INQUIRY & INVESTIGATION

Using Local Research as a Phenomenon in the Classroom

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Abstract

Model-based inquiry, inquiry-based learning, *and* phenomenon *are all popular terms in K–12 science education right now. Science education in our public education system is rapidly changing due to the implementation of the* Next Generation Science Standards *(NGSS). These standards ask teachers to move away from direct instruction to having students develop their understanding of the natural world through guided-learning activities. Under NGSS, students are expected to develop this understanding through one of the main scientific practices, model building, which requires a complex, real-world phenomenon to drive the learning experience. Phenomena work best in the classroom when they apply to students' lives and pique their interest. Finding such phenomena can be hard – especially finding ones that have not already been thoroughly explained on the internet. A great way to find a complex, real-world phenomenon that will interest students is to partner with a local research lab to bring part of their research project into the classroom. This article lays out a process for bringing a local research project into the classroom and designing NGSS-aligned curricula around this project to create a more authentic learning experience for high school students.*

Key Words: *phenomena; authentic learning experience; model building; Next Generation Science Standards; NGSS; curriculum design; scientific process.*

○ Introduction

In recent years, concerns have been raised about the state of science education in the United States. Now more than ever, the general American public is responsible for making decisions that affect scientific policy, funding, and several other scientific areas. It has been noted that the American public lacks a clear understanding of how science is conducted or of the basic principles that make up the scientific field of study. Most Americans receive their scientific information from secondary sources such as newspapers, magazines, television, and the internet. This information has been filtered from primary scientific literature sources and may get distorted during this filtering process (Hoskins, 2010). Because scientific policy decisions rely so heavily on American public perception, it is important that students have a solid understanding of the nature of science and how to interpret and analyze scientific information.

The goal of the *Framework for K–12 Science Education* and the *Next Generation Science Standards* (NGSS) is to transform science education to move away from lecture and regurgitation of scientific facts and toward having students develop a scientific understanding of the world around them through their own engagement in the entire scientific process (National Research Council, 2012; NGSS Lead States, 2013). One major focus of this new instructional shift is to incorporate scientific phenomena into curricula. Students are introduced to a complex, scientific phenomenon at the beginning of a unit of study and work collaboratively to develop an initial model that explains what they think is happening. The students then use the various scientific practices and crosscutting concepts to gather evidence to revise and finalize their model by the end of the unit. The phenomenon used needs to be relevant and perplexing to the students in order to engage them in the discovery process of developing a final model (Windschitl et al., 2008).

Choosing a phenomenon that is both complex and relevant to the students is a challenging aspect of designing curricula that align with the new standards. I was fortunate to spend two summers working in a local university research laboratory whose work is focused on discovering potential pharmaceutical drug compounds from extremophiles growing in the Berkeley Pit in Butte, Montana (Kharwar et al., 2011; Stierle et al., 2017). Part of this research experience was to incorporate what I learned while working in the lab into my high school classroom. This gave me the inspiration to design my curriculum units around the research occurring in the lab as a phenomenon. By using a local research project that is centered on an environmental disaster (Berkeley Pit), students are more likely to buy into the phenomenon and find it relevant, compared to using a phenomenon that is more generalized.

Students in my honors sophomore biology class engaged in a yearlong research project that supports the Stierle lab's research focus on discovering new microbes and potential antibiotic

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Figure 1. Flowchart of curriculum design process.

compounds. Students in my class are introduced to various aspects of the research project throughout the year, and each unit of study supports an aspect of the project by having the students learn the scientific concepts and lab techniques needed to carry out that part of the project. Then students are asked to explain the connection between the scientific concepts they have learned and the portion of the research project they have conducted.

○ Curriculum Design Process

The process of designing a curriculum centered around a local research project can be broken down into five steps (Figure 1). To begin the process of identifying a local research project that could be adapted to be used as a guiding phenomenon in the classroom, I assessed the feasibility of conducting the research portion in my classroom given the skill level of my students, the equipment available in my classroom, and the amount of time required to complete the various aspects of the research project. While working in the lab at the University of Montana, I was a part of two different research projects: determining the effectiveness of different secondary metabolic compounds in inhibiting cancer cells' migration and invasion and the effectiveness of a secondary metabolite compound in killing various antibiotic-resistant bacterial strains. The first project was too complex and required equipment that I could not bring into a classroom setting, while the second project relied on basic research techniques and concepts and thus was better suited for the high school classroom. It is important to take these considerations into account when using research as the guiding phenomenon, because you don't want to overwhelm yourself and your students when carrying out the lab portion.

It is also important to note that a teacher does not have to work in a town with a university or a two-year college engaged in scientific research. The state of Montana, for example, is mostly rural, and teachers around the state have limited access to research conducted at a university. This should not hinder the identification of scientific research being conducted nearby. State departments of fish and wildlife, the Bureau of Land Management, the U.S. Forest Service, and state and local environmental monitoring agencies can be great sources of local research projects. Something else to consider when starting this process is whether you want the research project to span multiple units that you teach or just one unit. The project I do with my students goes the entire school year and is integrated into almost every unit. I have worked with other teachers who use the research project phenomenon for only a single unit. Both are useful ways of incorporating research and phenomena into the classroom, and the choice will depend on your comfort level with using this methodology.

Next, I worked with Dr. Andrea Stierle and Dr. Don Stierle on bringing them into the classroom to present their research. In the middle of the research project, the Stierles present to the students about their work at the University of Montana and how the students' work ties in with their research. This step may not be possible in all situations, but it may be worth sending an e-mail or making a phone call to the principal investigator of the research project you have identified to use in your classroom to determine whether they are willing to come to speak with your students. Having the researchers speak to your students adds a level of buy-in and real-world application for your students because it reinforces the point that they are conducting actual science and potentially producing new scientific knowledge, not just doing a cookbook lab activity. A goal of using the research project in the classroom is to teach students according to the *Next Generation Science Standards*, so review the standards to see which ones will best align with your research project (Table 1). It works best if you can bundle several performance expectations into your research project, but that is not necessary.

Once the performance expectations have been identified, unit activities can be selected or designed that will introduce the students to the scientific concepts that will be utilized during the research project. Consideration of both the concepts and lab techniques needed for the research project is important and should be covered in the unit activities. Also, the phenomenon for the unit should be related to the research project so that students can connect what they are learning to the research project they are conducting. For example, one of the units I have designed focuses on antibiotic resistance, since the research project is aimed at identifying potential antibiotic compounds, and the students learn about antibiotic resistance, what is causing it, how to identify bacteria affected by antibiotics, and the difference between gram-positive and gram-negative. Finally, design an activity or activities that the students can follow to carry out the research project. This is typically in the form of a procedure written in a format that students can easily follow. It is helpful to work with the research lab in selecting lab techniques that can be carried out in your school and how best to adapt them; if this is not possible, then reading through the methods sections of published papers from the lab is an excellent way to determine what procedures to use for the research project. After students have completed the research project or

Table 1. Alignment of the research-based curriculum activity described here with *Next Generation Science Standards* dimensions (NGSS Lead States, 2013).

Unit	Standard Codes	Disciplinary Core Ideas
1	HS-LS2-1 HS-LS2-2 HS-LS2-6 HS-LS2-7 HS-LS2-8	LS2.A: Interdependent Relationships in Ecosystems LS2.C: Ecosystem Dynamics, Functioning, and Resilience LS2.D: Social Interactions and Group Behavior LS4.D: Biodiversity and Humans
2	HS-LS4-1 HS-LS4-2 HS-LS4-3 HS-LS4-4 HS-LS4-5	LS4.A: Evidence of Common Ancestry and Diversity LS4.B: Natural Selection LS4.C: Adaptation
3	HS-LS1-2 HS-LS1-3 HS-LS1-6	LS1.A: Structure and Function LS1.C: Organization for Matter and Energy Flow in Organisms
4	HS-LS1-5 HS-LS1-7 HS-LS2-3 HS-LS2-4 HS-LS2-5	LS1.C: Organization for Matter and Energy Flow in Organisms LS2.B: Cycles of Matter and Energy Transfer in Ecosystems PS3.D: Energy in Chemical Processes
5	HS-LS1-1 HS-LS1-4 HS-LS3-1 HS-LS3-2 HS-LS3-3	LS1.A: Structure and Function LS3.A: Inheritance of Traits

a portion of it, it is important to have them connect what they learned to what they discovered doing the research project. An easy formative assessment tool for this would be using a two-minute paper in which students explain the connection and then share their thoughts during class discussion.

For some teachers, it may be hard to find a researcher to collaborate with or design a research project to implement in the classroom. The University of Montana–Western Montana Area Health Education Center has a program called Classroom Chats (see link in the list of Supplemental Material below). This program connects health-care professionals and biomedical scientists with students via video conferencing. The Classroom Chats program could be used to connect a high school classroom with a university researcher for collaboration on a research project. Teachers can also access the research project curriculum described in this article by accessing the link in the Supplemental Material.

○ Example Research Project Curriculum & Research Project Methodology

Unit 1: Microbial Ecosystems

The yearlong research project starts by introducing students to microbial ecosystems through the introductory phenomenon of the microbiome. Students learn about how microbes interact in microbiomes and the different interactions that occur between the microbes to support the health and function or dysfunction of the ecosystem. During this unit, students learn how to culture bacteria using aseptic technique, which will be required for most of the procedures used in the research project. Next, the students are introduced to the "great plate anomaly" – the difficulty scientists have in determining the different microbes present in environmental samples. Then they read about a new technique called a diffusion chamber to help in culturing typically unculturable microbes. The technique of the diffusion chamber is applied to the concept of ecosystems because it simulates the ecosystem that microbes in the environmental sample normally function in. Students set up a diffusion chamber by collecting a sample of water or soil from a location of their choice in a sandwich-sized bag or a small Mason jar (Figure 2). The soil must be mixed with sterile water, and then a small amount of water from either the soil or water sample is further diluted using sterile water. This diluted sample is mixed with tryptic soy agar and added to a small piece of dialysis tubing tied at one end. Once the sample mixed with tryptic soy agar is added to the dialysis tubing, the other end is tied, creating a diffusion chamber; this diffusion chamber is added back to the undiluted soil or water sample and allowed to culture for about a month.

Unit 2: Antibiotic Resistance

To start this unit, students learn about the dramatic increase in antibiotic-resistant infections and the lack of production of new antibiotics. The main scientific concept covered in this unit is

Figure 2. Student-made growing chamber to isolate microbes.

natural selection from the DNA level to the macroscopic level. Students learn how mutations lead to new traits in the bacteria that can lead to antibiotic resistance, which leads to the new strain of bacteria thriving better than those without the mutation. Students learn about a couple of different traits that contribute to antibiotic resistance, such as cell wall structure (gram-positive and gram-negative) and biofilm formation. Then students read an article about the discovery that the Stierles made by co-culturing fungi together to produce a new antibiotic compound. The students then remove the agar from the diffusion chamber and pulverize it with sterile water in a conical tube. This mixture is plated out on a tryptic soy agar plate and allowed to grow at room temperature for one to seven days (Figure 3). Once growth has appeared on the plate, the students take small swabs of the different growth and plate it out on agar overlay plates containing *E. coli* and *S. epidermis* to test the ability of the different microbes to produce an antibiotic compound. These plates are allowed to grow for several days. If the microbe is capable of producing an antibiotic compound, a small sample is removed from the original culture plate and mixed with a sterile glycerol mixture to be frozen long-term, and this sample is given to the Stierle lab for further testing. Students remove a small sample of a microbe and mix this with sterile water in a microcentrifuge tube. This sample is frozen to be used during unit 5.

Unit 3: Biochemistry & Homeostasis

During this unit, students work to explain the connection between the human diet and the gut microbiome. In order to understand this part of the research project, students need to develop an understanding of the biochemistry of organisms. Students learn about the different types of macromolecules that support life and their various functions, the role of energy in sustaining life, and homeostasis. They learn how the gut microbiome assists in helping break down most of the macromolecules we eat so that we can obtain the proper nutrients and energy from them. Students will also learn about basic lab-testing techniques for macromolecules. Then students apply these concepts during the research project by testing the biochemical properties of their isolated microbe using the Carolina Bacterial Identification Kit. This activity is optional

Figure 3. Student-streaked plates with isolated microbes.

and may or may not be that helpful in identifying the microbe that students have isolated.

Unit 4: Energy Production in Organisms

This unit introduces students to different forms of energy production in organisms: aerobic, anaerobic, and photosynthetic. Students design experiments to determine how algae, *E. coli*, and yeast beads obtain energy and to see how matter cycles through different forms of life. Because these concepts do not directly tie into the Stierles' research, this unit does not contain an activity related to the research project.

Unit 5: Genetics

During this unit, students learn about protein synthesis, meiosis/mitosis, and how organisms inherit traits and express these traits. They look at why some people are more affected by certain infections compared to others. They learn common biotechnology techniques that are used to study genetics: DNA extraction, polymerase chain reaction (PCR), gel electrophoresis, and DNA sequencing through studying their own ability to taste the chemical PTC (Mini-One Systems PTC classroom kit). Students then apply these biotechnology techniques to determine what type of microbe they have isolated. To do this, students isolate DNA from their microbial sample (frozen sample from unit 2), amplify the rRNA gene using 16 s and 18 s rRNA primers, run the PCR products on an agarose gel, and determine the band size (18 s rRNA PCR product band will be larger). If a microbe has shown promise for producing an antibiotic compound, the microbe's DNA will be sent off for sequencing to determine the exact microbe through the Stierle Lab; also, the Stierles will continue to culture and extract compounds from the microbe in their lab. The student who discovered the microbe(s) (or any student who is interested) is invited to help the Stierles with this process in their lab.

Conclusion

Providing students with a real-world phenomenon that will engage them in the scientific process can seem like a daunting task for today's high school teacher. Inspiration for these phenomena is most likely readily available through local research projects happening at a university, state, or government lab or a private lab. High school teachers can establish collaborative relationships with researchers at these local labs to help identify phenomena and research projects to bring into the classroom. This method is a great way to meet the three-dimensional requirements set out in the NGSS and to help students better understand the scientific process.

Supplemental Material

- Biology Curriculum with Research Project Handouts: https://sites.google.com/view/phenomenalscience/home
- Classroom Chats: http://www.wmtahec.org/students/k-12/classroom-chats/default.php

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