Materials Science); (**E**) "Evolution of Life" (2017, School of Biotechnology); (**F**) "Protein Synthesis" (2017, School of Biotechnology); (**G**) "Chinese Pavilion, Shanghai Expo" (2017, School of Biotechnology); and (**H**) "Prosperity Brought by the Dragon and the Phoenix" (2018, School of Pharmacy and School of Materials Science).

- "How long after a watermelon has been cut can it not be eaten?"
- "What is the comparative sterilization effect of different hand soaps?"

For "good" microbes, students found microbes that can catalyze the synthesis of useful chemicals or degrade pollutants. Some students prepared samples one month in advance in order to enrich the degrading bacteria. The students themselves presented these specific problems, and they solved them using their own knowledge and skills.

In MC11 and MC12, we wanted to show students that science and art are twin siblings and that biotechnology can be beautiful and cool. We hoped to encourage students to create beauty with microbes. The topic was "Painting with Microbes," which required students to culture microbes on agar plates and make them grow into pictures. We provided students with strains of different colors, including *Saccharomyces cerevisiae* (white), *Rhodotorula* sp. (red), *Tetragenococcus* sp. (yellow), *Penicillium* sp. (blue), and genetically engineered *Escherichia coli* expressing green fluorescent proteins (green). Students used a variety of tools to culture microbes into various predetermined patterns, such as "Evolution of Life," "Protein Synthesis," "Chinese Pavilion, Shanghai Expo," and "Prosperity Brought by the Dragon and the Phoenix" (Figure 3). The beautiful results and excellent feedback from students convinced us that a well-designed competition with an interesting topic inspired students' curiosity and imagination—which, we believe, is a wonderful start for their study of biotechnology.

○ Establishment of the Evaluation System

To ensure that MC participants effectively learn new knowledge and gradually achieve the target competencies, we decided that, for the contest, teachers should supervise the whole process and establish a scientific evaluation system to assess students' performance. In the preliminary, test scores objectively determine how much knowledge a student has mastered. Students' scores in the semifinal are equally weighted between their experimental proposal (50%) and their performance in the oral presentation (50%). The final evaluation consists of three parts: first, the validation of the experimental results, accounting for 70%; second, students' performance in the oral presentation, accounting for 20%; and third, students' abilities to use scientific tools to perform experiments correctly as a team, accounting for 10%. This evaluation system covers all five target learning outcomes, fully reflecting the competencies students acquired during the contest.

○ Outcomes of the Microbe Competition

Student Feedback & Evolution of the Competition

We attempted to explore the possibility of applying the OBE philosophy to design, organize, and improve the competition continuously. Every year, after the competition, we surveyed students who experienced all three stages about their attitudes toward the contest topic, their attitudes toward the experimental conditions (i.e., materials, instruments, and equipment available), and their suggestions (Table 2).

As shown in Table 2, the ratio of satisfaction increased when we adjusted the contest topic in seasons 4 and 11. In MC1–MC3, 79% of students were satisfied with the competition topic. However, 30% of students suggested that the task was too simple. Starting with MC4, we changed the competition topic to "Finding Good or Bad Microbes," based on students' feedback, after which 91% of students were satisfied, although 32% of students reported that they did not finish the experiment on time. MC11 and MC12 were unique because students were allowed to paint with different microbes (see Figure 3), and all the students (100%) participating in the final stage stated that they were satisfied with the competition topic. Over all 12 seasons, >90% of students were satisfied with the experimental conditions, indicating that the materials, instruments, and equipment available for the contest were sufficient to fully support their experiments. Two months before the contest, teachers began to prepare the materials that students would need, which resulted in a smoothly run contest.

Competition Participants & Current Challenge

Because the contest usually lasts from April to August, it is important, and sometimes difficult, to keep participants' interest from the beginning to the end. Therefore, we compared students' participation at different stages of the competition. A total of 360 students passed the preliminary in MC1–MC3, but only 272 students (75%) participated in the semifinal; in MC4–MC10, 840 students passed the preliminary and 91% participated in the semifinal; in MC11 and MC12, the ratio reached 100% (Figure 4). Although many factors influenced students' participating in the whole competition, this result gave us encouragement to try to maintain students' attention throughout the semester.

According to the statistics, the competition attracted students from 13 schools across the university (Table 3). Besides biotechnology students, there were dozens of students each year from the schools of materials science, pharmacy, chemistry, chemical engineering, and business. However, the numbers of students from the schools of mathematics and physics, information technology, mechanical engineering, environmental engineering, arts, foreign languages, and law were small, perhaps indicating that students from these majors lack interest in biotechnology, although some research frontiers in these

Table 2. Students' Satisfaction Inventory from MC1 to MC12.

Satisfaction with:	MC1–MC3 (*N* = 108) Satisfied (%)	OK (%)	Dissatisfied (%)	MC4–MC10 (*N* = 255) Satisfied (%)	OK (%)	Dissatisfied (%)	MC11–MC12 (*N* = 84) Satisfied (%)	OK (%)	Dissatisfied (%)
Topics	79	21	0	91	9	0	100	0	0
Experiments	94	6	0	98	2	0	94	6	0

disciplines have an increasing trend of fusing with biotechnology. We also calculated the ratio of students from biotechnology and other majors who progressed into the semifinal and final stages compared to the preliminary. In total, 38.4% and 11.5% of students from biotechnology passed into the semifinal and final in MC3, MC6, and MC11. By contrast, 20.1% and 4.3% of students from other majors were able to attend the semifinal and final, respectively. Clearly, students from biotechnology have more knowledge and interest in microbiology than students from other majors, which helps them go far in the competition. However, talented students from other schools can also become champions with their innovative ideas and excellent experimental skills. For example, three students from the schools of pharmacy and materials science won the first prize in MC12 with their beautiful "painting" (Figure 3H).

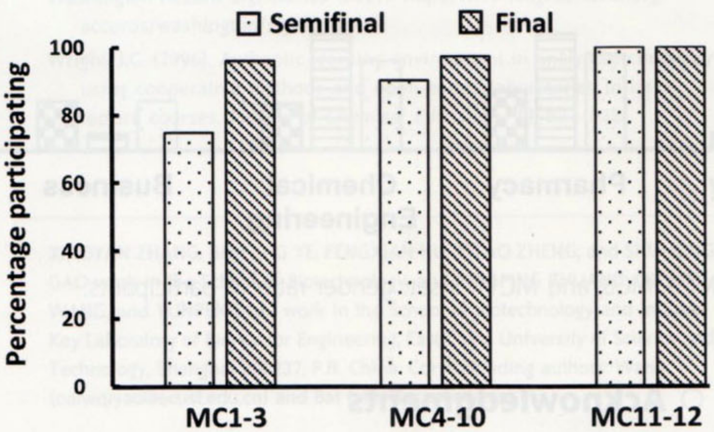

Figure 4. Percentage of students participating in the semifinal and the final stages in MC1 through MC12.

Numbers of participants from the top six schools during three of the competitions (MC3, MC6, and MC11) are plotted in Figure 5 (along with the ratio of male to female participants in those years, which is nearly equal). From MC3 to MC11, the number of biotechnology students participating has increased; the reason is that the number of students enrolled in the School of Biotechnology increased from 249 in MC3, to 338 in MC6, to 369 in MC11. More importantly, the participation ratio increased, from 83% (207), to 91% (308), to 99% (366) of the total number of enrolled biotechnology students, respectively, indicating that the competition is now a successful and attractive scientific event in the School of Biotechnology. However, the ratio of students from other schools has gradually decreased from 46% in MC3 to 15% in MC11. One possible reason is that the topics in the recent competitions were more specific to microbiology, which may give students the (incorrect) impression that the competition was designed only for biotechnology students. Furthermore, students from other majors are at a disadvantage due to their lack of background knowledge in microbiology, and the topics and test may make them less inclined to join. Thus, there is a challenge, but also an opportunity, to entice students with different scientific backgrounds to join the competition in the future.

Table 3. Participating students in each stage of MC3, MC6, and MC11.

	MC3 (*N* = 381)			MC6 (*N* = 451)			MC11 (*N* = 441)		
Schools	Preliminary	Semifinal	Final	Preliminary	Semifinal	Final	Preliminary	Semifinal	Final
Biotechnology	207	78	27	308	103	35	366	157	39
Materials Science	44	8	3	23	0	0	10	6	0
Chemistry	36	8	3	16	1	0	5	2	0
Pharmacy	29	7	2	35	6	1	18	7	0
Chemical Engineering	27	3	1	35	6	0	14	6	3
Business	15	0	0	5	1	0	15	1	0
Information Technology	10	0	0	1	1	0	4	3	0
Environmental Engineering	6	7	6	16	0	0	1	1	0
Math and Physics	3	0	0	4	1	0	2	1	0
Mechanical Engineering	1	0	0	4	1	0	2	0	0
Arts	1	0	0	1	0	0	2	1	0
Foreign Languages	1	0	0	2	0	0	2	1	0
Law	1	0	0	1	0	0	1	0	0

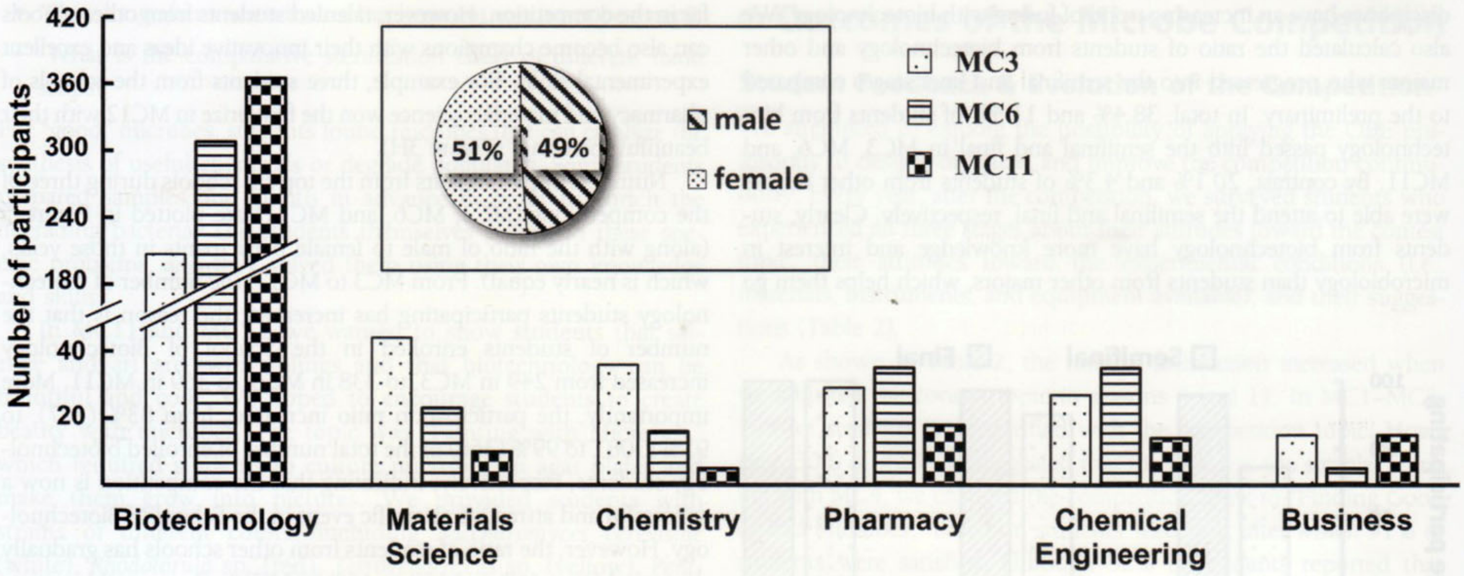

Figure 5. Numbers of participants from the top six schools in MC3, MC6, and MC11. Inset: gender ratio of participants.

○ Conclusion & Recommendations

It is important, and sometimes challenging, to attract students to their majors in the first year of university study. Our experience in the design, development, implementation, and evaluation of the MC for new biotechnology students at East China University of Science and Technology in the past 12 years suggests that a well-defined competition is a strong incentive to students and acts as an effective complement to the introductory courses. Students learned new knowledge and obtained new abilities from the competition, while faculty learned how to organize their teaching activities well using the OBE philosophy.

Participating in the MC was a good start for students wishing to do research in biotechnology. For example, a student who participated in MC9 has since won a national scholarship and a national outstanding undergraduate prize and is now studying as a PhD student at Tsinghua University. She told us that the first research experience on her résumé is the MC, during which she discovered the beauty of microbiology.

Looking at what has been achieved in past competitions, we conclude that this competition can still be improved in many ways. We have found that new university students are more active and curious in biology than their counterparts 10 years ago were, so the difficulty of the competition needs to be adjusted accordingly. With the fast development of synthetic and systematic biology, new students are not satisfied with simply finding new natural microbes; they also want to assemble artificial, engineered microbes for new biofunctions. More importantly, we think that the competition should further emphasize the significance and emergent nature of serious issues that humans are facing, such as climate change, energy shortage, environmental pollution, human health, food, and poverty. The competition should teach students that continuous creative work in biotechnology and other disciplines will result in the science and innovative technology needed to address these issues. We hope that our experience in holding the Microbe Competition can help our colleagues in various disciplines organize their own introductory activities to attract more undergraduate students to engage in science, technology, engineering, and mathematics programs.

○ Acknowledgments

We would like to thank all our biotechnology colleagues who have been involved in the MC project, as well as our graduate teaching assistants for their effort in its implementation over the years. We give special thanks to Yaning Chang, of the Undergraduate Lab Center in the School of Biotechnology, who has been a relentless supporter of the MC project. We value the outstanding dedication and creative work of all the students who joined us and worked toward the success of the MC events. We greatly appreciate the financial support of East China University of Science and Technology.

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