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Engaging Students in Informed Design Case Studies that Reinforce Laboratory Content

Brian R. Shmaefsky

Lone Star College – Kingwood, Department of Biology, 20000 Kingwood Dr, HSB 202V, Kingwood TX 77339 USA
(**Brian.r.shmaefsky@lonestar.edu**)

This pedagogical strategy being demonstrated in this workshop models the Vision and Change in Undergraduate Biology Education recommendations to highlight new and existing resources for effecting change in college biology teaching. The project uses student-centered-authentic applied investigations to reinforce laboratory content. In this informed design model, students work as teams on scenarios in which they apply biology laboratory content for designing sustainable ways of resolving a social need. Participants will learn to engage students in clarifying design specifications and constraints in a step-by-step progression that leads them to a final product that they can transfer to a real life application.

Keywords: case study, critical thinking, effecting change, informed design, student-centered learning, STEM, sustainability, team projects.

Introduction

In this activity, students will be presented with a case study involving water pollution in developing nations. The case provides the background for a problem they are going to resolve using an informed-designed approach to problem solving. Informed design uses activities in which students create scientific or technological models that they share and discuss with others. The literature shows that pedagogically solid design projects involve authentic learning, real-life hands-on tasks, use familiar and easy-to-work materials, possess clearly defined outcomes that allow for multiple solutions, promote student-centered, collaborative work and higher order thinking, and allow for multiple design iterations to improve the product (Loyd and Barreneche 2014). The informed design model directs students through the following student-driven steps (Hacker and Burghardt, 2004):

1. Clarify design specifications and constraints.
2. Research and investigate the problem.
3. Generate alternative designs.
4. Choose and justify optimal design.
5. Develop a prototype.
6. Test and evaluate the design solution.
7. Redesign the solution with modifications.
8. Communicate your achievements.
9. Reenter the design cycle if necessary.

The National Research Council's latest educational research publications recommend instruction where students monitor their understanding and progress in problem solving (Singer et al, 2012). Research reveals that professional scientists consider alternatives, note when additional information is required, and are mindful if the chosen alternative leads toward the desired end (Herried et al, 2014). These strategies are central to the culture of informed design which is typically not a component of traditional laboratory instruction.

Using design in the classroom can be challenging because students are not familiar, or initially not comfortable, with the open-ended nature of design (Wiggins and McTigue, 2005). Plus, it requires that students look up much of the details they need to complete the assignments. These two factors can also pose problems for teachers who must relinquish direct control of instruction. However, this cognitive discord also provides opportunity to use constructivist pedagogical practice to engage students in their own learning (Shmaefsky and Letargo, 2007). Research shows that the pedagogical outcomes of this design model are manifold in spite of the non-traditional nature of the laboratory activities. This model closely addresses the attributes of the universal design for learning model which creates "instructional experiences which make the acquisition of knowledge and skill more efficient, effective, and appealing." Thus, this method engages students with a variety of learning modalities and justifies the need to learn course content. A summary of the universal design pedagogical benefits achieved in the instructional model demonstrated in this workshop is shown in Table 1 (Wakefeld, 2011). The classroom dynamics of the informed design approach requires that students are divided into task groups working on different water quality scenarios (Beck and Blumer, 2011., Morgan and Shmaefsky, 2014). Students in one scenario will design a simple to use and low-cost water toxicology test using local resources in a developing nation. In a second scenario, students will design a water filtration system capable of providing safe water for families in a developing country. Both scenarios begin as students are told they have been accepted to be part of a team of engineering students that will be working with the local chapter of Scientists across Borders. Students learn about the world water crisis and water scarcity and become "experts" in designing resolutions to the issues using course content.

Table 1. Universal design for instruction attributes.

Universal Design for Learning Guidelines		
Provide Multiple Means of Representation	**Provide Multiple Means of Action and Expression**	**Provide Multiple Means of Engagement**
Provide choices for perception • Customize the display of information • Give alternatives for auditory information • Give alternatives for verbal information	**Provide choices for physical action** • Vary methods for response and navigation • Optimize access to learning tools • Access to assistive technologies	**Provide choices for recruiting interest** • Individual choice and autonomy • Give relevance, value, and authenticity • Minimize threats and distractions
Provide choices for language and symbols • Clarify vocabulary and symbols • Clarify syntax and structure • Support decoding of text, math notation, and symbols • Promote understanding across languages • Illustrate through multiple media	**Provide choices for expressive skills and fluency** • Use multiple media for communication • Have multiple tools for construction and composition • Build fluencies with graduated levels of support for practice and performance	**Provide choices for sustaining effort and persistence** • Heighten salience of goals and objectives • Vary demands and resources to optimize challenge • Increase mastery-oriented feedback
Provide choices for comprehension • Supply background knowledge • Highlight patterns, critical features, big ideas, and relationships • Guide information processing, visualization, and manipulation • Maximize transfer and generalization	**Provide choices for executive roles** • Guide appropriate goal-setting • Support planning and strategy development • Facilitate managing information and resources • Enhance capacity for monitoring progress	**Provide choices for self-regulation** • Promote expectations and beliefs that optimize motivation • Facilitate personal coping skills and strategies • Develop self-assessment and re-flection

Student Outline

Background

Expanding population, swelling cities, pollution, and climate change are placing immense pressure on the world's water supplies. We are living in the midst of a world water crisis. But the crisis is not about having too little water to satisfy our needs; it is a crisis of inadequate access to water for drinking and other uses and is a critical problem for many areas of the world.

The National Academy of Engineering reports that a lack of clean water is responsible for more deaths in the world than war. It is projected that 1 out of every 6 people living today have inadequate access to water, and even more than that lack basic sanitation. In many developing countries, the water is contaminated not only by people and unsanitary practices, but also by natural arsenic and other naturally occurring poisonous pollutants found in groundwater aquifers.

By 2050, it is projected that the global population will reach 8-9 billion, with 70% of people centralizing in cities and slums. The resulting effect will stress the local water resources due to greater withdrawals and pollution. In turn, water withdrawals for food, energy and industrial use will also increase. Water usage will be amplified to the maximum. Additionally, the demands and consequences of a growing population will be aggravated further by the effects of climate change and global warming .

Overcoming the water and sanitation crisis is recently reported by the UN to be one of the greatest human development challenges in the 21st century. Sustainable methods of ensuring safe water supplies are needed at all levels, from small communities to big industry. Unfortunately, developing nations have the greatest about of water pollutants and the least amount of resources to monitor and reduce pollution.

Problem Statement

Scenario 1: Developing a Water Quality Test

Objectives

The overall outcome of this long-term activity is for you to develop a simple, but accurate research model for testing the presence of cell toxins in environmental samples. You will be asked to use two existing cell toxicity strategies and a proposed research model to measure endotoxins in water accurately, inexpensively, and rapidly.

- You will design and carry out a procedure that tests whether your organism is susceptible to cell disruption
- You will design a controlled experiment to evaluate how your test can be blended with a cell viability test that can be used to test endotoxins
- You will evaluate the feasibility of using the test you develop by evaluating its accuracy, cost, and simplicity

Background

Three major types of water pollution are bacteria, sediment, and nutrients. In developing nations water pollution decreases the availability of clean water needed for bathing, drinking, and cooking. In developed nations, water pollution greatly contributes to the cost of maintaining clean waterways used for commerce, consumption, and recreation.

It is possible to detect and monitor pollution in water using a variety of techniques. However, there are few inexpensive, quick, and simple procedures for accurately determining the presence of pollution in water. Even these procedures are not feasible in many situations where urgent water testing is needed, such as in developing nations with limited resources.

You have just learned that you were selected for an internship with a nonprofit group called Scientists without Borders that studies global water issues. The group just formed a team that will investigate inexpensive and simple methods for determining the presence of cytotoxic pollutants in drinking water. This team is being led by a researcher, Dr. Erica Ojobi, who previously researched mysid shrimps as indicators or biomonitors of endocrine disruptors polluting water pollution. She did this by monitoring the health of the mysid shrimp in response to the different endocrine disrupting pollutants. Mysid shrimp are easy to grow and their response to pollutants is simple to measure. Plus, the method uses easy-to-find materials and does not need to be conducted in a laboratory.

Dr. Ojobi is interested in using other models that are appropriate for local water supplies in different regions. She also remembered studying two procedures that could help determine the cytotoxicity when cells are exposed to cytotoxic pollutants called endotoxins. One test, called the Limulus amoebocyte lysate (LAL) test, uses horseshoe crab blood cells as indicators of bacterial endotoxins. Endotoxins are harmful molecules released by specific bacteria during death and replication. These toxins have the capability of killing cells by disrupting the cell membrane.

Another test, called vital stain testing, is used to investigate the health of cells. One example of testing utilizes trypan blue which is a dye that is not taken up by healthy cells. Trypan blue will pass through the membranes of dead and dying cells making the inside of these cells dark blue. Unfortunately, trypan blue is very expensive and difficult to find in many regions.

As you approach this project for Dr. Ojobi, you will plan your strategy using the following steps:

1. Clarify design specifications and constraints. Describe the problem clearly and fully, noting constraints and specifications. Constraints are limits imposed upon the solution. Specifications are the performance requirements the solution must meet.

2. Research and investigate the problem. Search for and discuss solutions that presently exist to solve this or similar problems. Identify problems, issues and questions that relate to addressing this design challenge.

3. Generate alternative designs. Don't stop when you have one solution that might work. Continue by approaching the challenge in new ways. Describe the alternative solutions you develop.

4. Choose and justify optimal design. Defend your selection of an alternative solution. Why is it the optimal choice? Use engineering, mathematical and scientific data, and employ analysis techniques to justify why the proposed solution is the best one for addressing the design specifications. This chosen alternative will guide your preliminary design.

5. Develop a prototype. Make a model of the solution. Identify possible modifications that would lead to refinement of the design, and make these modifications.

6. Test and evaluate the design solution. Develop a test to assess the performance of the design solution. Test the design solution, collect performance data and analyze the data to show how well the design satisfies the problem constraints and specifications.

7. Redesign the solution with modifications. In the redesign phase, critically examine your design and note how other students' designs perform to see where improvements can be made. Identify the variables that affect performance and determine which science concepts underlie these variables. Indicate how you will use science concepts and mathematical modeling to further enhance the performance of your design.

8. Communicate your achievements.

Methods and Materials

In class, you will be provided with several live organisms to investigate as possible alternative models for replacing *Limulus* cells. Supplies for carrying out the testing are limited to what your instructor has supplied at your work stations. You will be provided with disinfecting chemicals that harm cells in a similar manner as exotoxins. Exotoxins in the form of a product called Mosquito Dunk® is also provided. In addition, you will be given items that can be used to conduct a test for investigating cell damage. Remember, you are working in a situation with limited resources and with many financial constraints that prevent you from using sophisticated techniques.

Resources

Use these resources to gather background information before approaching your project. Feel free to search other online resources include YouTube videos.

1. Protocol for Performing a Typan Blue Viability Test
   http://bio.lonza.com/uploads/tx_mwaxmarketingmaterial/Lonza_BenchGuides_Protocol_for_Performing_a_Trypan_Blue_Viability_Test__Technical_Reference_Guide.pdf
2. World Health Organization: Test For Bacterial Endotoxins
   http://www.who.int/medicines/publications/pharmacopoeia/Bacterial-endotoxins_QAS11-452_FINAL_July12.pdf
3. Control of endotoxins and their fate during wastewater reclamation
   http://www.eng.hokudai.ac.jp/e3/alumni/files/abstract/d119.pdf
4. Sigma-Aldrich: What is Endotoxin?
   http://www.sigmaaldrich.com/life-science/stem-cell-biology/3d-stem-cell-culture/learning-center/what-is-endotoxin.html
5. Comparison of the efficacy of various yeast viability stains
   https://www.beckmancoulter.com/wsrportal/bibliography?docname=Ta-204.doc.
6. Mosquito Dunk® information:
   http://www.summitchemical.com/wp-content/uploads/2012/06/FAQ-MosqDunksrev612.pdf

End of Scenario 1

Scenario 2: Producing Potable Drinking Water

Objectives

The overall outcome of this long-term activity is for you to develop a simple, but accurate method of removing metal and parasite pollution from waste water. You will be asked to research how sewage treatment is done to make potable water. This information will then be adapted to develop simpler methods of cleaning water.

- You will develop and carry out a procedure for removing nitrogen or phosphorus from water.
- You will design a controlled experiment to evaluate if your test would work with actual metal pollution in water.
- You will develop and carry out a procedure for removing or killing yeast in water.
- You will design a controlled experiment to evaluate if your test would work with actual parasites in the water.
- You will evaluate the feasibility of using the water purification methods you develop by evaluating its accuracy, cost, and simplicity

Background

Three major types of water pollution are bacteria, sediment, and nutrients. In developing nations water pollution decreases the availability of clean water needed for bathing, drinking, and cooking. In developed nations, water pollution greatly contributes to the cost of maintaining clean waterways used for commerce, consumption, and recreation.

It is possible to remove pollutants from water using a variety of techniques. However, there are few inexpensive, quick, and simple procedures for producing potable water. Even these procedures are not feasible in many situations where there is an urgency for safe water, such as in developing nations with limited resources.

You have just learned that you were selected for an internship with a nonprofit group called Scientists without Borders that studies global water issues. The group just formed a team that will investigate inexpensive and simple methods for removing toxic metal pollutants in drinking water. This team is being led by a researcher, Dr. Tony del Rosario, who previously researched sustainable water treatment systems using local material. He did this by monitoring the removal of chromium pollution using plant extracts in Bangladesh. Some of the local plants he used had mucilaginous fibers that settled out the chromium which was further removed by filtration.

Dr. del Rosario is interested in using other models that are appropriate for local water supplies in different regions. The plants he used in Bangladesh are not common elsewhere. So, he is wants to investigate using other local inexpensive materials to remove nitrogen and waterborne parasites for this next project. His ultimate goal is to design and construct a sustainable water filtration system for a small in a specific developing country.

As you approach this project for Dr. del Rosario, you will plan your strategy using the following steps:

1. Clarify design specifications and constraints. Describe the problem clearly and fully, noting constraints and specifications. Constraints are limits imposed upon the solution. Specifications are the performance requirements the solution must meet.

2. Research and investigate the problem. Search for and discuss solutions that presently exist to solve this or similar problems. Identify problems, issues and questions that relate to addressing this design challenge.

3. Generate alternative designs. Don't stop when you have one solution that might work. Continue by approaching the challenge in new ways. Describe the alternative solutions you develop.

4. Choose and justify optimal design. Defend your selection of an alternative solution. Why is it the optimal choice? Use engineering, mathematical and scientific data, and employ analysis techniques to justify why the proposed solution is the best one for addressing the design specifications. This chosen alternative will guide your preliminary design.

5. Develop a prototype. Make a model of the solution. Identify possible modifications that would lead to refinement of the design, and make these modifications.

6. Test and evaluate the design solution. Develop a test to assess the performance of the design solution. Test the design solution, collect performance data and analyze the data to show how well the design satisfies the problem constraints and specifications.

7. Redesign the solution with modifications. In the redesign phase, critically examine your design and note how other students' designs perform to see where improvements can be made. Identify the variables that affect performance and determine which science concepts underlie these variables. Indicate how you will use science concepts and mathematical modeling to further enhance the performance of your design.

8. Communicate your achievements. In this phase it is important to present your idea to the class using audiovisual materials and presentation software in a manner that clearly conveys the progression and outcomes of your project.

Methods and Materials

You will be provided with live yeast as a model for simulating parasites in contaminated water. Yeast are comparable to many parasitic protists and respond similarly to substances that kill parasites. You will be given a chemical called methylene blue to indicate the presence of the yeast. In methylene blue, healthy yeast appear clear to light blue and dying or unhealthy yeast cells turn dark blue. Also, you will be provided with plant fertilizer as a model to investigate the removal of toxic metals such as chromium from water. The nitrogen and phosphorus in fertilizer is chemically similar to many toxic metals and salts found in polluted water. So, a kit for testing the presence of nitrogen or phosphorus in water will be made available. Supplies for carrying out the testing are limited to what your instructor has supplied at your work stations. You will be provided with chemicals used in water treatment. In addition, you will be given items that can be used to test your ability to remove nitrogen and parasites from water. Remember, you are working in a situation with limited resources and with many financial constraints that prevent you from using sophisticated techniques.

Resources

1. World Bank Group: Introduction to Wastewater Treatment
   http://water.worldbank.org/shw-resource-guide/infrastructure/menu-technical-options/wastewater-treatment
2. USGS: A visit to a wastewater-treatment plant

http://water.usgs.gov/edu/wwvisit.html
3. Minnesota Pollution Control Agency: Phosphorus Treatment and Removal Technologies https://www.pca.state.mn.us/sites/default/files/wq-wwtp9-02.pdf
4. Comparison of the efficacy of various yeast viability stains https://www.beckmancoulter.com/wsrportal/bibliography?docname=Ta-204.doc.

End of Scenario 2

Materials

The materials for conducting the activities are specific for each scenario. Table 2 and Table 3 are recommended materials for the respective scenarios and can be substituted by the instructor. Additional items can be added at the discretion of the instructor. It is important to be receptive to providing other materials that the students request as long as the materials are low-tech and inexpensive. All the materials are available through any biological or chemical supply company. Hardware and gardening stores can be inexpensive sources of Mosquito Dunk®, liquid house plant fertilizer, and nitrogen or phosphate test kits.

Table 2. Scenario 1: Developing a Water Quality Test

Recommended Materials	**Quantity**
Safety Goggles	1 per student
Rubber/latex/vinyl gloves	1 pair per student
Brine shrimp	Several per group
Bean beetles (*Callosobruchus maculatus*)	Several per group
Cladocerans	Several per group
Green algae	Container per group
Laboratory disinfectant solutions	1 container of each per group
Mosquito Dunks® or Mosquito Bits®	¼ dunk per group
Petri dishes (35mm)	4 dishes per group
Trypan Blue solution (0.4% W/V)	1 bottle per class
Methylene blue solution	1 bottle per class
Assorted beakers	1 set per group
Microscope glass slides, cover slips	2-4 per group
Microscope	1 per class
Eye Droppers	8 per group

Notes for the Instructor

It is important to provide students with some background information on water quality and water treatment. A great faculty resource for water quality is available on the Water Quality Association website (2017). Once students show an awareness of water quality standards, it is important to stress the global water quality crisis. The United Nations provides excellent background about the worldwide need for safe, or potable, drinking water (UN Water, 2014). Then charge the students with the following mission for each of the case student scenarios in this activity. Note, it is likely best to divide up the class into Scenario 1 and Scenario 2. Several student groups can work one or the other scenario. Each scenario has the following structure:

1. Students develop at model for resolving the problem in the case study.
2. Students will build the model and carry out the process for resolving the problem in the case study.
3. Students devise on paper an experiment that the students could use to validate their model.
4. Students gather feedback on the feasibility of the model for the given scenario.
5. Students report about the model to the rest of the class.

Table 3. Scenario 2: Producing Potable Drinking Water

Recommended Materials	**Quantity**
Safety Goggles	1 per student
Rubber/latex/vinyl gloves	1 pair per student
Water	1 pint per group
Bucket	1 per group
¼ teaspoon (0.042 oz.) baker's yeast in 100ml	50ml per group
Solution of 4 drops of bleach to 500ml water	100ml per group
Methylene blue solution	1 bottle per group
Liquid house plant fertilizer	10ml per group
Nitrogen and phosphate test strips (for fish tanks or soil)	1 container per group
Potassium permanganate water purification solution	1 bottle per class
Teaspoon measure	1 per group
Assorted beakers	1 set per group
Alum powder	1 small container per group
Cotton Balls	Large bag for class
Window screen material	A standard-sized roll
Cheese cloth	1 packet for class
Microscope glass slides, cover slips	2-4 per group
Microscope	1 per class
Eye Droppers	4 per group
Small-Medium Tupperware type containers	4-6 per group
Assorted funnels	1 type of funnel per group
Toothpicks	3 per group

An example of one sustainable approach for making potable water should be presented in class before the students start their projects. The Ted Talk called "How to provide clean water for everyone" by Kitty Nijmeije (2016) demonstrates how inexpensive membranes can be used to make potable water in developing nations. Ask students to evaluate the pros and cons of the approach in order to give them the experience of evaluating a water purification project's feasibility in a poor nation.

In the informed design model, the instructor's role is to facilitate and not lead the students through the projects. Corrections by the instructor are permissible as long as the instructor uses the Socratic approach of asking and answering questions to stimulate critical thinking and to draw out ideas and underlying presumptions. Students should be encouraged to seek out information on the topics through resources other than the instructor. Encourage students to validate the information they are collecting to ensure the accuracy of their projects.

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About the Author

Dr. Brian Shmaefsky is currently a professor of biology and environmental sciences at Lone Star College – Kingwood, near Houston, TX and in the past coordinated the college's service learning program. His research emphasis is in environmental physiology. Dr. Shmaefsky attended Brooklyn College of CUNY, Southern Illinois University at Edwardsville, Rocky Mountain Biological Laboratory, and University of Illinois. He is past president of the Society for College Science Teachers and is active in other professional science and science education organizations. Dr. Shmaefsky also serves on international organizations and governing boards with natural resource conservation and environmental justice missions.

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