International Journal *of* Designs for Learning
2016 | Volume 7, Issue 1 | Pages 1-18

DESIGN OF A SOCIO-SCIENTIFIC ISSUE CURRICULUM UNIT: ANTIBIOTIC RESISTANCE, NATURAL SELECTION, AND MODELING

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In this design case, we describe our work to design and develop a socio-scientific issue (SSI) based unit of instruction for use in high school biology. Our team includes university based science educators, an experienced classroom teacher, and a microbiologist. The unit focuses on antibiotic resistant bacteria as a context for student exploration of natural selection and engagement in modeling practices. Our team recently presented a model for SSI instruction that highlights: (a) a focal issue, (b) interaction of science ideas and practices, (c) social considerations, (d) use of information and communications technologies, and (e) a culminating experience that encourages students to synthesize their ideas. We use this model to frame the design case and discuss key decision points that influenced design and development of the unit. The design product is a three-week unit that we implemented in the spring of 2014. Key challenges presented in the case include continually evolving notions of scientific modeling practices and implications for related learning activities, developing supports for student negotiation of the social dimensions of antibiotic resistance, and determining how much emphasis to place on student use of information and communications technologies.

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INTRODUCTION

Socio-scientific issues (SSI) are societal issues with conceptual, procedural, or technical associations with science (Sadler, 2004). They are frequently the focus of media reports and create opportunities for all citizens, regardless of background and profession, to interact with science. Common examples of SSI include climate change, genetic technologies, medical controversies like vaccination, and questions related to energy sources and consumption patterns. The science education community has long-embraced the notion of using SSI as contexts for science learning experiences (Zeidler, 2003); however, actual implementation of SSI-based teaching remains limited. Two of the primary reasons for this limited use of SSI are a paucity of well-designed, SSI-oriented curriculum materials and limited supports for teachers trying to enact SSI teaching (Hofstein, Eilks & Bybee, 2011). In this design case, we describe our work to address these issues by developing a collaborative partnership between education researchers, a scientist, and an experienced science teacher to develop an SSI curriculum unit.

DESIGN MOTIVATION

The desire to collaborate was our initial motivation for pursuing this work. Pat is a science educator at the University of Missouri and Troy joined the faculty in 2011. Over several years, Pat and Troy discussed possible collaborative research projects; however, our research interests differed. Troy's research focused on K-12 student science learning within SSI contexts while Pat's research focused on evolution education and secondary science teacher learning.

With the release of the Next Generation Science Standards (NGSS), we saw a potential area for collaboration (NGSS Lead States, 2013). The new standards emphasize innovative three-dimensional learning that includes crosscutting concepts, disciplinary core ideas, and science and engineering practices. Troy was interested in using an SSI approach to implement NGSS. Pat was working on a project designing an undergraduate evolution course for pre-service biology teachers. She was interested in collaborating with secondary biology teachers to design a new curriculum unit for that course. As science educators, we were both interested in deepening our understanding of NGSS. We decided to design a SSI curriculum unit aligned with the NGSS biology standards.

Our next step was to invite a secondary biology teacher to collaborate with us. Kerri, a local biology teacher, was a mentor teacher in our teacher education program. As a university supervisor, Pat enjoyed observing in Kerri's classroom and was interested in collaborating with her on other projects. Pat and Troy met with Kerri in August of 2013 to invite her to join our design team. At the time Kerri and the other biology teachers in the science department were revising their biology curriculum to align with NGSS. Kerri viewed this collaboration as an opportunity to learn from Pat and Troy, to increase the relevance of biology for her students, and to gain additional help in revising the biology curriculum. Given the varied and intense demands on Kerri's time as a classroom teacher, it was important that the design work was well aligned with her teaching responsibilities, rather than adding to her workload.

After we identified the science topic for the curriculum unit, we invited a scientist with related expertise to join our design team. Pam Brown is a new faculty member in the Division of Biological Sciences. In the previous year, Pat and Pam had conversations about teaching and educational research, which led to an interest in collaboration. This project was a good fit with Pam's expertise. Pam's motivation to collaborate was founded in her belief that hands-on microbiology labs provide an effective, low-cost means of teaching important concepts, including evolution. Pam expected that connecting with teachers to establish a microbiology outreach program in local schools would be beneficial to students, teachers, and the university.

CONTEXT

Currently, our state has not adopted the *NGSS*. However, the local school district decided to align its curricula and reform efforts with the ideals of the *NGSS*. In the high school in which we eventually worked, the biology teachers whole-heartedly accepted this challenge. Working together in their Biology Professional Learning Team (PLT), they took on the task of redesigning their on-level and honors 10th grade biology curricula. They began the process in the summer of 2013, creating an overall curriculum map.

In August, when Pat and Troy met with Kerri, the Biology PLT was implementing their first *NGSS* curriculum unit while simultaneously planning the next unit. The high school in which Kerri teaches is a comprehensive high school with approximately 2000 students in grades 9-12. During the 2013-2014 school year, the student population consisted of 73.1% White, 11.4% Black, 4.5% Hispanic, 0.35 Native Hawaiian or other Pacific Islander, 5.8% Asian, and 4.7% Multi-racial. The free or reduced lunch rate was 19.4%. In 2014, the high school's 4-year cohort graduation rate was 95.6%. The high school has a strong culture that focuses on learning for all through the following values and practices: shared leadership, student and faculty collaboration, student freedom with responsibility, and high rigor and relevance with cross-curricular connections and skill development.

We implemented the curriculum unit in the honors biology courses. Honors biology is designed for 10th grade students who wish to learn more biology than the on-level biology course, understanding the standards at a deeper level and learning additional biological concepts. Students also grow in their ability to practice science, think critically, and communicate effectively. The course demands high student motivation. We chose to implement the curriculum unit in the honors biology course because Kerri taught two sections of this course, and, at the time, was not teaching the on-level biology course. The honors course proved to be an ideal context to pilot the unit for several reasons: (a) the students were highly motivated learners; (b) there were only three teachers teaching this course, so the coordination across sections was more manageable; and (c) there were fewer sections of honors biology in comparison to the on-level course, reducing the amount of laboratory materials we needed.

DESIGN PROCESS

Primary Design Model: SSI Instruction

Given our commitment to designing for the implementation of SSI-based teaching, our process began with an SSI instructional model (see Figure 1 for a graphic representation of this model). At our earliest meetings we discussed the model and ways in which the model would be ideally manifested in science classrooms. We then used this model throughout the design process to help identify curricular emphases and priorities. We present a brief overview of the various model dimensions.

The instructional model begins with a focal issue, the defining element of what we see as SSI-based instruction. The idea here is that SSI-based instruction should start with presentation of a compelling issue as a means of contextualizing everything that may follow. The model posits three

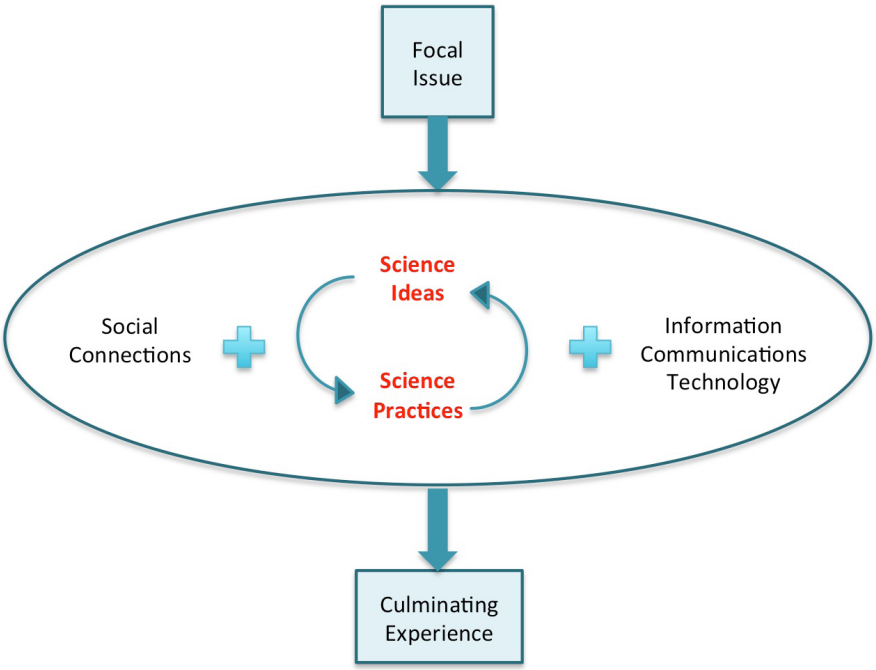

FIGURE 1. The Socio-scientific Issue (SSI) Instructional Model that served as a framework for our design work.

interacting elements as the primary substance of students' learning experiences: social connections, science ideas and practices, and information and communications technology (ICT). The suggestion here is that students ought to substantively apply science ideas and practices as they negotiate the focal issue. They should also have opportunities to consider the social complexities of the focal issue, which often interact with the ways in which the underlying science is interpreted or applied (Saunders & Rennie, 2013). As they make sense of the focal issue, students should interact with ICT in order to access and analyze new ideas as well as share their ideas with classmates or broader audiences (Klosterman, Sadler, & Brown, 2011). The final dimension of the instructional model is a culminating exercise in which learners synthesize their experiences with the focal issue including science ideas and practices, social connections, and information communication technology.

Secondary Design Model: 5E

Implicit in our design process was the use of a second model, the 5E instructional model (Bybee, 1997). As science educators, team members were familiar with this inquiry-based instructional model in our field. The 5E model includes the following sequential stages: engagement, exploration, explanation, elaboration, and evaluation. In the engagement phase, students are introduced to the topic. This can be accomplished in a variety of ways, including demonstrations, video clips, discussion, etc. Students' prior conceptions are also elicited in this phase. In the exploration phase, students explore the science phenomenon, which typically involves a laboratory investigation. In the explanation phase, students

SSI MODEL	5E MODEL
Focal issue	Engagement: Engage students with topic and assess students' ideas related to topic.
Social connections **+ science ideas and practices** + Information Communication Technology	Exploration of phenomenon
	Explanation: Developing a scientific explanation
	Elaboration: Apply scientific explanation in a new context
Culminating Experience	Evaluation

TABLE 1. Comparison of SSI and 5E models.

use their findings from the investigation to begin to generate an explanation of the phenomenon. The teacher builds on students' explanations and moves them toward a scientific explanation. In the elaboration phase, students test their recently acquired scientific understandings in a new context. Summative assessment occurs in the evaluation phase.

The 5E model dovetails well with the SSI model (see Table 1). Both models begin with engaging students with the topic. In the 5E model, the method of engagement is open to the teacher's discretion while in the SSI model students are introduced to the focal issue. In both models, a summative assessment occurs in the final phase. In the SSI model, there is a culminating experience in which students return to

the focal issue and apply their scientific understandings to grapple with the social aspects of the issue.

The value of the 5E model in supplementing the SSI model comes in the sequencing of the "science ideas and practices" component of the SSI model. The 5E model supports inquiry by having students investigate the science phenomenon first before scientific explanations are developed. The sequence is counter to the traditional approach of lecture followed by a confirmatory laboratory experience. Additionally, the elaboration phase of the 5E model supports a deeper understanding of the science ideas and practices by having students apply their knowledge and skills in a new context. Therefore, the 5E model informed the sequencing of the science content and scientific practices portion of the curriculum unit.

Roles of Team Members

We scheduled one-hour planning meetings approximately every two weeks in the fall semester of 2013. To facilitate Kerri's participation, we met in her classroom during her planning period. Early in the design process, Pat, Troy and Kerri completed the same homework tasks, e.g., identifying relevant *NGSS* performance expectations for the curriculum unit. At the meeting to follow, we would discuss and compare our individual work and work toward reaching consensus.

DAY*	INSTRUCTIONAL FOCUS	ACTIVITIES
0	Elicit student ideas.	Administer pre-tests for natural selection (NS).
1	Introduce antibiotic resistance (ABR) as significant issue. Review bacterial structure.	Video from a news magazine. Small group exploration of MRSA cases from multiple media sources. Students complete "Bacteria Study Guide."
2	Student exploration of bacterial evolution. Introduce ABR mechanisms.	Lab: set-up bacterial cultures (w/wo antibiotic in the agar) and make predictions. Lecture with references to the "Bacteria Study Guide."
3	Introduce modeling. Student exploration of bacterial evolution.	Students use the "Biological Levels of Modeling" worksheet as an organization tool to predict lab results. Lab: Document changes in bacterial growth.
4	Student exploration of bacterial evolution. Explain mechanisms for antibiotic resistance. Use models to account for lab results.	Lab: Examine second set of plates; record class data. Lecture. Students use "Biological Levels Modeling" tool to explain lab results.
5	Explore natural selection (NS) as a model for change in populations. Relate NS to lab results.	Students manipulate Netlogo models of NS. Students write lab conclusions with a NS perspective.
6	Review NS. Decision-making that links science to social challenges.	Class questions/discussion. Culminating activity (CA): Review epidemiological data on antibiotic resistance; jigsaw activity-students explore various social perspectives.
7	Decision-making that links science to social challenges.	CA: jigsaw activity-share various social perspectives; brainstorm policy options.
8	Decision-making that links science to social challenges. Apply NS model.	CA: Present and peer evaluate policy proposals. Read, interpret and make predictions of a case of herbicide resistance.
9	Elicit student ideas. Explain lateral gene transfer.	Administer pre-tests for NS. Lecture/discussion.

TABLE 2. Overview of the curriculum unit..

As the planning process progressed and our implementation deadline drew closer, we came to understand and draw on each other's strengths. We began to identify and volunteer to complete different tasks. For example, Troy worked on designing a scaffold for supporting students' understandings of natural selection at different levels of organization (e.g., molecular, individual, population). Pat reviewed natural selection simulations for inclusion in the curriculum unit while Kerri aligned the designated biology course skills with our unit.

As we divided the design work, each of us took on a specialized role. Troy had previously designed SSI curriculum units, so he took on the role of SSI expert. He kept the team members focused on the SSI instructional model. He developed the introductory lessons and the culminating assignment, which were key components of the SSI model. As an evolution educator, Pat shared evolution teaching resources and common student misconceptions. She found a natural selection NetLogo (Wilensky, 1999) model using bacteria and designed a student worksheet for use with the model. Kerri was the instructional leader and PLT liaison. She took the lead in finalizing the details of the instructional sequence and materials, and communicated our curriculum design to the other two honors biology teachers. As the microbiology expert, Pam took the lead on developing a laboratory investigation. As each of us worked on specific parts of the design, we brought our individual work back to the team for review and revision. We worked as a team to design the curriculum unit; however, by dividing the design tasks, we drew upon our individual strengths and took on expert roles within the team.

CURRICULUM UNIT

We describe the curriculum unit using the SSI instructional model as a framework (see Figure 1). The unit was taught over 9 class periods (85 minutes each), for a total of 13 hours of instruction. For an overview of the curriculum unit, see Table 2. The subsections that follow showcase various dimensions of the designed unit beginning with the student learning objectives and concluding with a description of the culminating experience. However, prior to presentation of the objectives, we discuss some of the initial design decisions made in this work. Throughout the discussion of the unit, we embed brief discussions of critical decisions that we faced in the design process and our rationales for the choices made.

Design Decision: Selecting the SSI approach and a science topic. An initial motivation for this work was creating opportunities for collaboration. The decision to use an SSI approach as a means of teaching evolution in the context of high school biology was closely connected to the formation of the partnership in its earliest stages. Troy was interested in extending his work in the area of SSI; Pat brought a history of work in the area of evolution education; and Kerri was teaching a high school biology class. We initiated the work in early fall, and the fact that Kerri's biology classes did not typically cover evolution until the spring gave us time to work through design of the unit. When Pat and Troy approached Kerri with a request to collaborate, Kerri immediately embraced the general idea of using an issue as an instructional context. Kerri's classes did not regularly use an SSI approach, but she did prioritize student decision-making, reasoning opportunities, and argumentation. The fact that students were accustomed to making and defending decisions and scientific claims made introducing the issue-oriented approach easier than attempts to bring SSI into more traditional classrooms (Zeidler, Applebaum, & Sadler 2011).

Student Learning Objectives

As a result of learning experiences in the unit, students will be able to:

1. Develop and explain a conceptual model of natural selection that accounts for (a) genetic variation associated with particular traits, (b) selective pressure that leads to differential reproductive success linked to these traits, and (c) changes in trait frequencies within the population.
2. Use a natural selection model as a basis for reasoning about novel problem situations.
3. Create and describe a model of a cellular mechanism that confers bacterial resistance to antibiotics. (Elements of this model should include targets of antibiotic activity and ways in which bacteria disrupt that activity.)
4. Demonstrate socio-scientific reasoning in response to complex SSI.
    a. Identify and discuss sources of issue complexity.
    b. Identify areas of uncertainty and ask related questions.
    c. Analyze the issue from multiple perspectives.
    d. Identify and discuss ways in which scientific evidence can inform issue resolution as well as limits on the use of scientific evidence.

Design Decision: Developing learning objectives. These learning objectives are presented unproblematically, which is typical of most science education curricula. However, developing good objectives can be challenging particularly with a diverse team. We had to work through several iterations in which we negotiated the balance of science content ideas, the desired emphasis on scientific practices, and the more atypical (at least with respect to science objectives) focus on outcomes related to student negotiation of SSI.

Given our collective interest in aligning the design work with the *NGSS*, it was important for us to consider how scientific practices would be featured in the unit. Early in our conversations, we made a decision to concentrate on a particular

scientific practice as opposed to attempting to cover all (or most) of the practices. The practice of argumentation would have been a natural fit: Kerri had featured argumentation in her class and this particular practice has been well documented in the context of SSI (Evagorou & Osborne, 2013). However, as a team, we were interested in exploring what we saw as new implications of *NGSS*. None of us had much experience with the teaching of modeling practices, and yet, we all recognized the growing significance of models and modeling in the field of science education (National Research Council, 2011). Therefore, we chose to feature modeling as a scientific practice of interest, and this decision is reflected in the first three learning objectives.

Exploration of the Issue

We selected the emergence of bacterial strains resistant to antibiotics as the focal issue of our curriculum unit. Antibiotic resistance is a growing problem globally, had been highlighted in the media so it was likely that at least some of the students had heard of the issue, and was conceptually related to the target content, that is, natural selection.

The introductory sequence for the unit presented several multimedia cases featuring methicillin resistant Staphylococcus aureus (MRSA). Students watched a video segment produced by PBS that told the story of an otherwise healthy young girl contracting and ultimately dying from MRSA (http://www.pbs.org/wgbh/pages/frontline/hunting-the-nightmare-bacteria/). Following this whole class experience, students worked in small groups to explore the MRSA issue from multiple perspectives. Individual students in each group reviewed a set of resources and reported their findings to other group members. The resources reviewed included:

1. The personal blog of a woman dealing with MRSA (http://tutusandtantrums.blogspot.com/2012/02/my-experience-with-mrsa.html).
2. A personal account of a man suffering from MRSA reported through a support group website (http://www.dailystrength.org/c/Methicillin_Resistant_Staphylococcus_Aureus/forum/7578667-my-experience-ca-mrsa).
3. A popular media account of MRSA including a written article and an embedded video account (http://www.usatoday.com/story/news/nation/2013/12/16/mrsa-infection-community-schools-victims-doctors/3991833/).
4. A medical website with images and descriptions of the disease (http://www.medicinenet.com/mrsa_picture_slideshow/article.htm).

As students explored these cases, they were asked to discuss several questions related to what MRSA was, how people contract MRSA, how it is typically treated, and strategies to stem the spread of the disease. Students were also encouraged to begin considering how the bacteria that cause staph infections could change over time such that populations became resistant to treatments (i.e., common antibiotics) that at one time were highly effective. See Appendix A for the student instructions.

Design Decision: Selecting an issue. Selecting the rise of antibiotic resistant bacterial infections as the focal issue for the unit was a key decision made early in our design process. In searching for an issue that we could use to teach evolution and natural selection, the evolution of resistance was immediately appealing. Several examples of organismal populations evolving resistances and creating societal opportunities or problems had been recently showcased in the news. Two particular situations seemed promising for our purposes: emergence of antibiotic resistant bacteria due to the misapplication of antibiotics and evolution of resistance to pesticides and herbicides among agricultural pests and weeds. To make this early design decision, we relied on Kerri's knowledge of her students. Most of her students exceled in school and came from middle class families with few direct ties to agriculture. Many of the students had expressed interest in careers in healthcare. Ultimately, we chose to focus on emergence of antibiotic resistant bacteria because we thought that this issue, with its ties to human health, would generate the most interest among the students.

Interaction of Science Ideas and Practices

The 5E model informed the sequencing of instruction related to science ideas and practices.

Experience with the Phenomenon

In keeping with the 5E model of exploration before explanation, we wanted students to observe the phenomenon of antibiotic resistance early in the unit. Pam took the lead on designing an antibiotic resistance lab using a nonpathogenic bacterium, *Bacillus megaterium*. In the first day of the lab, students plated the bacteria onto two different petri plates. Both petri plates contained growth medium (Luria broth and agar). One of the plates included an antibiotic, while the other plate served as a control for the experiment. The expected results were no growth on the antibiotic petri plate and heavy bacterial growth on the control plate.

This showed that the original culture lacked antibiotic resistance. Figures 2 and 3 present images from the laboratory experience.

The students sub-cultured the original bacterial culture and allowed it to grow for several days. While the bacteria were growing and dividing, random mutations accumulated, with some of the mutations conferring antibiotic resistance. Next, the students repeated the plating procedure, each student group inoculating two plates, one with and one without antibiotic. The expected results were heavy growth on the

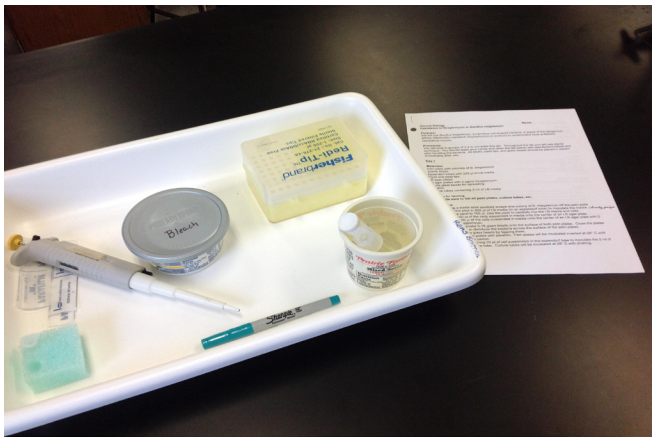

FIGURE 2. Materials used for the laboratory experience.

control plate and relatively light growth on the antibiotic plate. Students observed variations in the numbers of antibiotic resistant colonies, which was indicative of the random nature of the mutations.

Design Decision: Inclusion of a laboratory investigation. Prior to inviting Pam to collaborate, we discussed whether or not to include a laboratory component. Certainly, the topic of antibiotic resistance could have been taught without a laboratory experience. It was time-consuming to develop the lab and fairly labor intensive to manage the multi-day experiment. Implementation of the lab was also challenging due to weather-related school cancellations. However, we made the decision to include the lab despite these challenges because we valued giving students the opportunity to explore the phenomenon of antibiotic resistance first-hand by growing and plating bacteria. In many high school biology curricula, the emphasis on molecular biology has greatly reduced students' opportunities to study organismal biology.

Design Decision: Use of Bacillus megaterium and the antibiotic streptomycin. Pam explored the use of several different bacteria and antibiotics for the laboratory investigation. Safety, ease of culturing, bacterial growth rate, and the mechanism of resistance were our primary considerations. The bacteria needed to be safe for use in a high school setting and easy to grow at room temperature or in an inexpensive incubator. At the cellular level, there are multiple mechanisms of antibiotic resistance. We wanted to avoid a "black box" approach to antibiotic resistance, i.e., the antibiotic simply killed the bacteria. Rather we wanted students to understand what was happening at the cellular level. We chose streptomycin because it targets a biochemical pathway (protein synthesis) taught in a previous unit. Therefore, the resistance mechanism would be fairly easy for students to understand. As curriculum designers, we wanted to make strong content connections to previous curriculum units.

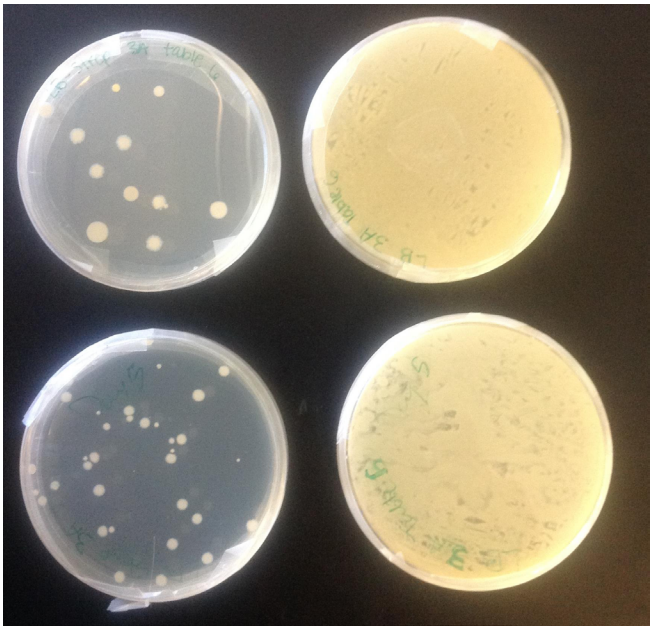

FIGURE 3. Bacterial plates from two student groups following the second stage of the experiment (control plates on the right).

Developing Content Understandings through Models

We designed two modeling lessons to develop students' scientific understanding of the mechanisms of antibiotic resistance and natural selection. The sequencing of these modeling activities aligns with the 5E model's explanation and elaboration phases.

The first modeling lesson, "The Biological Levels Modeling Worksheet," was designed to help students develop explanations of the phenomenon across the following levels of biological organization: molecular, cellular, organism and population levels. In the first version of their models, we captured students' initial ideas about antibiotic resistance and natural selection. Because of their unfamiliarity with microbiology, students struggled to make sense of their laboratory results at the individual and population levels. In response to this difficulty, we added a short PowerPoint presentation with images of individual bacterium, colonies and populations. We explained how one colony represented clones of an individual bacterium. As we anticipated, students left the molecular and cellular levels blank in their initial models. Through class discussions and short presentations, we made connections to previous units (cells, genetics, protein synthesis) and introduced new science content. During this explanation phase, students revised their models to reflect their expanded understanding of antibiotic resistance and natural selection. See Appendix B for a completed student worksheet.

The second modeling lesson aligns with the elaborate phase of the 5E model in which students apply and test their recently developed scientific explanations in a new context.

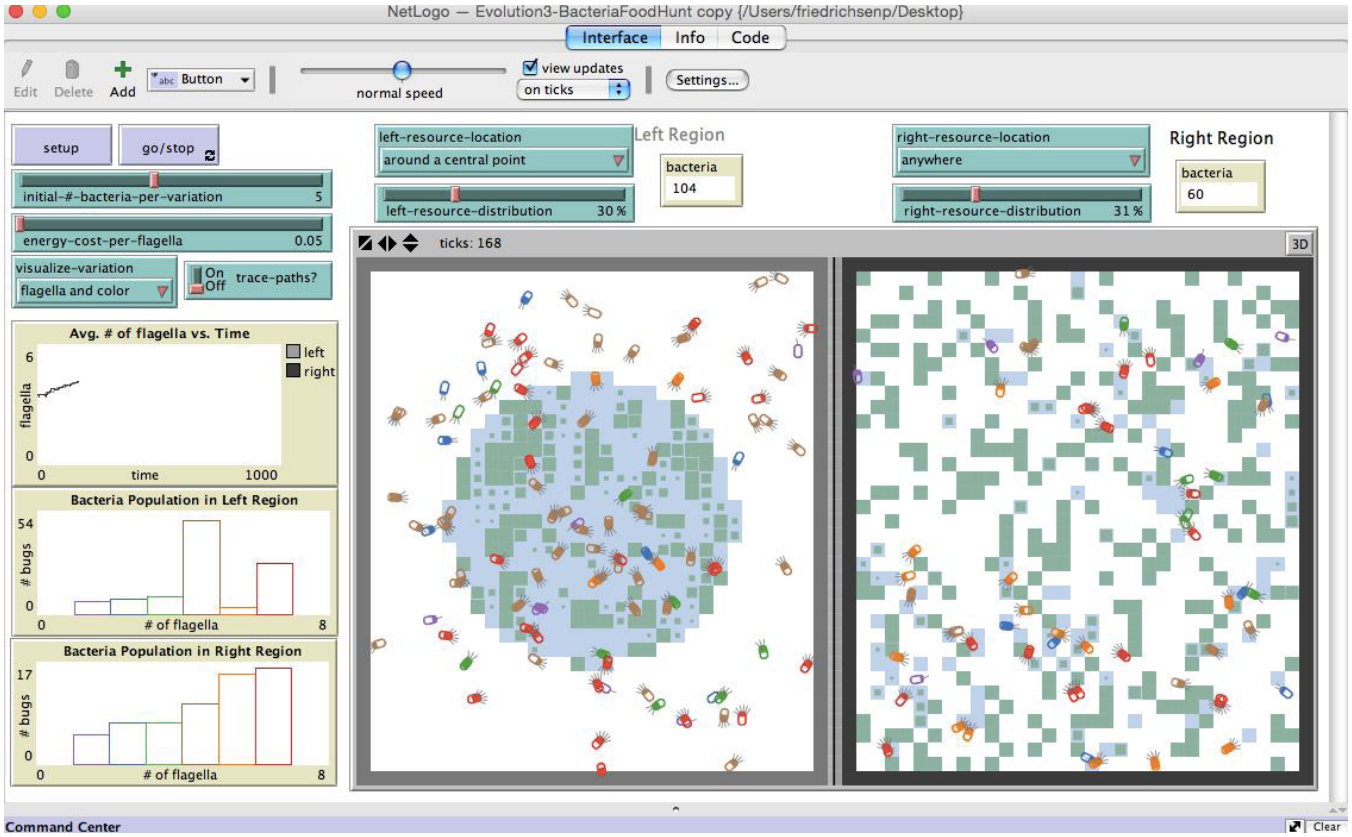

FIGURE 4. NetLogo Model, Bacteria Food Hunt.

After reviewing a wide variety of web-based natural selection simulations, we selected the NetLogo model, "Bacteria Food Hunt" (Novak & Wilensky, 2013; see Figure 4). This model simulates natural selection acting on a population of bacteria that vary in the number of flagella. Students can manipulate several variables: amount of food, distribution of food, and the energy-cost per flagellum. As they change the variables, students can observe the effect at the population level by analyzing the bar graphs to the left of the screen.

To help students navigate the NetLogo model, we designed a scaffold in the format of a worksheet (see Appendix C). In this modeling lesson, we introduce the concept that all models have built-in assumptions. In the worksheet, we are explicit in listing the NetLogo model assumptions (e.g., Bacteria die when they don't obtain enough food).

We structure the students' use of the NetLogo model through a sequential exploration of Darwin's four postulates: (1) variation within a population, (2) heritability, (3) over-reproduction and limited resources, and (4) differential survival and reproduction tied to favorable variations. In the first part of the worksheet, students are asked to observe variation among the bacteria. We highlight a "trace path" feature of the model that allows students to visualize the effect of flagella number on the organism's speed. As heritability of flagella number is a difficult concept to observe in the model, we added a short explanation of how bacteria reproduce through binary fission, producing two identical bacteria. Next we have students manipulate the "energy-cost-per-flagella" feature of the model to introduce the concept of trade-offs in evolution. The students learn that having a large number of flagella increases the organism's energy needs. To understand differential survival and reproduction, we have students make specific changes to the food amount and distribution to observe that differential survival is not random but rather tied to the flagella number. We purposefully designate comparisons of specific food conditions so that students observe that there is no one best variation (e.g., the largest flagella number is the "best" variation). Rather, the favorable variation is dependent on environmental conditions and energy trade-offs. Toward the end of the lesson, we held a whole class discussion in which Kerri is explicit in reviewing Darwin's postulates. The modeling lesson ends with a challenge problem in which students develop and test their own hypotheses using the model.

Design Decision: Creation/selection of scaffolds for modeling. Students often have difficulty reasoning across levels of representations (i.e., microscopic, macroscopic and symbolic; Johnstone, 1993). The Biological Levels Modeling worksheet was designed to help students make connections across the molecular, cellular, individual and population levels. These levels of biological organization were introduced in the first unit of the course. By returning to these levels, we provided

a framework for developing a deeper understanding of antibiotic resistance and natural selection. In reflecting on this modeling activity, the students' initial models would be classified as relatively simple models, in which "students construct and use models that show literal illustrations of a single phenomenon, depicting only observable features, rather than attempting to explain the phenomenon" (Schwarz et al., 2009, p. 640). As students developed their models during the unit, their products became more sophisticated such that the models not only illustrated the phenomenon but also provided explanations. Consistent with research on modeling practices, students seemed to view their models as "a *means of communicating their understanding of a phenomenon* rather than a tool to support their own thinking" (Schwarz et al., 2009, p. 640). In future iterations, we want to further develop our modeling lessons to push students toward higher levels of modeling performance in which they use models to explain and predict.

The elaboration phase of the 5E model influenced our decision to include a natural selection example beyond the immediate context of the unit. The NetLogo model allowed students to test and further develop their ideas about natural selection in a new context, using the same organism. Typically a natural selection unit would include examples of a variety of organisms, including plants and animals. Staying true to the SSI approach, the issue of MRSA influenced our decision to select a second natural selection model using bacteria. In the second model, the variation was not in antibiotic resistance but in the number of flagella. The advantage of the NetLogo model was that it allowed students to see selective pressures acting on individual bacteria and analyze the resulting changes in the population, whereas in the laboratory investigation students were required to make more inferences from their observations.

Use of Information and Communication Technologies (ICT)

The SSI instruction model calls for learner experiences with ICT. For the antibiotic resistance unit, our focus in this area related to student negotiation of the credibility, reliability and potential bias represented in media. Learners' initial experiences in the unit involved exploration of multimedia cases from various sources representing a range of perspectives on MRSA. The cases were communicated through mainstream media outlets, personal blogs, subscription websites, and the public information page for a medical website. Each of these sources of information has varied strengths and limitations, and in designing the unit we tried to draw explicit attention to these issues such that students considered them as they made sense of the ideas presented. Likewise, in the culminating experience (to be described in the next subsection), the design called for students to access information from a variety of sources including scientific reports (both primary and secondary representations of scientific and epidemiological data), websites and blogs created by interested individuals, mainstream media outlets, governmental reports, and articles from a business periodical. Here again, the designed activities attempted to draw student attention to issues of perspective-taking, reliability, credibility and bias as they interrogated the sources provided. The primary mechanism for doing this was a series of media literacy questions that students were encouraged to ask of their sources whenever accessing information:

- Who (or what organization or company) is presenting the information?
- What is the purpose of the publication?
- What expertise and/or relevant experience does the author (or organization or company) have?
- What biases does the author (or organization or company) have and how might those biases affect the presentation of information?
- Does the information presented seem to be accurately reported? Are the claims made in the presentation supported? Do any facts or analyses seem to be distorted?
- Does the presentation leave important information out? Does the presentation offer information that is unnecessary (particularly if the extra information distorts the message)?

These questions and a rationale for posing these questions was the topic of a teacher-led discussion and provided to students in the form of a worksheet. Whenever students had opportunity to search for information, they were encouraged to revisit their worksheet and consider these questions and related issues as they attempted to make sense of the information.

Design Decision: Balancing emphases. In reflecting on our design and development processes it is clear to us that student experiences with ICT did not receive the same level of design attention as science ideas and practices. As science educators, we were all more familiar with planning for science content learning experiences. Coming into this design work, Troy had recently worked on a media and science project (Klosterman, Sadler, & Brown, 2012), and the ideas and tools of this project significantly shaped how he was thinking about the kinds of considerations that students ought to be making as they consider varied sources of information. Given that the ICT component of the instructional model was more novel to the other design team members, there was little critical discussion of other ways in which students could be engaged with ICT. In this case, our "design decision" around what to include as ICT-related experiences for learners was more implicit and limited by our group's lack of experience in this area. As we consider future iterations of the design, we would like to expand our focus on ICT experiences, particularly for students to represent their own ideas and analyses.

Culminating Experience

The culminating experience was designed as an activity for students to synthesize and apply their learning throughout the antibiotic resistance unit (see Appendix D). The assignment asked students to make a policy recommendation related to bacterial diseases and antibiotic resistance. These recommendations could include regulating ways in which doctors prescribe antibiotics, regulating patient access to antibiotics, incentivizing investment in antibiotic development, recommending cooperation among nations in different regions of the world, launching educational campaigns, and so forth. The first part of the activity was a structured exercise in which small groups explored epidemiological data related to the spread of antibiotic resistant bacterial diseases. The second part was designed as a jigsaw activity in which each member of the group explored perspectives of a particular stakeholder group and then reported their findings back to the group. Stakeholder groups included: (a) parents with sick children, (b) individuals concerned about the international scope of antibiotic policies and politics, (c) opponents of governmental intervention in healthcare issues, and (d) drug manufacturers. After each member of the group studied the perspective of one of these stakeholder groups, s/he shared findings and insights with the full group. The final part of the experience called for individual students to create their own policy recommendations. Students were asked to describe the policy they suggested and to provide a rationale. Next they were asked to address several questions associated with their recommendation:

- What are the potential benefits of the enactment of this policy?
- What are the potential disadvantages of the enactment of this policy?
- Who would likely support this policy? Why?
- Who would likely oppose this policy? Why?
- If this is a good solution to the problem of antibiotic resistance, why has it not already been implemented?
- What scientific evidence or scientific models can be used to strengthen the case to be made to support your recommendation?

Our intent with the initial design was for students to share their policy recommendations with classmates and to engage in a peer review process. During the actual implementation, it was not possible to follow through with the peer review and subsequent revision opportunities because of limits to the amount of time available for implementing the unit.

Design Decision: Selecting social connections. The SSI instructional model highlights the need to draw attention to the social dimensions of the focal issue. The culminating activity was the primary vehicle through which we encouraged student consideration of the social dimensions of antibiotic resistance. Some of the social connections of interest were fairly obvious given the issue; these included the economics of healthcare, particularly the economic disincentives for drug manufacturers to develop new antibiotics, and international disparities in the use and regulation of antibiotics. In addition to these relatively obvious social connections, we chose to also highlight a social complexity that related to a topic that was generating a lot of attention as we engaged in planning and design. In the midst of our work, national headlines were dominated by political debates over the Affordable Care Act (i.e., "Obamacare"). The key political talking point related to concerns over the extent to which government should be involved in healthcare decisions. We chose to extend this argument to questions about what government might do (or not do) in response to the antibiotic resistance issue. We saw this as a mechanism to make the unit more societally relevant, a natural goal of the general SSI approach.

CONCLUSION

For the design team, this project represents a successful, collaborative design. The desire to collaborate was our initial motivation for engaging in the design project. As science educators, a common desire to deepen our understanding of NGSS provided an area of overlapping interests for collaboration. The SSI model guided the design of our unit, while the 5E model informed the sequencing of science ideas and practices. The SSI model was a useful design tool for team members new to the SSI approach. Based on perceived student interest, we selected antibiotic resistance as the focal issue for the unit and it did, indeed, prove to be an engaging issue for the students. The antibiotic resistance laboratory investigation gave students an important, hands-on experience with the phenomenon. For *NGSS* scientific practices, we chose to highlight modeling in the unit. This decision led to on-going discussions about modeling which deepened our understanding of this scientific practice. We designed two modeling lessons for the unit; however, in future iterations, we plan to increase the students' level of modeling so that students see models as both explanatory and predictive tools. Although the unit did engage students with ICT, we were dissatisfied with the emphasis placed on ICT relative to other components of the SSI model. In the future we plan to explore additional ICT tools for use in the unit. In the culminating activity, students wrote policy recommendations for reducing the spread of antibiotic resistance. This assignment was designed to engage students in examining the social aspects of the issue from multiple perspectives. Due to school cancellations, students spent less time on the culminating activity than we had originally planned. Overall, the design process deepened our understanding of *NGSS* and illustrated the potential of using an SSI approach to implementing *NGSS*.

ACKNOWLEDGMENTS

This work is based, in part, upon work supported by the National Science Foundation Transforming Undergraduate Education in Science (TUES) program under Grant No. 1140462. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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APPENDIX A

Exploring Cases- MRSA

You will work in small groups (about 4 people) to explore multiple resources related to people struggling with MRSA. Each student is responsible for exploring one resource and completing the questions listed below. However, no single resource has all the answers for all the questions. After each group member explores her/his resource, the group should work together to complete the questions. Keep in mind that some of the questions have multiple answers provided by the various sources. As you consider the information in your resource, it is very important to consider the source and quality of information (refer to the "Know Your Sources of Information" for some helpful tips).

Resources

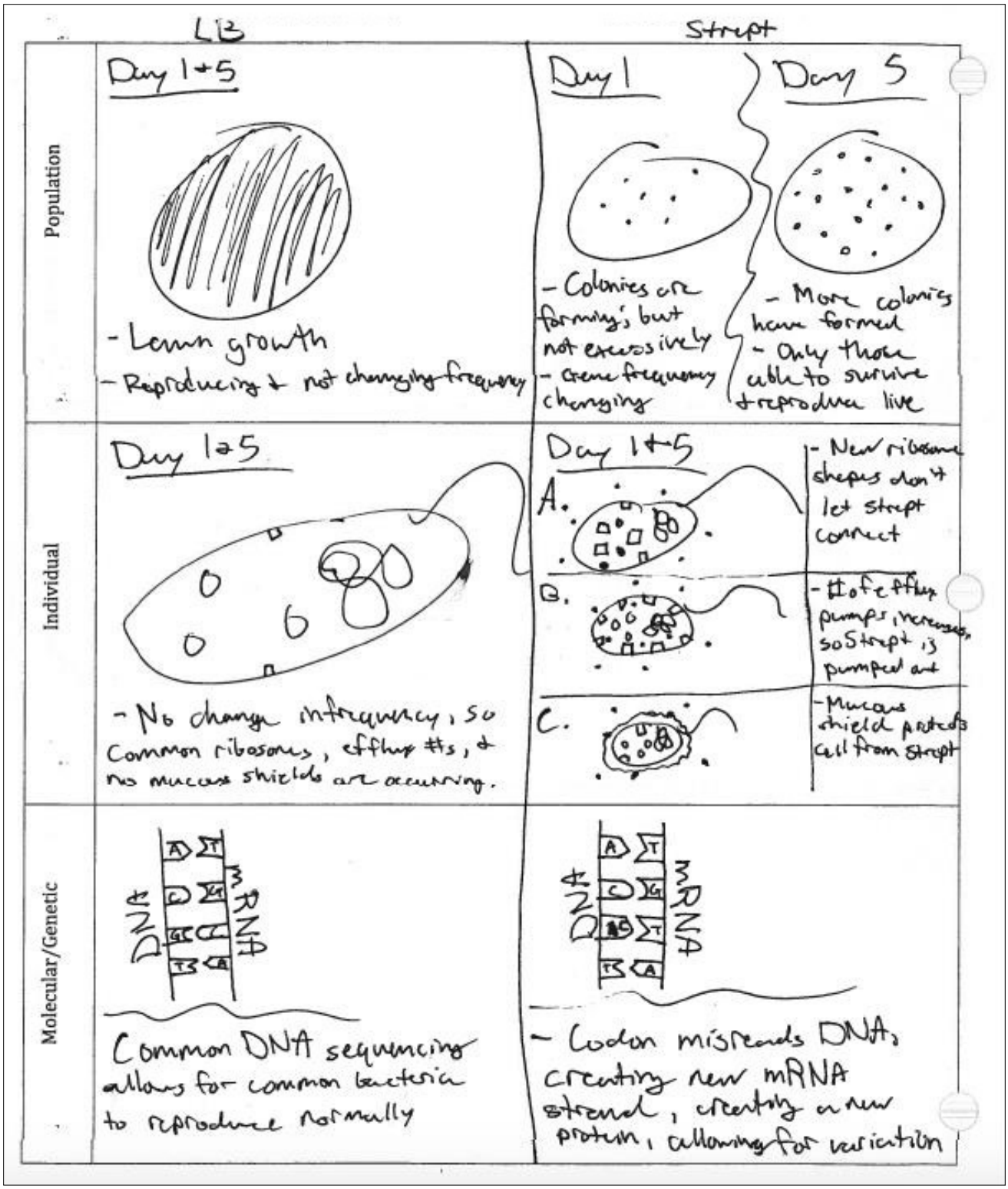
A. Personal account of dealing with MRSA, *Personal Blog*: http://tutusandtantrums.blogspot.com/2012/02/my-experience-with-mrsa.html
B. Personal account of dealing with MRSA, *Daily Strength Support Group*: http://www.dailystrength.org/c/Methicillin_Resistant_Staphylococcus_Aureus/forum/7578667-my-experience-ca-mrsa
C. Popular media account with an embedded case, *USA Today article*: http://www.usatoday.com/story/news/nation/2013/12/16/mrsa-infection-community-schools-victims-doctors/3991833/
D. Medical website pictures and descriptions, *MedicineNet slideshow*: http://www.medicinenet.com/mrsa_picture_slideshow/article.htm

Collaborative Questions

1. MRSA is an acronym for methicillin-resistant *Staphylococcus aureus*. What does it mean for these bacteria to be "resistant"?
2. How many people are affected by MRSA infections in the US on annual basis? How many people die because of MRSA on an annual basis?
3. Who is at a high risk for contracting MRSA?
4. Why is MRSA often referred to as a "super bug"?
5. How do people catch MRSA?
6. What percentage of the US population carries staph infections? According to the Centers for Disease Control, what percentage of the US population carries MRSA?
7. What are symptoms associated with a MRSA infection?
8. Keep a list of the various medicines (particularly antibiotics) that patients featured in the cases are prescribed.
9. What strategies can be used to control the spread of staph infections?
10. Why do you think doctors prescribe multiple medicines for MRSA infected patients?

APPENDIX B

Completed Student Worksheet



APPENDIX C

Student Worksheet

HONORS Biology

Name_____

NetLogo Bacteria Modeling

Scientists often use models and simulations to help develop explanations for phenomena. Models allow you to make predictions and test possible explanations. We will be using NetLogo to model bacterial populations. The model we will be using is "Bacteria Food Hunt" (Novak, M., & Wilensky, U., 2013).

NetLogo Model Assumptions: All models have assumptions built into them. The NetLogo Model we are using is built on the following assumptions:

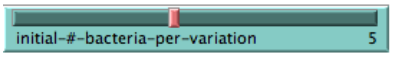
- Bacteria are heterotrophs, need to hunt for food
- Bacterial movement is determined by an algorithm
- Bacteria feed, when they are "full" they divide into two
- Bacteria die when they don't have enough food
- Rates of energy use are fixed and directly relate to # of flagella
- Food regenerates in the same place

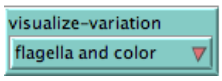
Exploring: Play with the NetLogo model and change as many variables as possible.

1. What two variables can you change in the bacterial population? (Ignore visualize-variation.)

2. What two variables can you change in the environment?

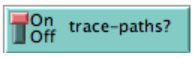
Initial Bacteria Population Variation:

Set the following: 



, then click 

3. Describe the variation in the initial bacteria population.

Now turn on a new feature: 

. Click on 

and 

. Let the simulation run for a few seconds.

4. Summarize what you observed. What is the relationship between flagella number and speed?

Reproduction and Inheritance:

Bacteria reproduce asexually by a process called binary fission. A single cell copies its genetic material, grows to twice its size and then splits into two. The result is two identical daughter cells. The bacteria we are using in lab, *Bacillus megaterium,* which can divide every 25 minutes.

5. If a bacterium has 5 flagella, after reproducing, how many flagella will each of the daughter cells have?

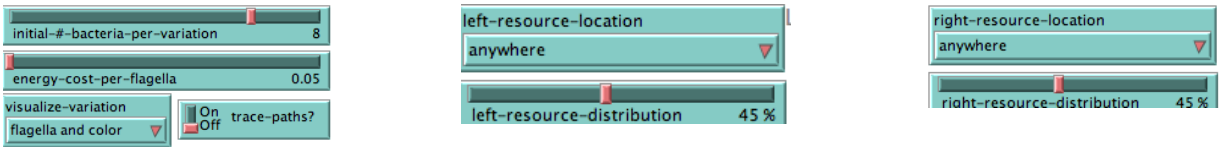
6. Explain your reasoning.

In the NetLogo model, one assumption is that the number of flagella is an inherited trait.

Over-Reproduction and Limited Resources:

In a population, more offspring are produced than can survive due to limited resources, such as food.

MODEL 1: Set the following parameters so the bacteria have limited food resources, and then click on Setup. BEFORE you click on GO, make a prediction below.



7. Prediction: Which bacteria are more likely to survive?

8. Explain your reasoning for your prediction.

Click on Go, and let the simulation run until the population appears to stabilize. Run the simulations multiple times until you think you see a trend.

Survival & Reproduction:

9. Which bacteria survived?

10. Give a possible reason to explain your results.

Adaptations: An adaptation is a heritable trait that gives an individual an advantage in a particular environment. An adaptation increases an individual's fitness – the ability to survive and reproduce.

11. What adaptation allowed some individuals to survive and reproduce in Model 1, in which the food was somewhat scare and randomly distributed?

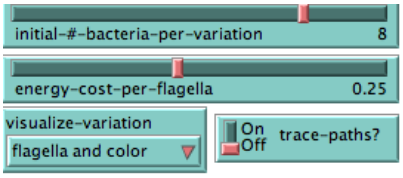
Cost and Benefits: Adaptations have both benefits and costs to the individual.

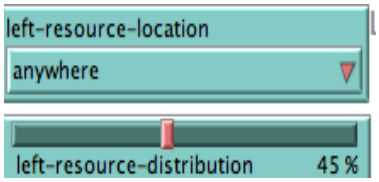
12. What is the benefit of having more flagella?

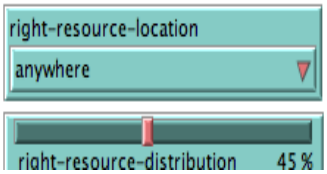
There is a cost to the bacterium for each flagellum. It requires more energy to move when a bacterium has more flagella. Let's explore this cost.

Model 2: This model will be more realistic in that we will add a cost to the organism for each flagella. Set the parameters to the following. We will keep all the parameters the same as in Model 1, with the exception of the energy-cost-per-flagella. BEFORE you click on GO, make a prediction.

ENERGY







13. Model 2 Prediction: Which bacteria are more likely to survive?

14. Explain your reason.

Run Model 2 several times until you see a trend in the results.

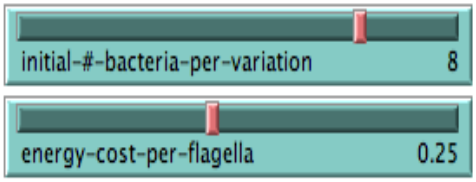
15. Which bacteria survived and reproduced?

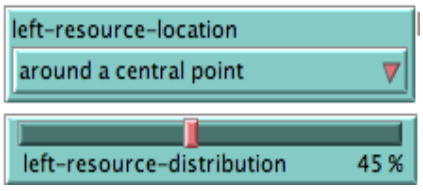
16. Explain why the surviving population in Model 2 was different from the surviving population in Model 1, even though the environment stayed the same.

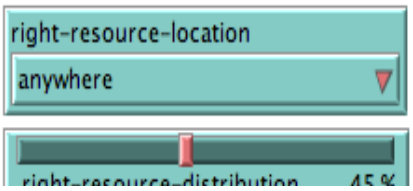
Changing Environment Pressure:

For Model 3, we will change the environmental pressure. In the left region, the food will be concentrated around a central point, while in the right region, the food will be randomly distributed anywhere. We are also reducing the energy-cost/flagella to 0.25

Set the following parameters:







17. Model 3 Prediction:
    a. Which bacteria are more likely to survive in the left region where the food is concentrated around a central point? Explain your reasoning.

    b. Which bacteria are more likely to survive in the right region where the food is randomly distributed? Explain your reasoning.

Run Model 3 several times:

18. Which bacteria survived in the left region?

19. Which bacteria survived in the right region?

20. Give a possible explanation for why different adaptations were selected for in each of the two environments.

NetLogo Model Reflections on Learning

1. Each time you ran the simulation, what did you notice *about the initial population* of the bacteria?

2. In the table below, list two *different environmental conditions* that you set up in the model.

3. Complete the second column of the table below. In each condition, which bacteria *survived*?

ENVIRONMENTAL CHANGE	EFFECT OF POPULATION

4. *Reproduction:* How does the number of flagella in the offspring compare to the number of flagella in the parent bacterium?

5. With each model you ran in NetLogo, what did you notice when you *compared the initial population to the final population*?

Challenge Problem: If you are waiting for your classmates to finish, run the simulation with different variables to determine under which conditions the purple bacteria (1 flagella) have the highest fitness? (Fitness refers to surviving and reproducing)

Conditions:

Reference

Novak, M., & Wilensky, U. (2013). *NetLogo bacteria food hunt*. Evanston, IL: Center for Connected Learning and Computer-Based Modeling, Northwestern University.

APPENDIX D

Policy Development & Analysis

Assignment Overview

Throughout the rest of the Antibiotic Resistance unit, you will be asked to think about making a specific *policy recommendation* related to bacterial diseases and antibiotic resistance. A *policy recommendation is a suggested course of action* that could be implemented at one of several levels of government. For example, recommendations could be made for a state (like the state of Missouri) or a country (like the US). International policy can be implemented through an organization like the United Nations.

The purpose of this exercise is to get you thinking about what should be done (or not done) to deal with the problem of antibiotic resistance. This thinking should be informed by what you know about the science behind this issue, but your thinking may also be influenced by the social aspects of the issue. For this project, you will collaborate with classmates in small groups but you will be responsible for making your own policy recommendation and analysis of that recommendation.

As you review information about the issue and various perspectives on the issue, remember the importance of evaluating your sources of information. The "Know Your Sources of Information" handout provides helpful questions to ask when looking at websites or other information resources.

Process and Products

1. Students are assigned to groups of ~4.
2. Everyone in the group should review resources that highlight epidemiological data related to antibiotic resistant bacteria. Then individual students will review a couple resources that present information and perspectives about a particular aspect of the AB-resistance issue:
   a. Parental and doctor concerns
   b. Use of antibiotics in international settings
   c. Government intervention in healthcare issues (like AB-resistance)
   d. Drug company perspectives on new antibiotics.
3. Each group member is responsible for reviewing information pertinent to her/his assigned perspective AND for sharing the basic ideas about this perspective with her/his group. Each student should be prepared to share information corresponding to the discussion question (shown in #4).
4. Group discussion. Students should present the information they find relative to each aspect.
   a. What sources did you access? What is the quality of these sources?
   b. Describe the aspect on AB-resistance you explored.
   c. Who is involved with this aspect? What are their likely interests?
   d. What would the stakeholders represented in your readings recommend in terms of policy for AB-resistance?

After presenting information about the various aspects, the groups should brainstorm possible courses of action that could serve as the basis for a policy recommendation. Examples include doing nothing, regulating doctors' activities, regulating patient access to AB, incentivizing corporate investment in AB development, launching an educational campaign.

1. Individual students select a governmental level for policy enactment and create a policy recommendation.
   a. Policy Statement
      i. Identify the target level for policy (state, national, international)
      ii. Describe the policy you are proposing and provide a sound rationale for implementation of that policy.
   b. In addition to creating the policy, students must provide a written analysis of the policy guided by the following questions.
      i. What are the potential benefits of the enactment of this policy?
      ii. What are the potential disadvantages of the enactment of this policy?
      iii. Who would likely support this policy? Why?
      iv. Who would likely oppose this policy? Why?
      v. If this is a good solution to the problem of AB-resistance, why has it not already been implemented?
      vi. What scientific evidence or scientific models can be used to strengthen the case to be made to support your recommendation?