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INQUIRY & INVESTIGATION

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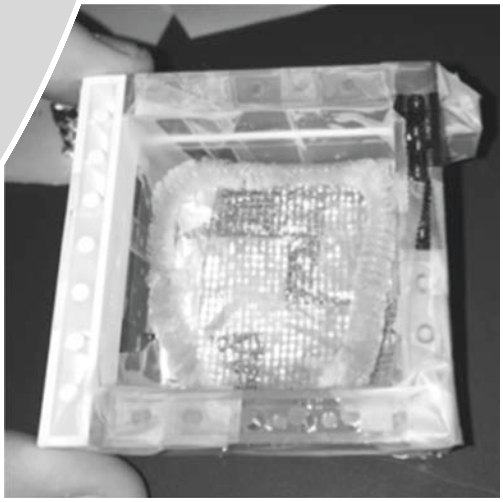

TAYLOR HOLDER, LAURA POTTMEYER, FRACKSON MUMBA

Abstract

Students often find it challenging to learn about complex and abstract biological processes. Using the engineering design process, which involves designing, building, and testing prototypes, can help students visualize the processes and anchor ideas from lab activities. We describe an engineering-design-integrated biology unit designed for high school students in which they learn about the properties of slime molds, the difference between eukaryotes and prokaryotes, and the iterative nature of the engineering design process. Using the engineering design process, students were successful in quarantining the slime mold from the non-inoculated oats. A t-test revealed statistically significant differences in students' understanding of slime mold characteristics, the difference between eukaryotes and prokaryotes, and the engineering design process before and after the unit. Overall, students demonstrated sound understanding of the biology core ideas and engineering design skills inherent in this unit.

Key Words: *Engineering design; slime mold; high school; integration.*

Introduction

Current science education standards call for the integration of engineering design into science instruction (NGSS Lead States, 2013). According to the National Research Council (2009), integrating engineering design into science instruction provides the following benefits to students: improved learning and achievement in science and mathematics; increased awareness of engineering and the work of engineers; an understanding of, and ability to engage in, engineering design; enhanced interest in pursuing engineering as a career; and increased technological literacy (pp. 49–50). Despite these benefits, there are still very few examples of engineering-design-integrated biology lessons and units for teachers to use in their classrooms. We have been developing and testing engineering-design-integrated science units and activities for middle and high school science classrooms. Here, we describe one of these units, which we have developed and implemented in ninth- and tenth-grade advanced and honors biology classes. This unit was taught at the beginning of the school year to build foundational knowledge for engineering design and biology concepts.

This unit originally existed for students to gain a deeper understanding of the scientific method and basic biological principles through structured inquiry in creating mazes for the slime mold *Physarum polycephalum* to solve. However, when reflecting on the unit, it became evident that it lacked various aspects of inquiry, as students were made aware of the outcome prior to beginning the lab. While students enjoyed this hands-on approach to learning, we realized that the unit and already-available materials could lend themselves to teaching the engineering design process, as well as provide deeper understanding of the scientific method and foundational biological principles such as characteristics of slime molds. Instead of having students build mazes, we created an authentic problem for students to solve in which the slime mold modeled an infectious disease that needed to be quarantined in order to save the world's population.

What Is a Slime Mold?

Despite its name, a slime mold is an amoeboid protozoan, not a mold or fungus (Waggoner & Speer, 2006). It is a eukaryote and thus has membrane-bound organelles. Slime molds begin their lives as amoeba-like cells and emit chemical signals, which allow the cells to come together as plasmodia. The chemical signals also allow the mass of cells to "reunite" when separated. Slime molds typically live in soil among deciduous logs or on the forest floor. They feed on microorganisms that live in dead plant material.

Ideal for use in the classroom, slime molds exist in both an inactive state (sclerotia) and an active state (plasmodial stage). The sclerotia can remain viable for long periods if kept in a dark, dry, room-temperature-controlled environment. Once ready, the sclerotia can be activated in an agar-filled Petri dish and will survive on a diet of oats. Its relatively low maintenance nature, inexpensive diet,

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and ability to communicate and move make it a great introduction to working with living organisms for high school biology students.

○ Unit Overview

This article describes an engineering-design-integrated science unit that was developed for and tested in a ninth- and tenth-grade high school biology classroom. The unit occurred over the course of three double periods (90 minutes each). Throughout this unit, students used the engineering design process to learn about the properties of slime molds and related biological concepts. The students took on the role of engineers tasked with "quarantining" a spreading slime mold, which served as a model for an infectious disease. This unit enabled students to engage with the engineering design process to solve an authentic problem.

○ Learning Objectives

This unit connects engineering design with biology content knowledge (see Table 1 for connections to the NGSS). After the unit, students should be able to do the following.

- Explain the characteristics of slime molds
- Explain the difference between eukaryotes and prokaryotes
- Understand the steps of the engineering design process and that the process is fluid and iterative
- Understand that questions posed in science can be solved with solutions designed through engineering design
- Identify aspects of the slime mold quarantine lab as steps of the engineering design process
- Make qualitative observations to determine whether their design was successful and then use these data to make design revisions; and
- Communicate their findings using scientific and engineering language

○ Materials

Each group needs the following materials:

- Slime mold (*P. polycephalum*)
- Agar and starter plates
- Glass Petri dish with plastic wrap and a rubber band to cover the dish
- Dry oats
- Inoculated oats

The following are the construction materials that should be available for all groups to use:

- Legos
- Paper
- Aluminum foil
- Mesh
- Pipe cleaners
- Tape
- Straws
- Overhead transparencies
- Scissors

○ Safety Concerns

The safety concerns for this unit will be largely mitigated by having the teacher preparing the slime mold for student use. Once the Petri dishes have been inoculated with slime mold, they will be taped shut and students will be instructed not to open them. Students may look at the bottom side of the dish to see if their slime mold has escaped or not. At the end of the unit, all Petri dishes should be dunked in bleach water to ensure that the spores have been killed before being disposed of.

○ Engineering Design Lab: Day 1 (90 minutes)

At the start of the lab, the teacher reviewed the scientific method with the students and then added that there are additional ways of solving problems. The teacher then led a class discussion centered on the following topics: what engineering is, types of engineering jobs, how engineering is related to science, and the similarities and differences between the engineering design process and the scientific method. At this point, the teacher formally introduced the engineering design process and its steps. While there are many versions of the engineering design process, our students used the steps depicted in Figure 1.

Step 1: Identify the need or problem. After introducing the engineering design process, a message flashed across the board that read "ALERT" in large red letters. This alert introduced students to the design challenge they would be working to solve. Next, the

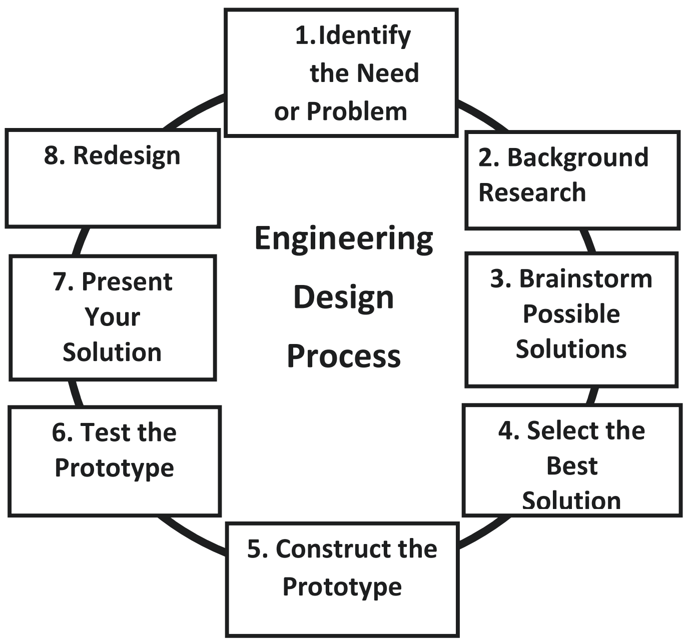

Figure 1. Engineering design process model.

students were instructed to read the design challenge/problem to gain a better understanding of the task at hand (see Figure 2). At this point, the teacher explained the criteria and constraints of the challenge and answered students' questions about the overarching goal of the lab. Students were also introduced to the design portfolios (see Figure 3). They were instructed to use this portfolio, in addition to a Google Slides presentation, to document all their ideas and observations as they moved through the engineering design steps.

Step 2: Background research. Next, the teacher introduced the essential characteristics of slime molds and the vocabulary associated with them, such as *prokaryote*, *eukaryote*, and *plasmoid*, to help students better understand their own research later in the design process. Students watched a short video about slime molds and learned about their biological significance through interactive instruction. Then the students were given time to use books and online resources to learn about the characteristics of slime molds and to document their findings in their design portfolios.

Design Challenge
A deadly disease outbreak is sweeping through the nation, making its way east and leaving mass destruction in its path. Patient zero has not been located, making the source of the disease unknown. However, it has been observed that when the disease is quarantined and not provided with a new food source or host, it dies off and does not continue to spread. Quarantine facilities are being constructed around the country to help combat the disease and promote the survival of our nation's population. Please consider building a quarantine facility yourself to join in the efforts.

Design Constraints
- Use only the materials provided.
- The design must fit inside the covered glass culture dish.
- Quarantine facility must be open on at least one side to allow the facility to be placed on top of the agar.
- Facility must exist as one piece.
- You must use a minimum of two different construction materials to help mitigate material shortages.

Figure 2. Design challenge and constraints.

Student Design Portfolio

Use the space to answer the questions in the lefthand column and to document your ideas and observations throughout each step of the engineering design process. You can include diagrams and pictures.

Design Process	Engineer Notes
Problem Definition What is the problem that you are trying to solve? What are the constraints?	
Background Research What are some important characteristics of slime molds that might be important to your design solution?	
Brainstorm Possible Solutions Draw several examples of your quarantine facility. Label each part of your facility with the material that you will use to construct it.	
Select the Best Solution Draw the design solution that your group has selected.	
Construct the Prototype What were some of the challenges that your group faced during construction? What does your completed prototype look like?	
Test the Prototype What would make a design successful? Based on these criteria, was your group's design successful? List some observations about your prototype.	
Present Your Solution List at least three things that you learned from other groups' presentations.	
Redesign With the knowledge that you have from your own design and from listening to other groups' presentations, redesign your prototype.	

Figure 3. Student design portfolio.

The teacher then led a class discussion about what the students learned. (We recommend that the instructor makes sure that students understand that a slime mold is an amoeboid protozoan and *not* a mold or fungus. Use this as an opportunity to further explain the use of modeling in engineering, and help students understand that slime molds do not carry infectious diseases, nor do infectious diseases spread through protozoans. This is a good time to review eukaryotic organisms and their properties. Students should also know how slime molds spread.) Then students were given a few minutes to explore the different construction materials available to them. (It is important that students are familiar with the size of a Petri dish and understand that their facility needs to fit within the dish as one piece.)

Step 3: Brainstorm possible solutions. In order to ensure that all students came up with their own solution first and to promote the idea of multiple solutions, students were asked to independently sketch a potential design solution for their quarantine facility. Students were given a blank piece of paper to quietly sketch their own idea. Students were expected to label all parts of their facility and identify which materials they would use for each part. Figure 4 provides examples of student designs.

Step 4: Select the best solution. After students developed their individual solutions, they were placed into groups of three or four. Students then presented their individual design solution to their group members. After all the design solutions were presented, the group either selected one of the designs or created a new design solution that combined aspects from several of the designs. Students then drew and labeled their group's best design solution in their design portfolios. The teacher concluded the class period by leading a class discussion about each group's design solution, allowing the class to see that there was more than one possible solution to the problem.

○ Engineering Design Lab: Day 2 (90 minutes)

At the start of the following class period, the teacher reviewed the engineering design process and reviewed all of the lab safety rules and expectations before students gathered in their lab groups.

Step 5: Construct the prototype. The rest of the class period was devoted to the building of design prototypes, based on the design solution that each group agreed upon in the previous class period. The construction materials were placed in a central location in the room, so that the teacher was able to supervise the use of the materials and minimize waste. Figure 5 shows some examples of student prototypes. The teacher was available to students to help address design problems through guided questioning. When problems arose, the teacher took this time to emphasize the engineering design process as a fluid and iterative cycle.

For student groups that finished construction early, they were instructed to work on their individual design portfolios. Additionally, students were told that at the end of the unit, they would be required to present their design project to the class. Therefore, groups that finished construction early could also work on their presentations. (One way to organize the presentations is to have each group create a Google slide presentation in which they compile all their design portfolios and create one electronic portfolio.

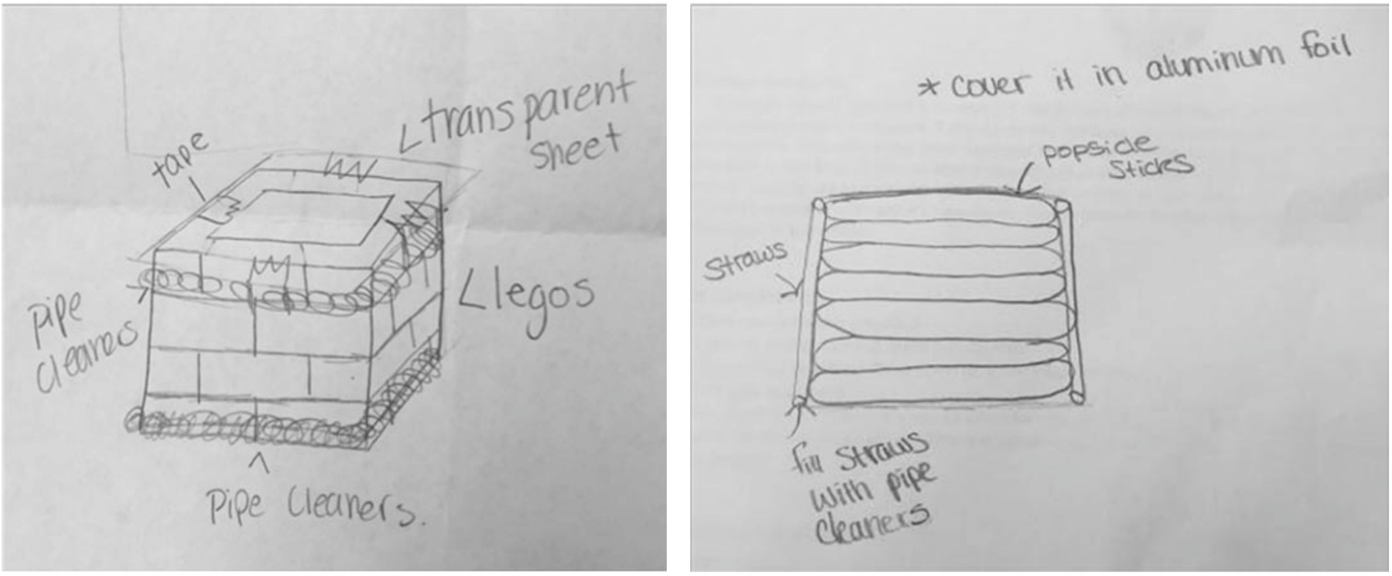

Figure 4. Examples of initial student design solutions.

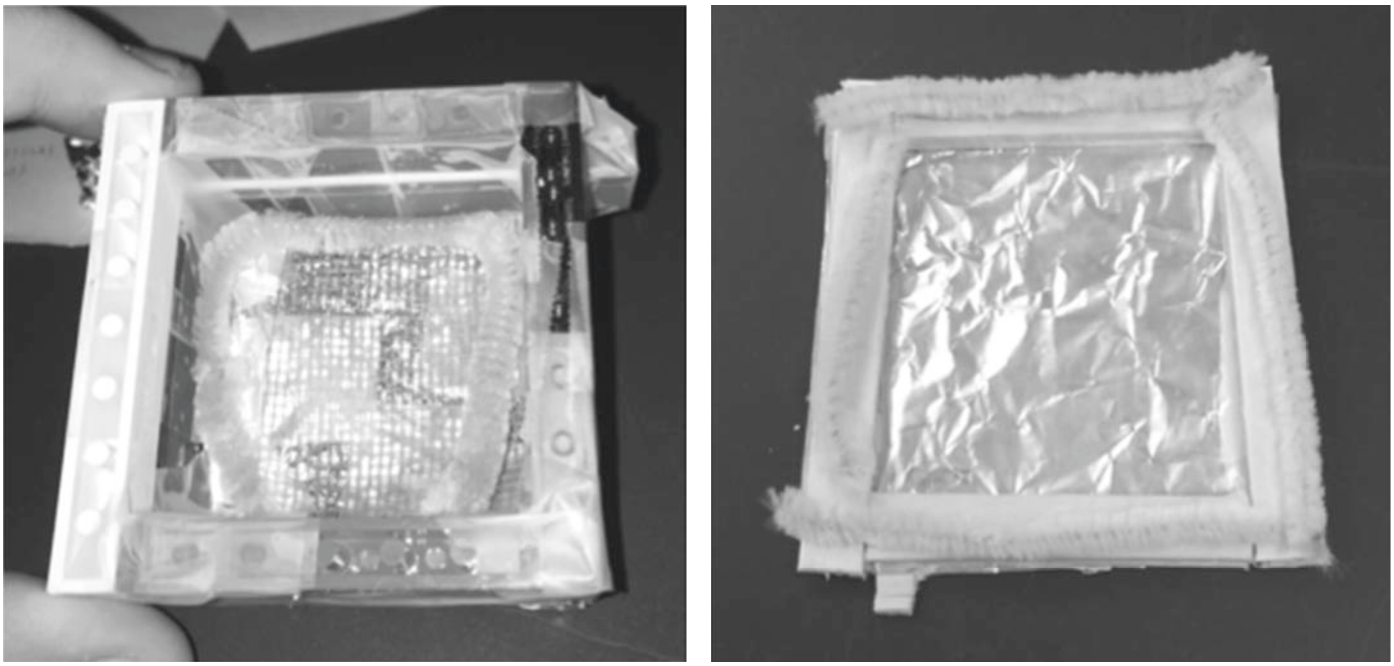

Figure 5. Examples of student prototypes.

Students can use cameras or phones to take pictures of their drawings and prototypes and upload them to Google slides. In our class, we used Google slides so that all the students could simultaneously collaborate on one presentation.) For a rubric of the presentation expectations, see Table 1.

At the conclusion of the class period, students cleaned up their lab space, and the teacher discussed how the quarantine facilities would be exposed to oats inoculated with the slime mold. After class, the teacher placed the inoculated oats in the center of the agar on the Petri dish. The teacher then placed the quarantine facility on top of the agar. Next, the teacher situated oats (that were not inoculated) on the agar surrounding the quarantine facility. The fresh oats serve as the healthy population the students are trying to protect from the infectious disease. (The teacher should explain to the students that if the structures are unsuccessful, then the slime mold will escape the structure in search of food – the oats.) These Petri dishes were left for three to four days, depending on whether the class met on even or odd days, before students returned to the lab activity to determine whether their designs were successful.

Table 1. Group presentation rubric.

Item	Description	Points Available
Title Page	The first slide of the presentation should have a descriptive title for the lab. Include your group members' first and last names, period, and lab group number.	5
Problem	In your own words, summarize the problem that you are addressing. List the design criteria and constraints that you must abide by in your design.	5
Background Research	Write a brief introduction to slime mold as a living organism. What are some of its characteristics? Describe briefly what you hope to find out. Cite at least one reference source.	5
Possible and Best Solutions	Describe your group members' possible design solutions, as well as the solution that you chose. Provide a short justification for why you chose this design.	10
Creating a Prototype	Include a picture and description of your prototype. List the construction materials that you used to build it and discuss any of the challenges that you had in the construction process.	5
Test the Prototype	Include a description of how you tested your design. Discuss the results of your design. Was your design successful? Why or why not?	10
Presentation	You will be assessed on your group's overall presentation of your slime mold quarantine facility and the results of your tests.	15

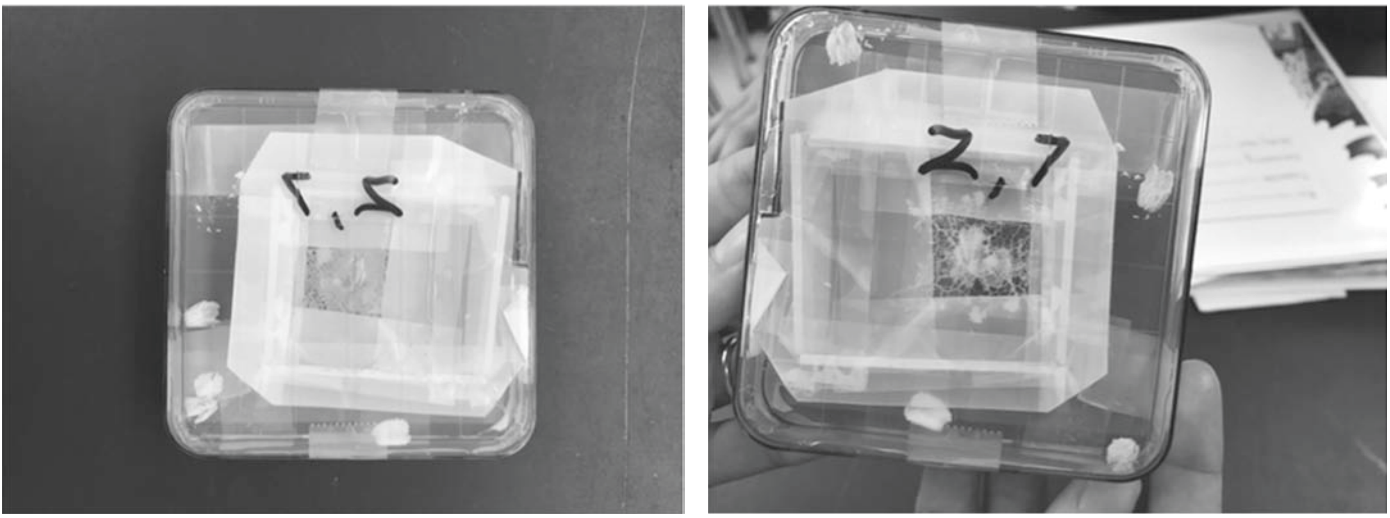

Figure 6. "Before" and "after" images of a group's quarantine facility.

○ Engineering Design Lab: Day 3 (90 minutes)

Step 6: Test the prototype. Before students examined their quarantine facilities, the teacher reviewed the engineering design process and led a class discussion in which the students developed shared criteria for evaluating the design solutions. The teacher asked the students what they would consider a "successful" design. (The teacher should guide students to the idea that the quarantine facility is successful if the slime mold is not able to escape the prototype facility.) Students then obtained their Petri dishes and assessed whether they were successful, based on their class's definition of success. The students then documented their qualitative observations in their individual design portfolios. Figure 6 shows one group's prototype right after the inoculation and then several days after the inoculation. The slime mold was not able to escape the quarantine, and therefore, based on their class definition of success, the prototype was successful.

Step 7: Present your solution. Students were then given ~30 minutes to work within their groups on their online design portfolio/presentation. They were instructed to compile their observations and notes from their individual design portfolios. Groups then presented their designs to the class using their online portfolio. They included pictures of their prototype and whether they were successful in quarantining the slime mold.

Step 8: Redesign. After all the groups presented their findings, students then individually redesigned the facilities. Students used their knowledge of their group's results, as well as information learned through other group presentations, to justify changes made as they redesigned their prototype. Because of time limitations, students only had the opportunity to sketch their redesigned prototypes in their individual design portfolios. (If time permits, students can go through the engineering design cycle again and come up with a group prototype and retest their new design.) The teacher then concluded the unit by discussing the benefits of the engineering design process and how this process could be used to solve other problems in society. (The teacher should stress that students can always optimize their design even if they were successful the first time. This should be done with guided questioning so as not to give away potential changes from the teacher's perspective.)

○ Assessment

Students were assessed on their individual design portfolios, as well as on their group presentation. The evaluation rubric for the group presentation is provided in Table 1. Students should be aware that their grade does not depend on the success or failure of their quarantine structure, because one of the important components of the engineering design is the emphasis on learning from failure. One option is for teachers to award extra credit to successful structures.

In addition, students were assessed on biology content knowledge and engineering design knowledge both before and after they participated in the unit. The biology content assessment consisted of questions regarding slime molds, and the engineering design assessment contained open-ended questions about the engineering design. Students also took a survey prior to and following the engineering-design-integrated unit that measured their perceptions of engineering design. Pre/post test results for all assessments are provided below.

○ Summary & Results

Overall, the purpose of this lab activity was to teach students the characteristics of slime molds and related biological principles using the engineering design process. More than 100 students received instruction in this unit. Students were able to learn the engineering design process and apply it to solve an authentic, real-world problem from their biology classroom and also learn how they could potentially apply it to solve other problems as well. Most groups were successful in quarantining the slime mold from the non-inoculated oats. Students demonstrated sound understanding of the engineering design process through their design portfolios. Student responses to pre/post test items regarding biology content knowledge and engineering design knowledge were scored on a scale of 0–2 points (0 = completely incorrect, 1 = partially correct, and 2 = completely correct). A paired-sample *t*-test revealed a statistically significant difference between pretests and posttests in students' biology content knowledge ($t_{70} = 12.09$, $P < 0.000$) and the engineering design process ($t_{70} = -12.97$, $P < 0.000$). Furthermore, after participating in the engineering design unit, students' perceptions of engineering design increased by a statistically significant amount ($t_{67} = -7.71$, $P < 0.000$). Overall, these findings suggest that teaching a science concept, such as slime molds, through engineering design may increase students' content knowledge in science and engineering design as well as their perceptions of engineering design.

○ Suggestions for Future Teaching

While this unit was extremely successful in teaching students biology concepts and engineering design, it was created to help students learn biology content knowledge prescribed in our state standards using engineering design. When restructuring this unit for future use, teachers should consider building in an extra day to explicitly address the science content objectives they wish to achieve. This unit provides a great opportunity for students to build background knowledge for key vocabulary words, such as *eukaryotic*, *prokaryotic*, *classification systems*, and *cellular organelles*. We recommend introducing these terms as they relate to slime molds, to help students make connections with the vocabulary.

○ Connecting to NGSS

Table 2 shows how the activities in this unit are connected to NGSS core ideas, science and engineering practices, and crosscutting concepts.

Table 2. Connecting to the *Next Generation Science Standards*.

Standards **HS-LS1 Structure and Function** **HS-ETS1 Engineering Design**
Performance Expectation(s) **HS-LS1-2.** Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms. **HS-LS1-3.** Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis. **HS-ETS1-1.** Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants. **HS-ETS1-2.** Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering. **HS-ETS1-3.** Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.

(continued)

Table 2. Continued

Dimension	Name and *NGSS* Code/Citation	Specific Connections to Classroom Activity
Science and Engineering Practices	**Developing and Using Models** • Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system. (HS-LS1-2) **Planning and Carrying Out Investigations** • Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design decide on the types of data, how much data, and the accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data. (HS-LS1-3)	Students use a prototype to demonstrate the concepts of containing an outbreak. Students brainstorm and design their own individual solutions. They then work in groups to select the best solution and create their prototype. Students work under the constraints provided in the design challenge.
Disciplinary Core Ideas	**LS1.A: Structure and Function** • Multicellular organisms have a hierarchical structural organization, in which any one system is made up of numerous parts and is itself a component of the next level. (HS-LS1-2) • Feedback mechanisms maintain a living system's internal conditions within certain limits and mediate behaviors, allowing it to remain alive and functional even as external conditions change within some range. (HS-LS1-3)	Students connect the characteristics of the slime mold to how it functions. They use their knowledge of the slime mold's behavior to contain it. Students observe slime molds attempting to navigate through the quarantine facility using chemical signals to move toward the food.
Crosscutting Concept(s)	**Systems and System Models** • Models (e.g., physical, mathematical, computer) can be used to simulate systems and interactions – including energy, matter, and information flows – within and between systems at different scales. (HS-LS1-2) **Stability and Change:** Feedback (negative or positive) can stabilize or destabilize a system. (HS-LS1-3)	Students use the slime mold as a model organism to simulate a disease or outbreak. Students observe the slime mold's movements over the course of several days. Slime molds will grow toward a food source and retreat from avenues that do not lead to food. Students receive feedback and revise their designs.

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