Bacterial Survivor: An Interactive Game that Combats Misconceptions about Antibiotic Resistance †

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INTRODUCTION

Antibiotic resistance is an increasingly major global public health threat that has sparked numerous headlines in recent years. In the past year, the United Nations had 193 member states sign a declaration to combat the proliferation of antibiotic resistance (1). Despite public awareness of the problem, however, the general population has a very limited understanding of how antibiotic resistance arises and how it is connected to antibiotic misuse and bacterial evolution. Common myths include, "Only people who use antibiotics regularly are at risk for getting an antibiotic resistant infection." Another is that the human body "develops resistance" to antibiotics (2). Studies of biology majors have also uncovered similar misconceptions (3). Many students do not understand how the spread of antibiotic resistance is connected to bacterial evolution. Specifically, the concept of natural selection seems challenging to students in the context of antibiotic resistance. Some misconceptions include thinking that "antibiotics make bacteria resistant," "people become immune/build resistance to antibiotics," and "bacteria mutate in order to survive antibiotics" (4, 5).

Student misconceptions are highly resistant to change (6) and require concerted effort by instructors to unpack the "wrong answers" in order to shift conceptual understanding. One recent study with biology majors showed an improvement in student understanding of natural selection by using specific case studies from different contexts, including antibiotic resistance in *E. coli* (7). Many online games (8, 9), mobile apps (such as the Superbugs app by Preloaded or the BrainPop Antibiotic Resistance game), and interactive lab games have successfully explored antibiotic resistance using simulations and manipulatives (10–12). However, these games typically require significant time and resources, which limits their implementation in a large lecture setting.

We sought to develop a short (15 min), high-impact, easily scalable activity that could be implemented in a large lecture course to specifically address the misconception that "antibiotics cause mutations in bacteria." Furthermore, as this is an introductory activity, it is amenable to both majors and nonmajors courses in microbiology.

PROCEDURE

This activity takes about 15 minutes to conduct and requires very little resource management. In this game, called "Bacterial Survivor," students in a large nonmajors microbiology lecture class (160 students) were divided into groups of four, and each group was given the following: a handout with a starting phenotype (all of them were the same), a cardboard "spinner" (numbered from 0 to 9), and a worksheet (Appendix 1). Cardboard game spinners are easily and cheaply available for purchase online, or multifaceted dice sets may be used instead. At the beginning of the game, each student wrote down his or her starting phenotype. In one round of play, each student spun three times and recorded the corresponding phenotype (Appendix 1).

At the end of the first round of play, representing a generation of bacterial growth, students were challenged with a change in their environment when the instructor informed them that a specific antibiotic was now present. The instructor randomly chose the antibiotic out of those listed on the worksheet. Based on their final phenotype in that round, students determined whether or not they would survive in that environment. Only those who survived were allowed to "reproduce" and continue playing in the next round. Everyone who had been eliminated from play by the antibiotics was asked to put their heads down on their desks.

After the second round, the instructor informed students that their environment now had an additional antibiotic added and asked the class, "Who are the survivors?" A show of hands indicated those who could continue into the next round of play.

After three rounds of play, the "survivors" came up to the front of the class and revealed their "winning" phenotype, and the rest of the class understood that only the survivors reproduced themselves, passing their genotype on to the next generation. Since students spun three times in each round, one-third of the students in each round were

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expected to have a specific drug-resistance phenotype. Thus, in a class of 150 students, after three rounds of play only five students would be expected to be "survivors" of three different antibiotics. The instructor diagrammed this on the board in parallel to illustrate the principle of natural selection. At the end of the game, students filled out a worksheet (Appendix 2) and participated in a whole-class discussion. There are no safety issues with this activity.

CONCLUSION

"Bacterial Survivor" was a productive active learning strategy to combat specific misconceptions about antibiotic resistance in bacterial populations. In particular, this activity served to clarify the concept that mutations and horizontal gene transfers are *random*, and that antibiotics themselves do not *cause* mutations in individual bacteria. The concept of natural selection was reinforced with students' physical handling of the spinner, as they learned that when environments change, those individuals with favorable traits will survive and pass those traits on to offspring. Our pre/post assessment analysis showed that this activity directly addresses several misconceptions that students have about the effect of antibiotics on the survival of bacterial populations.

Prior to the activity, 48.5% of the students mistakenly chose the statement "antibiotics cause mutations in bacterial DNA that create new drug-resistant strains" to explain how the overuse of antibiotics in animal feed influences the emergence of drug-resistant bacterial strains (Fig. 1). After the activity, only 23.7% of the students chose this incorrect statement (Fig. 1). Interestingly, when asked whether they agreed or disagreed with the statement, "Antibiotic resistance is an example of evolution," 74% of students (*n*=124) agreed or strongly agreed prior to the activity and 91% of students (*n*=101) agreed or strongly agreed after participating in the activity. Finally, we analyzed student responses to the open-ended question, "Explain antibiotic resistance to a fellow student." Prior to participating in the activity, student responses fell into four main categories: "bacteria can't be killed by antibiotics," "antibiotics cause mutations in bacteria," "resistance is caused by overuse of antibiotics," and "learned adaptation" (Fig. 2). After the activity, student responses to this question showed a shift toward explanations that included an understanding of natural selection (Fig. 2) and a decrease in prior misconceptions. Taken together, this suggests that while students may have some prior knowledge that antibiotic resistance is connected to the concept of evolution, this activity enabled them to gain a deeper understanding of the role of natural selection in the emergence of antibiotic-resistant bacterial strains.

SUPPLEMENTAL MATERIALS

Appendix 1. Game instructions handout
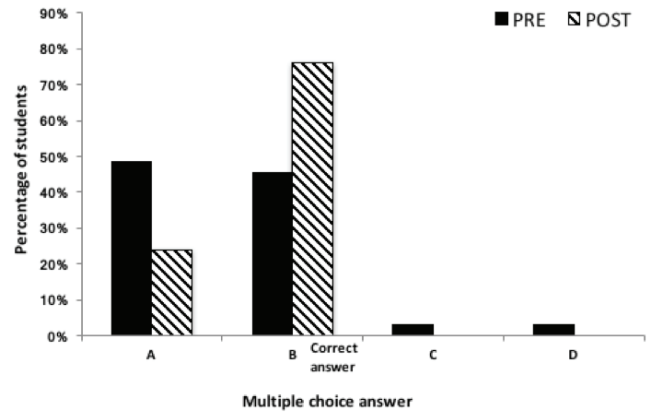Appendix 2. Assessment questions

FIGURE 1. Pre- and post-activity test question about antibiotic resistance. Students (*n*=101) responded to the following multiple-choice question: "How does the overuse of antibiotics in animal feed influence the emergence of drug-resistant strains of bacteria?" (ASM Sample Questions in Microbiology 2016, ASM Education Board). The percentage of students selecting each answer choice (A–D) was recorded. Answer choices were as follows, with the correct answer being "B" (13): A) Antibiotics cause mutations in bacterial DNA that create new drug-resistant strains; B) Antibiotics exert selective pressure on bacterial populations, allowing existing drug-resistant strains to reproduce; C) Overuse of antibiotics has no effect on the emergence of drug-resistant strains; D) Antibiotics provide nutrition to drug-resistant strains that consume them.
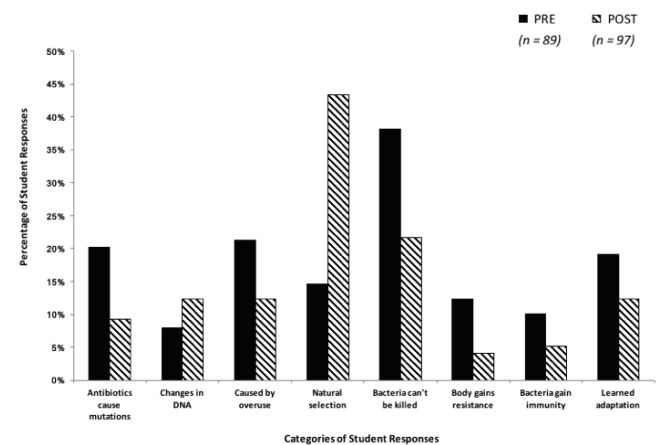

FIGURE 2. Pre/post assessment of student ideas about antibiotic resistance. Coding of anonymous student responses to the open-ended prompt, "How would you explain antibiotic resistance to a fellow student?" resulted in eight main categories. The prompt was given to students during the class period prior to conducting the "Bacterial Survivor" activity and after the activity. The percentage of student responses in each category was recorded.

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